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State-of-the-Science Data and Methods Need to Guide Place-Based Efforts to Reduce Air Pollution Inequity

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Background: Recently enacted environmental justice policies in the United States at the state and federal level emphasize addressing place-based inequities, including persistent disparities in air pollution exposure and associated health impacts. Advances in air quality measurement, models, and analytic methods have demonstrated the importance of finer-scale data and analysis in accurately quantifying the extent of inequity in intraurban pollution exposure, although the necessary degree of spatial resolution remains a complex and context-dependent question.

Objective: The objectives of this commentary were to *a*) discuss ways to maximize and evaluate the effectiveness of efforts to reduce air pollution disparities, and *b*) argue that environmental regulators must employ improved methods to project, measure, and track the distributional impacts of new policies at finer geographic and temporal scales.

Discussion: The historic federal investments from the Inflation Reduction Act, the Infrastructure Investment and Jobs Act, and the Biden Administration's commitment to Justice40 present an unprecedented opportunity to advance climate and energy policies that deliver real reductions in pollution-related health inequities. In our opinion, scientists, advocates, policymakers, and implementing agencies must work together to harness critical advances in air quality measurements, models, and analytic methods to ensure success. https://doi.org/10.1289/EHP13063

Introduction

Twenty-three states and the federal government have enacted environmental justice policies since the 1990s, but only recently have significant resources been allocated at both state and federal levels. Currently, five states (California, Colorado, Illinois, New York, and Washington) and the Biden Administration's Justice40 Initiative[1] directly designate a minimum percentage investment allocation to prioritized locations (Climate and Economic Justice screening tool (https://screeningtool.geoplatform.gov), ClimateXchange (https://climate-xchange.org/dashboard/), Colorado Department of Public Health and Environment (https://teeo-cdphe.shinyapps.io/COEnviroScreen_English/), Illinois Power Agency,[2] California Office of Environmental Health Hazard Assessment,[3] New York State Climate Justice Working Group,[4] and Washington State Department of Health[5]). (Table 1; see also "Place-based environmental justice policies with investment or resource allocations" in the Supplemental Material). To define which locations qualify under these environmental justice investment allocation programs, a range of socioeconomic, demographic, and environmental variables at the census tract or census block group scale are currently being used (Table 1; see also "Place-based environmental justice policies with investment or resource allocations" in the Supplemental Material). Notably, the Biden Administration has allocated tens of billions of dollars via the Justice40 Initiative,[1] which calls for 40% of federal program benefits to be directed to geographically defined "disadvantaged communities" (Table 1; see also "Place-based environmental justice policies with investment or resource allocations" in the Supplemental Material). The Inflation Reduction Act (IRA) allocates $296 million for investments in air monitoring specifically.[6] In addition, for the first time, the federal government is inviting the use of air pollution data to guide investment of >$30 billion in funds focused on climate pollution reduction, advanced industrials, community revitalization, and other pollution mitigation programs.[6] These new place-based prioritizations, combined with federal climate and clean energy funding through the Infrastructure Investment and Jobs Act (IIJA),[7] present an unprecedented opportunity to address longstanding disparities in air pollution exposure and impacts that have persisted under prior regulatory structures (e.g., the Clean Air Act). We assert that to maximize and evaluate the effectiveness of these efforts, federal and state agencies will require improved methods to measure, model, project, and track the distributional impacts of new policies. Hence, there is a pressing need for scientists, advocates, policymakers, and implementing agencies to collaboratively develop new data collection and analytic frameworks to aid the implementation of place-based policies. Here, we offer recommendations informed by relevant recent research on criteria air pollutants leveraging satellite remote sensing, new monitoring technologies, hybrid models, and fine-scale health impact assessment approaches to *a*) characterize past and current inequities in air pollution exposure, *b*) model expected health equity benefits of past and potential future air pollution policies, and *c*) empirically determine whether expected air quality and health benefits are achieved following policy implementation.

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Table 1. Environmental justice policies with place-based allocations or investment provisions.

Policy (date)	Allocation provision	Spatial unit	Qualifying criteria				
			Climate burden	Pollution burden	Health burden	Proportion non-White/ Hispanic	Proportion low income
California Climate Investment Act (2016)	At least 25%[a]	Census tract	—	✓	✓	—	✓
Colorado Modernize the Public Utilities Commission Act (2021)	At least 40% renewable energy	Census block group	✓	✓	✓	✓	✓
Illinois Climate and Equitable Jobs Act (2021)	25% solar funding, 45% EV funding	Census block group	—	✓	—	✓	✓
New York Climate Leadership and Community Protection Act (2019)	35%, with a goal of 40%	Census tract	✓	✓	✓	✓	✓
Washington Climate Commitment Act (2021)	35%, with a goal of 40%, 10% to Indian tribes	Census tract	—	✓	✓	✓	✓
United States Justice40 Executive Order (2020)	40% for qualifying federal programs	Census tract	✓	✓	✓	—	✓

Note: Table is based on Climate and Economic Justice screening tool (https://screeningtool.geoplatform.gov), ClimateXchange (https://climate-xchange.org/dashboard/), Colorado Department of Public Health and Environment (https://teeo-cdphe.shinyapps.io/COEnviroScreen_English/), Illinois Power Agency,[2] California Office of Environmental Health Hazard Assessment,[3] New York State Climate Justice Working Group,[4] and Washington State Department of Health.[5] —, not applicable; EV, electric vehicle.
[a]10% to low-income communities, individuals, and households.

Discussion

Characterizing Inequities in Air Pollution Exposures

Advances in air pollution modeling and satellite-derived measurements have enabled progress in characterizing criteria air pollutants at spatial resolutions relevant to current environmental justice place-based policies (e.g., census tract). Most analyses find significantly higher pollution concentrations in areas with higher proportions of residents identifying as Black, Asian, or Hispanic; reporting low income; or residing in an area subjected to historic patterns of discrimination.[8–14] Generally, intraurban differences in air pollutant concentrations are greater for primary (i.e., directly emitted) pollutants, such as nitrogen dioxide (NO_2) and ultrafine particles, compared with secondary pollutants (i.e., which are formed from chemical reactions), such as ozone and a portion of particulate matter ≤ 2.5 μm in aerodynamic diameter ($PM_{2.5}$).[11,14,15] Research into the spatial resolution needed to accurately quantify pollution inequities suggests that county-scale analyses can underestimate the magnitude of total U.S. $PM_{2.5}$ and NO_2 exposure disparities by race and ethnicity compared with those employing finer-scale data aggregation (census tract, block group, and block)[16] but that the resolution of current satellite measurements (e.g., 20–60 km^2) can quantify a large (although perhaps incomplete) fraction of intraurban NO_2 inequality.[8,17,18] National, state, regional, and city government agencies, along with private companies, now have access to funding (and are subject to mandates) that welcome or require a focus on remedying health inequities. There is great potential to leverage recent research and novel data to inform strategies in reducing intraurban and regional pollution disparities.

Modeling to Evaluate Health Equity Impacts of Pollution Mitigation Policies

Recent research has also advanced modeling frameworks to predict expected benefits of policies aimed at reducing race, ethnicity, and income inequities. To estimate health burdens associated with air pollution exposure within a given geography and the expected benefits of exposure reductions, health impact assessments generally use area-level (e.g., county, census tract, census block group) exposure, baseline disease rates, and concentration–response functions derived from previous epidemiological studies. Values for each of these quantities can vary across geographies and population subgroups, driven by environmental and social determinants of health.

Inequities in baseline disease burden are a result of many processes.[19–21] As one example, current and historical discriminatory practices based on presenting race and ethnicity can lead to inequities in health burden via chronic social stress, in addition to causing air pollution exposure differences via segregation.[22,23] A recent study has demonstrated the use of fine-scale baseline disease rates in identifying overburdened neighborhoods with overlapping high exposures and poor health.[24] An assessment of the San Francisco Bay Area (California) using census block group mortality rates yielded 15% higher spatially aggregated estimates of pollutant-attributable mortality rates, as compared with the application of county baseline disease rates.[25] Despite their potential importance in health impact assessment, highly resolved baseline disease rates or individual-level air pollution exposure data are rarely publicly available, in part because of concerns around identifiability; instead, for baseline disease rates, many health impact assessments rely on coarsely resolved data (e.g., county-level or coarser) or modeled estimates at a finer resolution (e.g., census tract or finer).

Recent analyses using a fine-scale (1-km^2) gridded exposure data set[26] aggregated to the census tract, concentration–response functions derived from a longitudinal study of Medicare recipients,[27] and fine-scale (census tract) incidence data estimated $PM_{2.5}$-attributable mortality for Americans >65 years of age, and reported mortality rates three times higher for Black Americans compared with white Americans.[28,29] These studies applied race-specific concentration–response functions to represent a range of race-based disparities and discriminatory processes that result in health burden inequities. The race-specific concentration–response functions used in the above studies were derived from an underlying epidemiological study with exposure estimates at the ZIP code level,[27] which could lead to mischaracterization due to exposure variation within ZIP codes. In addition, nonlinear concentration–response relationships may be important to consider in accounting for the known drivers of disparities.[30]

To effectively implement place-based policies in support of environmental justice, we believe it will be critical to identify specific emission sources and sectors contributing to air quality inequities with the highest spatial precision that is feasible. In addition, current evidence using reduced-form air pollution models—developed to reduce the computational costs of model runs—suggests the magnitude of disparities and relative contributions of different sectors can vary across U.S. Regions, as well as urban and rural areas.[31] Therefore, we suggest that the emission sources that need to be reduced to maximally reduce exposure inequalities may differ by location. Fine-scale (e.g., census tract or higher resolution) source attribution may need to reflect weather patterns, built infrastructure, and local sources[32]; current regulatory modeling typically operates at broader spatial scales (county or state) and without fine-scale local information. Source attribution at the hyperlocal scale is currently limited both by input data (e.g., emissions inventories, meteorological fields) and, for conventional models, by the spatial precision of computationally tractable models.[33] Air pollution-relevant emission inventories based on data provided through the U.S. Environmental Protection Agency (EPA) National Emissions Inventory (NEI)[34] for the continental United States are available at 12-, 4-, and 1-km^2 resolution.[12,31,35–38]

Researchers have made advances in identifying census block or finer exposure inequities associated with different sources, such as restaurants[39] and traffic-related air pollution.[8,11,15,40–44] Other research has studied inequities associated with other sectors of the economy, such as electricity generation[45,46] and interstate freight.[47] Using fine-scale air quality change estimates, Wang et al.[48] and Dressel et al.[17] suggested that targeted, location-specific reduction strategies are needed to reduce current racial and ethnic $PM_{2.5}$ and NO_2 exposure inequalities, with Wang et al.[49] demonstrating the potential of reduced-form modeling to inform selection of locations for emission reductions. In our view, such location-specific regulatory approaches would complement the main current approaches to air pollution regulation, such as the National Ambient Air Quality Standards and sector-specific emission-reduction technology requirements.

In summary, we believe characterizing within-neighborhood ambient air pollution concentrations and health metrics will enable *a*) more refined characterization of exposure in epidemiological analyses used for defining concentration–response functions, *b*) improved exposure and baseline disease rate inputs for health impact assessments, and *c*) enhanced attribution to emissions sources. The end result would be to better prioritize policies that could substantially reduce air pollution-mediated health inequities (e.g., utility investments in electric vehicle charging infrastructure).

Monitoring Policy Effectiveness

Although the existing federal regulatory monitoring network is essential to develop and evaluate clean air policies and standards, it does not provide geographic coverage adequate to resolve neighborhood-scale pollution variability.[50,51] Expanding innovative approaches to monitoring will help track and verify progress [i.e., accountability research (see Boogaard et al.[52])] in reducing air pollution exposure inequities. For example, the impact of closures of industrial facilities on air pollution and associated health outcomes was quantified using an ensemble model that incorporates land-use and satellite-derived variables to estimate weekly ambient $PM_{2.5}$ concentrations in each ZIP code before and after facility closure.[53] Recent research has demonstrated the potential utility of fine-scale satellite atmospheric composition measurements for evaluating the impacts of policy changes on exposure disparities, such as quantifying changes in the magnitude of racial/ethnic disparities in NO_2 concentrations in U.S. urban areas associated with reductions in traffic during the early months of the COVID-19 pandemic,[10] evaluating the effect of diesel emission control strategies on air pollution inequity,[8,54] and examining the localized air quality impacts of freeway rerouting.[55] Studies also show that diesel emission control technologies reduce but do not eliminate disparities.[8,56] Other research has used empirical models that incorporate regulatory monitor measurements and satellite observations to quantify changes in the magnitude of national racial/ethnic and socioeconomic air pollution disparities over multiple decades.[9,11]

From our perspective, further advancement in methods for monitoring fine-scale changes in pollution concentrations over time (e.g., mobile monitoring,[48] low-cost sensors[57]) will assist in tracking and confirmation of the impact of place-based policy interventions on reducing air pollution-related health disparities. Characterizing uncertainty (e.g., data quality, accuracy, representativeness) also must be a key priority.[58] For example, hourly, daily, and weekly temporal variation in emissions, as well as data on residents' movements through space, can refine analyses of exposure inequities.[59] In addition, movements of residents over yearly timescales should be considered when tracking effectiveness given that lessons from other place-based programs, such as hazardous waste clean-ups and allocation of education resources, indicate gentrification processes could reduce long-term benefits accrued to the original residents.[60–62]

Recommendations

We believe that to ensure the effectiveness of future environmental and climate policies in addressing longstanding and persistent air pollution inequities, scientists, advocates, and environmental regulators must collaboratively develop new data collection and analytic frameworks to aid the design and implementation of place-based policies [Figure 1 (inspired by a California Air Resources Board white paper[63])]. Specifically, environmental regulators must prioritize projecting and tracking the distributional impacts of new policies at appropriate geographic and temporal scales. The U.S. EPA Scientific Advisory Board recently emphasized this need in calling for the U.S. EPA to "develop a strategy for systematic, quantitative evaluation of the environmental justice impacts of . . . regulations," as part of their recent regulatory reviews of science supporting the U.S. EPA's proposed rule on control of air pollution from new motor vehicle standards.[64] Novel monitoring and modeling technologies have the potential to greatly aid the effort to characterize and abate air pollution sources contributing to health disparities. To meet that potential, regulators will need to update and expand regulatory frameworks to incorporate new data. For example, a recent analysis in California demonstrated how satellite-derived estimates can inform air quality management by screening locations not represented within the regulatory monitoring network.[65] Recent public comments from a coalition of environmental and public health advocates emphasized that the U.S. "EPA must amend its monitoring network requirements to ensure adequate monitoring of air pollution in at-risk communities, including communities of color and low-income communities" and called on the U.S. EPA to "issue guidance as soon as possible to ensure that data collected. . .using new technologies and hybrid approaches may factor into regulatory decision-making."[66] We recommend that regulators leverage insights from novel data sources, including community-led monitoring supported by new U.S. EPA funding, to improve and expand the regulatory monitoring network and inform regulatory decision-making that alleviates pollution disparities.

The scientific community must work closely with regulators, advocates, and impacted communities to advance data collection and analysis strategies that match the goals of environmental and climate justice policies, integrating diverse data streams using accessible reporting methods while also acknowledging and characterizing uncertainty as accurately as possible.[58] We assert that collaboration by governments, scientists, and advocates will be critical to address key technical, governance, and ethical questions and challenges, including how to enable broad access and

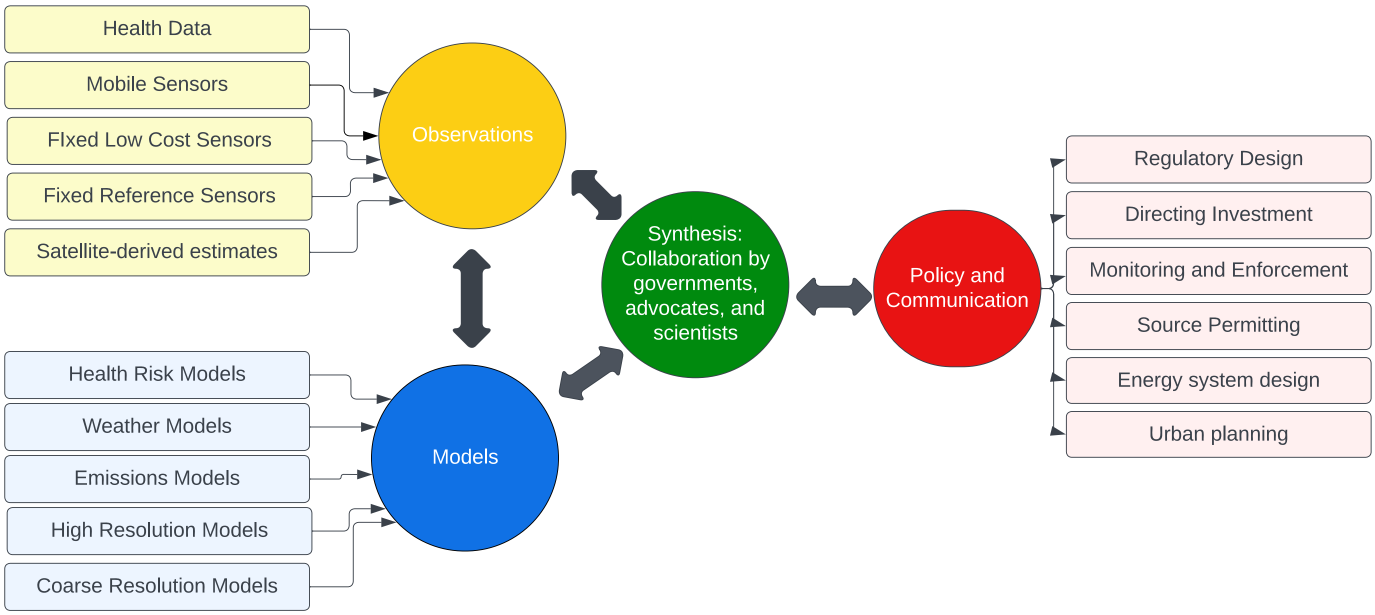

Figure 1. Diagram illustrating relationships between data sources, models, collaboration for synthesis, and policy and communication. Central circles represent components of an integrated data analysis and policy framework to maximize reduction in air pollution-related health inequities. Lighter colored rectangles are examples of observational data sets, models across health and environmental sciences, and relevant policy and communication outcomes. This figure was modified from a figure by the California Air Resources Board.[63]

understanding of an increasingly complex data ecosystem, synthesize data from multiple sources into information useful to policymakers and community leaders, and ensure feedback mechanisms that incorporate local lived experience. Critically, this collaborative work must be grounded in the principles of environmental justice,[67] antiracism,[68,69] and community science,[70] including centering the priorities of impacted communities and ensuring that community representatives serve in decision-making roles. These efforts can build on work already underway, including the collaborative work of the community-based organization Comite Civico del Valle and government and academic partners to deploy the Imperial County Community Air Monitoring Network[71] and the activities of the National Aeronautics and Space Administration Health and Air Quality Applied Sciences Team to advance the use of satellite data for environmental justice (https://haqast.org/tiger-teams/), and can leverage new resources, including funding through the U.S. EPA's Environmental Justice Collaborative Problem Solving Cooperative Agreement Program (https://www.epa.gov/environmentaljustice/environmental-justice-collaborative-problem-solving-cooperative-agreement-5), and the Environmental Justice Thriving Communities Technical Assistance Centers (https://www.epa.gov/environmentaljustice/environmental-justice-thriving-communities-technical-assistance-centers).

With federal resources made available via the IIJA and IRA, we believe it is now more important than ever to advance the collection and analysis of fine-scale spatial and temporal environmental and health data to support the design, implementation, and evaluation of policies that reduce inequities in air pollution exposure and associated health impacts.

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