Recent Findings and Methodologies in Economics Research in Environmental Justice

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Abstract

This review synthesizes economics-oriented research in environmental justice with a focus on the last decade. We first categorize this literature into broad areas of inquiry and review main findings. Then, we review recent advances in data and methodologies that have allowed for new study designs and research questions. After identifying breakthroughs, we offer some guidance on how to continue to advance research in this area.

[1] The views expressed in this paper are the authors' and do not necessarily reflect the views of the Federal Reserve Bank of Chicago or the Federal Reserve System.

Introduction

This paper is inspired by the recent growth in environmental and urban economics research that documents and quantifies disparate exposures to an array of environmental burdens, explores the mechanisms generating these disparities, and studies government interventions that address and interact with these patterns and mechanisms; or more succinctly, research in environmental justice. Our goal is to synthesize the past decade of economics-oriented research in environmental justice by reviewing papers from the fields of economics, environmental and ecological economics, sociology, public health, and general interest science. We review approximately 100 papers produced or published in the last decade and synthesize the body of work in two ways. In Section A, we discuss the types of questions that this work generally seeks to answer. In Section B, we present the key methodological decision points and debates in the recent work. In Section C, we highlight on-going discussions and directions for future environmental justice research. While this review focuses on research done by economists or closely related fields, this focus does not reflect a prioritization of disciplines; rather, this paper is intended to be instructive for economics-oriented researchers seeking to contribute to a growing body of research questions in environmental justice.

This is not the first review of environmental justice literature and is very much related to previous reviews, notably by Banzhaf et al. (2019a) and Banzhaf et al. (2019b). This paper's contribution is to cover more recent work published since these reviews, focusing on topics that were not previously emphasized, including advances in methodological approaches and data availability. Agyeman et al. (2016) also review the history of the environmental justice *movement*, paying particular attention to trends and histories of activism and policy-making in this area. Mohai et al. (2009) review the key trends and methodological debates in environmental justice research at that time. While some of the key debates in Mohai et al. (2009), such as "race versus class" as the locus of the environmental injustice and the "chicken or the egg" problem of polluter siting versus residential sorting continue to be at play in the last decade of research, other debates such as whether the allocation of environmental burdens across communities should be based on "unit-hazard coincidence" (assigning population to hazards based on geographic coincidence defined by administrative boundaries) versus distance to pollution sources have transitioned to discussions of alternative pollution transport and dispersion models.

The political landscape has also evolved in the last decade, with increasing inclusion of environmental justice criteria in environmental policy at federal, state, and local levels. For example, the EPA now includes EJ criteria in their regulatory impact assessments, federal agencies must consider EJ analyses in their proposed programs and policies via the National Environmental Policy Act, and the federal government now aims to advance environmental justice by delivering at least 40 percent of benefits from federal investments in clean energy and climate in socioeconomically disadvantaged communities with the Justice40 Initiative (Young et al. 2021). Given these trends, we find it a particularly prudent time to take stock of the recent literature and findings in environmental justice from the economics community.

A. Types of research questions addressed

1. **Document and quantify**

Many papers in this literature focus on documenting and quantifying differences in exposure or damages from environmental hazards across different communities. Table 1 includes a list of all 49 papers reviewed in this category, close to half of all reviewed papers. Documenting the exposure gap remains an important contribution for policy-making. When there are constraints on policy making, the relative size of the pollution gap across hazards and settings can inform where policymakers target regulation when working toward equity-related goals. Cost-benefit analyses used in regulatory proceedings also benefit from studies that provide monetary estimates of environmental damages, which many of these papers do.

Documenting a gap requires defining both the environmental outcome of interest and the sub populations for which the gap is measured. Studies that characterize disparities in concentrations and exposure (Colmer et al. 2020; Currie, Voorheis, and Walker 2020) calculate the differences in pollution concentrations (weighted or unweighted) across demographic groups. Others characterize disparities in damages by calculating the differences in hospitalizations, mortality, and morbidity by race or income groups (Gillingham and Huang 2021). While the choice of outcome of interest may be driven by the research question, the set of outcomes studied are constrained by data availability. Section B discusses how expansions in measurement and data have expanded this set.

Computing a gap also requires choosing comparison groups. Existing studies have used different definitions depending on the question or institutional details of the setting. For example, Currie, Voorheis and Walker (2020) and Gillingham and Huang (2021) compare exposure and health gaps between African American/Black and white populations. Other studies additionally consider other minority groups such as Hispanic/Latino or Asian American (Fowlie, Holland, and Mansur 2012; Hausman and Stolper 2020; Mansur and Sheriff 2021; 2021; Shapiro and Walker 2021). Other work compares exposure differences between low- and high-income groups or compares groups above and below the federal poverty line (Fowlie, Holland, and Mansur 2012; Mansur and Sheriff 2021; Shapiro and Walker 2021). The choice of comparison groups dictates the types of conclusions these papers can make. For example, these studies have two main findings, (i) that African American/Black, Hispanic/Latino, and Asian American communities experience higher pollution exposure compared to predominantly white communities, and (ii) that low-income groups experience a higher pollution burden than high-income groups.

Studies have also leveraged specific policy or institutional details related to their setting to calculate pollution disparities or analyze the distributional consequences of different policies. Hoffman et al. (2020) and Nardone et al. (2020) compare differences in environmental risk by historical status as a redlined area. Other studies have compared groups depending on institutional definitions of vulnerability, for example using the EPA demographic index (Campa and Muehlenbachs 2021) or the “disadvantaged community” definition used by the California EPA (Cushing et al. 2018; Hernandez-Cortes and Meng 2020). The designation of a community as disadvantaged comes from a pollution score developed by the State of California which estimates relative pollution burdens across census tracts in California, the CalEnviroScreen (OEHHA, 2017). The publicly available scores facilitate researchers' ability to compare total pollution burdens across communities. The White House also recently published a similar tool, allowing practitioners to identify census block groups that are particularly polluted (White House 2022).

Deciding how to make comparisons in this research is not trivial. For example, should one control for income in a comparison of exposures by race? Should groups be based on race, ethnicity, national origin, or linguistic isolation? The EPA’s definition of environmental justice offers a helpful perspective:

> *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. This goal will be achieved when everyone enjoys: The same degree of protection from environmental and health hazards, and equal access to the decision-making process to have a healthy environment in which to live, learn, and work.*

This definition underlines that environmental injustice exists wherever there are gaps in fair treatment and meaningful involvement across all people. Accordingly, well-done comparisons across many different demographic and socio-economic characteristics can all contribute to our understating of environmental injustice. Though, the researcher needs to be fastidious in interpreting results across models, being cognizant of how seemingly small methodological decisions (e.g. conditioning on certain demographic characteristics or not) change the interpretation of their results.

Table 1. Environmental Justice Papers by Contribution Type

Contribution	**Papers**	**Count**
Document and Quantify	Abel & White 2011, Ard 2015, Bakkensen & Ma 2020, Bento et al. 2015, Bouvier 2014, Boyce et al. 2016, Christensen & Timmins 2018, Christensen et al. 2020, Clark et al. 2014, Clark et al. 2017, Collins et al. 2016, Colmer & Voorheis 2020, Colmer et al. 2020, Currie et al. 2015, Currie et al. 2020, Cushing et al. 2015, De Silva 2016, Depro et al. 2015, Deryugina et al. 2019, Downey & Hawkins 2008, Fann et al. 2011, Gamper-Rabindran & Timmins 2011, Heblich et al. 2021, Hernandez-Cortes & Meng 2020, Hernandez-Cortes et al. 2022, Hipp & Lakon 2010, Hoffman et al. 2020, Holland et al. 2019, Hsu et al. 2021, Keenan et al. 2018, Konisky et al. 2021, Kravitz-Wirtz et al. 2016, Melstrom and Mohammadi 2021, Mikati et al. 2018, Morello-Frosch et al. 2001, Nardone et al. 2020, Pais et al. 2014, Paolella et al. 2018, Prochaska et al. 2014, Sager and Singer 2022, Shadbegian & Gray 2012, Tessum et al. 2021, Timmins & Vissing 2021, Voorheis 2016, Voorheis 2017, Voorheis 2017, Wang 2021, Wang et al. 2021, Wolverton 2009.	49
Mechanisms	Adams and Charnley 2018, Bakkensen & Ma 2020, Benatiya Andaloussi & Isaksen 2017, Borenstein and Bushnell 2021, Campa & Muehlenbachs 2021, Christensen & Timmins 2018, Christensen et al.	47

	2020, Collins et al. 2016, Currie et al. 2015, Currie et al. 2020, Cushing et al. 2015, Cushing et al. 2018, Dauwalter and Harris 2021, Davis and Hausman 2021, De Silva 2016, Depro et al. 2015, Downey & Hawkins 2008, Fowlie et al. 2012, Fowlie et al. 2020, Gamper-Rabindran & Timmins 2011, Goulder et al. 2019, Grainger & Ruangmas 2018, Grainger 2012, Haninger et al. 2017, Hausman & Stolper 2020, Heblich et al. 2021, Hernandez-Cortes & Meng 2020, Hernandez-Cortes et al. 2022, Hoffman et al. 2020, Keenan et al. 2018, Konisky et al. 2021, Mansur & Sheriff 2021, Melstrom and Mohammadi 2021, Morehouse & Rubin 2021, Nardone et al. 2020, Pais et al. 2014, Plantinga Walsh and Wibbenmeyer 2020, Shadbegian & Gray 2012, Shapiro & Walker 2021, Timmins & Vissing 2021, Voorheis 2017, Voorheis 2017, Wang 2021, Wang et al. 2021, Weber 2021, Pizer and Sexton 2019, Wolverton 2009.	
Welfare Impacts	Anthoff & Tol 2010, Bakkensen & Ma 2020, Bayer et al. 2016, Bento et al. 2015, Bouvier 2014, Boyce et al. 2016, Campa & Muehlenbachs 2021, Christensen & Timmins 2018, Colmer & Voorheis 2020, Cropper et al. 2016, Currie & Walker 2019, Currie et al. 2015, Depro et al. 2015, Goulder et al. 2019, Grainger 2012, Haninger et al. 2017, Hausman & Stolper 2020, Heblich et al. 2021, Hsiang et al. 2019, Keiser and Shapiro 2019, Maguire & Sheriff 2011, Mansur & Sheriff 2021, Melstrom and Mohammadi 2021, Sheriff & Maguire 2020, Timmins & Vissing 2021, Voorheis 2016, Wang 2021, Pizer and Sexton 2019.	28
Government Interventions	Adams and Charnley 2018, Benatiya Andaloussi & Isaksen 2017, Bento et al. 2015, Bin et al. 2017, Campa & Muehlenbachs 2021, Currie & Walker 2019, Cushing et al. 2018, Fowlie et al. 2012, Fowlie et al. 2020, Gamper-Rabindran & Timmins 2011, Grainger & Ruangmas 2018, Haninger et al. 2017, Hernandez-Cortes & Meng 2020, Keiser and Shapiro 2019, Konisky et al. 2021, Levy et al. 2007.	16
Climate Justice	Auffhammer 2021, Bin et al. 2017, Borenstein and Bushnell 2021, Dauwalter and Harris 2021, Davis and Hausman 2021, Doremus et al. 2020, Goulder et al. 2019, Hardy & Hauer 2018, Hoffman et al. 2020, Holland et al. 2019, Hsu et al. 2021, Keenan et al. 2018, Plantinga Walsh and Wibbenmeyer 2020, Pizer and Sexton 2019.	14
Frontier Methods or Data	Adams and Charnley 2018, Anthoff & Tol 2010, Ard 2015, Baker et al. 2020, Bayer et al. 2016, Boyce et al. 2016, Christensen & Timmins 2018, Christensen et al. 2020, Colmer & Voorheis 2020, Colmer et al. 2020, Cropper et al. 2016, Currie et al. 2020, Depro et al. 2015, Deryugina et al. 2019, Fann et al. 2011, Grainger & Ruangmas 2018, Hausman & Stolper 2020, Heblich et al. 2021, Hsiang et al. 2019, Keiser and Shapiro 2019, Leelőssy et al. 2014, Levy et al. 2009, Mansur & Sheriff 2021, Paolella et al. 2018, Sadd et al. 2011), Sheriff & Maguire 2020, Su et al. 2009, Tessum et al. 2021, Voorheis 2016, Voorheis 2017, Voorheis 2017.	31

Metanalysis or Review	Agyeman et al. 2016, Baker et al. 2020, Banzhaf et al. 2019, Cushing et al. 2015, Maguire & Sheriff 2011, Pizer and Sexton 2019.	6

Notes: Categories are not mutually exclusive and reviewed papers are allowed up to two categorizations. Papers in the Document and Quantify category document and/or study a disparity in an environmental related (dis)amenity, irrespective of findings (does not include disparities in prices and expenditures). Papers in the Government Intervention category take a broad stance on what constitutes a government intervention and include government policies and programs. The Individual Welfare category includes papers that study or estimate willingness to pay and environmental justice related impacts to individual and/or social welfare.

2. Mechanisms

Making predictions is a key weakness in studies that only quantify the pollution exposure gap. And understanding the mechanisms that contribute to environmental injustice is necessary to move beyond program evaluation. Banzhaf et al. (2019) outline four general mechanisms, all of which also appear in Mohai et al. (2009)'s review. These mechanisms include: residential sorting, firm sorting, discriminatory policy and/or enforcement, and coordination between firm and household sorting. The mechanisms studied over the last decade follow a similar categorization. We list papers studying residential sorting and firm sorting in rows one and two of Table 2. We group papers studying discriminatory politics and enforcement as relating to procedural justice, listed in row three of Table 2. We add a fourth category of papers studying markets and market-based policy in row four. Individual welfare impacts are discussed in this section, though since papers in this area span multiple categories, they are listed in Table 1.

Residential Sorting

Economic intuition tells us that households make residential location decisions by trading off their preference for better amenities with costly housing. Yet, formulating environmental injustice as the equilibrium result of standard economic models of residential sorting can greatly obscure the mechanisms generating the injustice, with recent empirical work demonstrating the ill-suitability of several of the standard assumptions included in these models. For example, a standard sorting model would ignore pure discrimination in the housing search process, and the results of Christensen and Timmins (2019) demonstrate the bias introduced by such an assumption. The authors combine a large-scale experiment in renters' housing search with a structural sorting model and identify race-based discrimination in rental housing markets, demonstrating that sorting models that exclude this form of discrimination would otherwise yield significantly biased estimates of willingness to pay. Christensen et al. (2020) find that renters with African American and Hispanic/Latino names are less likely than renters with white names to receive responses to rental inquiries for properties in low-exposure locations.

Several methodological developments over the last decade have improved the ability of sorting models to provide insights on environmental justice-related research questions. Bishop and Murphy (2011) and Bayer, McMillan, Murphy and Timmins (2016) demonstrate the potential bias that occurs from ignoring the dynamic components of the sorting decision. Bishop and Murphy (2011) develop a simplified dynamic estimator to estimate willingness to pay to avoid violent crimes, finding that a myopic model underestimates willingness to pay (WTP). Bayer, McMillan, Murphy and Timmins (2016), develop a dynamic structural model of neighborhood choice and apply it to estimate willingness to pay for environmental amenities for forward looking agents, finding that a static model underestimates willingness to pay to avoid pollution and crime, with the size of the bias varying by income level. Hausman & Stolper (2020) study the role of known and unknown information in the sorting decision, and show that sorting-induced environmental injustices are amplified when unobserved disamenities are correlated with observed disamenities. Complicating the role of information on EJ outcomes, Wang et al. (2021) find indirect evidence that information-based interventions in the form of disclosures can aggravate equity outcomes due to differential community effort. Depro et al. (2015) study the contribution of household mobility to the pollution disparities, estimating differences in willingness to pay for clean air across race groups, and demonstrating how residential mobility contributes to differences in environmental health risks, which may work against policies intended to address environmental injustice. Gamper-Raindran and Timmins (2011) find evidence of a related unintended consequence of an environmental clean-up, where the remediation of Superfund sites benefits the rich households that migrate to the cleaned-up areas rather than the households that were originally exposed to the contamination. Heblich et al. (2021) study path dependence and persistence in pollution and neighborhood effects, finding that temporary industrial and coal pollution has long run implications on pollution and segregation, explaining up to 20 percent of neighborhood sorting 40 years later. Bakkensen and Ma (2020) use a boundary discontinuity design to study sorting and flood risk, finding evidence that low-income minority residents are more likely to move to high-risk flood zones.

Advances in data access have allowed researchers to study longer term disparities in exposure across location decisions. Voorheis (2017a) uses a new of kind longitudinal data to study environmental gentrification, where amenity improvements induce cost of living price increases leading disadvantaged individuals to sort out newly improved regions, and finds that longer term environmental gentrification leads socioeconomically advantaged individuals in the sample to experience larger pollution exposure reductions than initially disadvantaged individuals. Pais et al. (2014) study exposure and residential location over two decades, finding exposure differences are only partially explained by racial differences in suburban neighborhood attainment, socioeconomic status, and the frequency of inter-neighborhood moves.

Many of the sorting models in empirical work include amenities that are additively separable in the utility function, ignoring any potential cumulative impacts of pollution that may magnify exposures and vulnerabilities to environmental hazards. These effects have been studied in environmental and health-oriented research, including calculating population risk measures of cumulative pollution (Morello-Frosch et al., 2001) and generating vulnerability indices that account for exposure to multiple sources of pollution and other risks (Su et al., 2009; Sadd et al., 2011). Hsiang et al. (2019) discuss a related dimension, the differences between exposure and vulnerability, highlighting that differences in location-based exposure predicted by sorting models may tell an incomplete story of environmental justice due to differences in vulnerabilities to the environmental hazards across race and socio-economic demographics. Future economics research in this area would do well to consider the non-additive and potentially interactive effects of environmental disamenities, as well as the differences and connections between exposure and vulnerabilities and their unique contributions to environmental injustice.

Welfare Impacts

The aforementioned literature highlights that at least some component of choosing where to live involves trading off housing prices for amenities. If households are compensated for disamenities, then what are the welfare impacts of environmental injustice? Answering this question requires unbiased estimates of individuals' willingness to pay for environmental amenities, which is done in Wang (2021), Bento et al. (2015), Cropper et al. (2016), and Depro et al. (2015), and discussions of the connection between environmental inequalities and individual or social welfare are found in almost one third of the surveyed papers. Yet, many of the existing methodological approaches are unable to separately identify willingness to pay net of all other potential discriminatory forces impacting the household sorting decision. Further, Greenstone and Jack (2015) discuss four possible reasons why estimates of marginal willingness to pay among low-income individuals are seemingly low. Future research and continued innovation in modelling residential location decisions is needed to better connect environmental justice to individual welfare. We highlight the subset of papers in our review that discuss individual welfare impacts and/or estimation willingness to pay(s) in Table 1.

Firm Sorting

Other work studies how firm location decisions impact the distribution of environmental hazards. Morehouse and Rubin (2021) find that power plants strategically locate near borders, so that pollution disperses downwind of the local or state authority. Wolverton (2009) reviews the role of timing in the firm siting decisions -- the difference in matching firms to communities at the time of making the location decision, versus the demographics of communities once located. While focusing on the latter informs which communities are expected to see pollution from firms, the former approach is more instructive for understanding how polluting firms decide where to locate (Abel and White 2015; Collins, Munoz, and JaJa 2016; Currie et al. 2015; De Silva 2016; Mikati et al. 2018; Timmins and Vissing 2021; W. Wang 2021; X. Wang et al. 2021; Wolverton 2009). Additionally, there are potential interactions between firm sorting and residential sorting. Heblich et al.(2021) show that historical pollution and residential sorting with respect to firm locations can explain current segregation patterns. Ho (2021) studies the location of solid waste disposal, finding that NIMBY-motivated bans on waste disposal could lead to substitution of waste from facilities near white residents to facilities near Hispanic residents.

Procedural Justice

As the EPA definition above discusses, environmental justice is not solely about fair treatment, but also meaningful involvement, which has been studied recently through the lens of procedural justice and makes up a small share of the work in our review. Procedural justice concerns the fairness of the processes that resolve disputes and allocation resources (Department of Justice 2021). Bell & Carrick (2017) highlight that the decisions that change the environment are usually made by people who enjoy the benefits of the decisions rather than the burdens. Hamilton (1993) shows that communities that are better able to organize politically are less likely to see local firms expand hazardous waste processing. Gray & Shadbegian (2004) and Shadbegian & Gray (2012) study the determinants of regulatory stringency in communities near pollution facilities and find that collective action is an important determinant of stringencies. Timmins & Vissing

(2021) study outcomes from leases signed between shale operators and households in Texas, finding that race and English-speaking are correlated with lease terms and royalty compensation. Campa & Muehlenbachs (2021) study outcomes when companies negotiate with local communities as to whether to pay a monetary fine for breaking an environmental law or undertake a local environmental project. They find that richer communities are more likely to settle with in-kind transfers and that empirically, fewer in-kind settlements occur than would be optimal in an analogous theoretical model of welfare maximization. Fowlie, Walker & Wooley (2020) study the connections between climate change policy, local air pollution policy, and environmental justice by evaluating recent legislative experiences, and find that a community driven process to address pollution hotspots is likely to be a “political prerequisite” for policy in EJ and climate, a finding that implicitly highlights the role of procedural justice in shaping historical outcomes.

Table 2. Papers Studying Mechanisms in Environmental Justice

Mechanism	Papers	Count
Residential Sorting	Bakkensen & Ma 2020, Bayer et al. 2016, Christensen & Timmins 2018, Christensen et al. 2020, Depro et al. 2015, Downey & Hawkins 2008, Gamper-Rabindran & Timmins 2011, Grainger 2012, Haninger et al. 2017, Hausman & Stolper 2020, Heblich et al. 2021, Keenan et al. 2018, Melstrom and Mohammadi 2021, Pais et al. 2014, Voorheis 2017, Wang 2021.	16
Firm-Side Sorting	Collins et al. 2016, Currie et al. 2015, De Silva 2016, Morehouse & Rubin 2021, Wang et al. 2021, Wolverton 2009.	6
Procedural Justice	Adams and Charnley 2018, Campa & Muehlenbachs 2021, Fowlie et al. 2020, Hoffman et al. 2020, Keiser and Shapiro 2019, Morello-Frosch et al. 2001, Paolella et al. 2018, Sager and Singer 2022.	8
Markets and Market Based Policy	Benatiya Andaloussi & Isaksen 2017, Cushing et al. 2015, Cushing et al. 2018, Dauwalter and Harris 2021, Davis and Hausman 2021, Fowlie et al. 2012, Goulder et al. 2019, Grainger & Ruangmas 2018, Hernandez-Cortes & Meng 2020, Hernandez-Cortes et al. 2022, Mansur & Sheriff 2021, Shapiro & Walker 2021, Simeonova et al. 2018, Timmins & Vissing 2021, Pizer and Sexton 2019, Weber 2021.	16

3. Government interventions

Another body of work examines the impact of regulations and policy on disproportionate exposures and damages from environmental hazards. The papers that fall in the category are listed in Table 1.

Market-based

Within this literature, recent attention has been paid to whether market-based policies, such as emissions trading programs and pollution taxes, exacerbate inequities. In a market-based regulation, firms with lower abatement costs will reduce emissions relatively more than firms with higher abatement costs. Thus, households near and downwind of low abatement cost firms are expected to benefit more from the program compared to households living near and downwind of high abatement cost firms. Shapiro and Walker (2021) study offset trading in the Clean Air Act, a program which includes market-based elements but is distinct from cap-and-trade programs, and find little evidence that the location of emissions offset purchases and sales is correlated with larger Black or Hispanic population shares or lower mean income. Fowlie et al. (2012) investigate the impact of Southern California's emissions trading program (RECLAIM) for local air pollution, assuming uniform pollution dispersal around point sources, and do not find evidence of disproportionate impact by demographics. Grainger and Ruangmas (2018) replicate the study relaxing the assumption of uniform pollution dispersion and do find evidence that high income areas benefited from emissions trading more than low-income areas, and predominantly Black communities benefited from emissions trading relative to Hispanic communities. The difference in findings highlights the importance of the chosen method of modeling pollution transport, a methodology further discussed in Section B.

Market-based regulations to address global climate change have recently come under scrutiny, at least in part due to their impacts on co-pollutants emitted alongside greenhouse gases. While these policies regulate greenhouse gas emissions, they also impact the location and quantity of co-pollutants emitted alongside GHGs, which have human health effects for the exposed populations. Hernandez-Cortes and Meng (2021), Weber (2021), and Walch (2020) study this question in the context of California's cap-and-trade program, all finding that pollution does not increase in vulnerable communities following the regulation, and Hernandez-Cortes and Meng (2021) find evidence of a gap narrowing. On the other hand, Cushing et al. (2018) study the same program in California and find descriptive evidence of increases in pollution exposure among heavily polluted communities following the program's implementation. Overall, research on emissions trading programs and EJ effects is beginning to establish that the anticipated EJ impacts from these types of policies are a priori ambiguous, depending critically on the empirical setting; namely, the spatial distribution of abatement costs and communities.

Non-market based

Among the literature studying non-market based regulations, an extensive body of work documents the welfare impacts of pollution decreases induced by the 1970 Clean Air Act (CAA) amendments.[2] The CAA amendments of 1970 and 1977 were based on a command and control approach for local air pollutants (Currie and Walker 2019), requiring that counties that exceed emissions standards create their own air quality improvement plans. The CAA amendments of 1990 established similar standards for toxic emissions. Studies examining the effects of the CAA have found that improvements in air quality due to the CAA amendments caused significant health benefits (Aizer et al. 2018; Aizer and Currie 2019; Colmer et al. 2020; Isen, Rossin-Slater, and Walker 2017).

[2] These amendments established the maximum level of pollution concentrations of six pollutants: carbon monoxide, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide.

Currie, Voorheis & Walker (2020) show that pollution concentrations throughout the United States have decreased in the last few decades, with concentrations in predominantly Black neighborhoods decreasing more than those in predominantly white neighborhoods. The authors examine whether the gaps closed due to the implementation of the CAA amendments, specifically, the revised PM2.5 standard in 2006. The authors find that the CAA accounts for over 60 percent of the relative improvement between Black-white pollution concentrations. The authors also find that this decline in the gap cannot be explained by changes in mobility, individual, or neighborhood characteristics, which allows them to attribute the change in the gap to the CAA Act PM2.5 standard. A recent working paper by Sager and Singer (2022) also shows that the 2005 PM2.5 CAA standards contributed to narrowing Urban-Rural and Black-white PM2.5 exposure disparities.

Other non-market based regulations involve the disclosure of information about pollution sources. For example, the information disclosure provided by the Toxic Release Inventory in 1990 provided information on existing pollution sources across communities in the United States. Although toxic emissions fell after the disclosure of the TRI (Wang et al. 2021, EPA 2014), studies have found that these reductions are not evenly distributed across communities. In particular, toxic emissions fell more in high-income counties compared to low-income counties (Kalnins and Dowell 2017) and African American communities experienced a smaller decrease in toxic pollution compared to other communities (Ard 2015). Releasing information about existing pollution sources might exacerbate pollution exposure depending on how and to what extent these releases re-sort individuals (Banzhaf and Walsh 2008; Hausman and Stolper 2020) and/or facilities (De Silva 2016; Wolverton 2009). A study by Wang et al. (2021) finds that TRI facilities located in communities with higher population density and higher education levels were more likely to relocate to lower income and lower educational attainment communities.

Cleanup programs such as the Brownfield Program and the Superfund Program are other examples of non-market based policies. Superfund sites are high risk areas that pose a significant threat for human and environmental health, while areas designated as Brownfields are currently low-risk areas that have been previously used for industrial or commercial purposes. Haninger, Ma & Timmins (2017) examine whether the US EPA Brownfield grants program, designed to provide economic support to redevelop Brownfields, had positive impacts on property values. The Brownfields Program cleanups increased property values by 5-11.5 percent, however, the authors find that these impacts were highly localized near these areas. Moreover, Melstrom & Mohammadi (2020) find that Black residents are more likely to be displaced after a Brownfield cleanup, suggesting that the program contributed to environmental gentrification. Wang (2021) finds a similar result when looking at environmental improvements following the installment of abatement technologies in gas-fired power plants in Los Angeles following the California Electricity Crisis, finding that environmental improvements can benefit housing owners but have a negative impact on renters.

The EPA's Supplemental Environmental Projects constitutes another non-market based policy, and allows firms to address non-compliance with environmental regulation through environmental and community projects. Campa & Muehlenbachs (2021) finds that these in-kind transfers can be beneficial for the violating firms, and that such projects are more likely to occur in communities that are high-income and predominantly white. Another non-market government intervention occurs in the siting and permitting of polluting facilities, and more broadly, land-use planning. Not much has been done in this area since Hamilton (1995), which studied how differences in the probability that residents would engage in collective action to oppose expansions of hazardous waste facilities impacted the locations of these expansions.

Finally, another non-market based approach for the EPA to regulate environmental injustice may come through new and evolving interpretations of the Agency's legal authority under Title VI of the Civil Rights Act of 1964 (Title VI). A recent report by the EPA notes that, as discussed in Executive Order 12898, "existing environmental and civil rights statues [Title VI] provide many opportunities to ensure that all communities live in a safe and healthful environment". The report also highlights that all EPA funding recipients are required to comply with Title VI (EPA 2022). While developments on the legal authority of the EPA in the context of Title VI are on-going, recent updates indicate potential expansions in the EPA's legal tools to address environmental injustice.

4. Climate Justice

Climate impacts

Recent research increasingly connects environmental injustice to climate induced environmental hazards. Urban "heat islands" have been found to disproportionately affect non-white and lower-income populations (Hsu et al. 2021). Heat-related disparities have also been linked to historical discrimination in housing markets through the practice of redlining. In an analysis of 108 American urban settings, Hoffman et al. (2020) found that "94% of studied areas display consistent city-scale patterns of elevated land surface temperatures in formerly redlined areas", finding that the main associated mechanisms are disparities in canopy coverage, landscape features, and the types of construction in these areas.

Climate related natural disasters such as floods and wildfires have also been shown to disproportionately affect low-income and minority communities. Bakkensen & Ma (2020) find that housing prices lead low income and minority communities to be disproportionately likely to move into high-risk zones in south Florida. Keenan et al. (2018) use Miami-Dade County, FL as a case study to descriptively study climate gentrification, finding that elevation levels are positively correlated with housing prices. Hardy and Hauer (2018) project sea-level risk in coastal Georgia out to 2050, finding disproportionate sea-level risk increases among women and Hispanic/Latino populations. There is also documented evidence of differential adaptive capacity and mitigation responses. Bin et al. (2017) find that while payouts in the National Flood Insurance Program tend to be progressive, both coverage and net premiums divided by coverage, are regressive. Anderson et al. (2020) show that fire control agencies increase the use of preventive measures in communities with higher income, more education, and a higher share of white population.

Climate policy costs and incidence

More recent policy discussions around the equity impacts of decarbonization policies have invigorated the debate around how regulating GHGs will impact equity outcomes. Existing studies show that increases in electricity bills associated with the energy transition to a decarbonized economy are likely to affect low-income groups. Pizer and Sexton (2019) provide an extensive summary of the existing evidence on the distributional impacts of energy taxes and discuss the main findings. They find that energy taxes tend to be regressive and much of the regressivity is driven by electricity consumption, given that households in the United States in the lowest decile spend a higher share of income on electricity than wealthier households. Other studies have found that these taxes are not necessarily regressive, as the distributional impacts also depend on the redistribution of the revenue generated by these policies (Chen, Goulder, and Hafstead 2018). Doremus et al. (2020) find that energy expenditures for low-income consumers are about half as responsive to extreme temperatures as all other households, indicating disparities in climate adaptation options available across income.

A report (Borenstein et al. 2022) on electricity rates in CA finds that half to two-thirds of electricity costs in the state are essentially a tax covering activities outside of the costs of supplying electricity (including climate mitigation and adaptation related activities), and these costs are distributed inequitably since electricity bills account for a larger share of income for low-income households. Other work finds that an increase in electrification and substitution from fossil fuels such as natural gas might affect low-income and minority consumers more due to the structure of capital cost recovery (Davis and Hausman 2021). Dauwalter and Harris (2021) show that there are heterogenous environmental benefits from rooftop solar installation, that these environmental benefits increase with income, and that minority households receive higher environmental benefits per capita.

Holland et al. (2016) study the environmental benefits of electric vehicles, including not only the climate related benefits, but the also the air quality costs from the electricity produced to fuel electric vehicles. They find highly heterogenous environmental benefits to subsidizing electric vehicles across space, and Holland et al. (2020) find that electric vehicles only switch from being cleaner than the average gas powered recently, over the period 2010 to 2017. Holland et al. (2019) study the distributional consequences of electric vehicle adoption and find that on average (without census region fixed effects), Asian and Hispanic residents receive positive environmental benefits from electric vehicles, while white and Black residents see environmental costs. These findings underline that the future impacts from increasing electrification of the transportation sector are likely to be highly heterogenous across space, and thus may come with mixed implications for environmental justice.

B. Study Design and Methodological Considerations

The work reviewed in the previous section includes an array of methodological decisions at various stages, from formulating the study question to calculating the outcomes of interest. The differences in study designs and approaches prevent a quantitative meta-analysis of pollution inequities, but perhaps more importantly, highlight a need to carefully consider how and why these decisions are made. In many cases, decisions stem from data and methodological constraints. Recent advances in both dimensions provide an opportunity to relax some of these constraints. Below we discuss several methodological areas in which the research over the last decade has advanced: modeling of pollution transport, use of new data sources from satellites and crowd-sourced pollution monitors, and use of new administrative data sets to study long-run trends in exposure.

1. Pollution transport

Early literature in this field assigned pollution to people using the "unit-hazard coincidence" approach. This approach involves selecting predefined geographic units, determining which units contain environmental hazards, and comparing demographics of geographic units with and without those hazards. A key weakness of this approach is that it assigns environmental burdens equally to all people within the same unit, regardless of the size of the unit, people's distance to the hazard, transport of the hazard, and varying population vulnerabilities and defensive behaviors and investments. In 2006 Mohai and Saha describe unit-hazard coincidence as the "classic" and "most widely used" approach for assessing environmental disparities at the time. A related issue concerns to the "ecological fallacy", whereby an individual unit might have a different exposure than the assigned exposure after aggregating these units to some spatial scale. Banzhaf et al. (2019a) discuss how the ecological fallacy creates bias when assigning individuals to hazards using grouped data.

Since then, increasingly sophisticated methods have been developed to model the transport of air pollutants, allowing for the assignment of people to air quality at finer spatial levels. And some new models embed the physical and chemical properties of pollutants into the transport models, though with different methodologies and assumptions. For example, dispersion models based on planetary boundary layers include Gaussian dispersion models such as AERMOD or ADMS, or Lagrangian dispersion models such as HYSPLIT or HyAD. Other pollution transport models consider the primary release of pollutants along with secondary chemical atmospheric reactions, examples of these models are WRF-Chem and GEOS-Chem. Models like AERMOD or HYSPLIT can be less computationally intensive than WRF/GEOS-Chem, though WRF/GEOS-chem model chemical reactions that are important for the formation of secondary PM2.5.

Reduced Complexity Models for air pollution modeling have surged in popularity, as they avoid the computational burdens required for full chemical transport models discussed above. Examples of these reduced complexity models are EASIUR, AP3 and InMAP (Gilmore et al. 2019). These models calculate total PM2.5 from precursors pollutants including primary PM2.5, NOx, Sox, and NH3, at different resolutions: EIASUR at a 36km x 36km pixel, AP3 at the county level, and InMAP at a varying grid of 1km x 1km in urban areas and 48km x 48km in rural areas). These models have improved researchers' overall access to more sophisticated pollution transport model though caveats and inconsistencies of the RCMs exist and have been documented (see Gilmore et al. 2019).

2. Satellite data

Recent advances in satellite data availability have also allowed for research at finer spatial scales and various time resolutions. Most of these satellite products measure Aerosol Optical Depth, which measures aerosol optical thickness based on how the atmosphere reflects the visible and infrared light. Di et al. (2016) use MODIS AOD data together with a neural network to predict daily PM2.5 concentrations in the United States at a 1km x 1km grid cell level resolution. Di et al. (2019) use machine learning algorithms such as random forests, gradient boosting and neural networks to estimate PM2.5 levels at a 1 km x 1 km resolution across the United States. Hammer et al. (2020) use a combination of satellite remote-sensing data with chemical transport modeling and geographically weighted regression to predict annual PM2.5 concentrations at a 1km x 1km resolution.

These satellite products have been validated using monitoring stations data; however, they can also underestimate total PM2.5 concentrations in some areas (Fowlie, Rubin, and Walker 2019). One potential problem with these pollution products is that the construction and training of the data is based on the location and data availability of the existing pollution monitoring networks, which has been found to be endogenous to socio-demographics (Grainger and Schreiber 2019; Mu, Rubin, and Zou 2021; Zou 2021). For example, Grainger and Schreiber (2019) find that regulators tend to avoid monitoring pollution in pollution hotspots, especially in poor areas. Although improvements in satellite data can provide opportunities for measuring pollution concentrations at spatially disaggregated areas, finding non-biased approaches to calibrating the data remains an important area for future research.

3. Crowd-source pollution monitoring

The recent deployment of "consumer" air quality monitors provides opportunities to observe air qualities at richer geographies though endogeneity concerns persist here as these areas select into finer measurement collection through consumer monitor adoption. Singer and Delp (2018) compare air quality measurements from these monitors, including -- AirBeam, AirVisual, Foobot, and Purple Air. They find that while the estimated mass concentrations for all four of these measurements were time correlated, all of the consumer and both research monitors studied substantially under-reported emissions for particles smaller than 0.3 μm diameter.

Table 3. Pollution Transport Models and New Data Sources

Pollution measure	**Model type**	**Model name example**	**Papers example (*)**
Pollution transport models	Dispersion model based on planetary boundary layers	AERMOD	Sullivan (2017)
		HYSPLIT	Grainger & Ruangmas (2017); Hernandez-Cortes & Meng (2021); Morehouse & Rubin (2021)
		EASIUR	Heo and Strauss (2020)

	Reduced complexity air quality modeling	AP2/AP3/APEEP	Holland, Mansur, Muller & Yates (2016); Chan, Chupp, Cropper & Muller (2018)
		InMAP	Tessum et al. (2021); Auffhamer (2021); Hernandez-Cortes et al. (2022)
	Eulerian photochemical models	CAMx	Marshall et al. (2014)
		CMAQ	Bravo et al. (2016)
		WRF-Chem and GEOS-Chem	
	Toxics exposure	RSEI	Sheriff (2021)
Satellite data	AOD	MODIS	Zou (2021)
	Satellite data and machine learning/chemical transport	Neural network (Di et al., 2016)	Fowlie et al. (2019)
		Chemical transport modeling and geographic-weighted regression (Hammer et al., 2020)	Fowlie et al. (2019); Currie et al. (2020).

Notes: (*) Papers listed are examples of papers that use these models for EJ related research, not intended as an exhaustive list.

4. Short and Long-Run Outcomes

Another decision point occurs in this literature when connecting a particular environmental burden to the policy-relevant outcome of interest. Example outcomes of interest include pollution concentration, population-weighted pollution concentration or exposure, or human health damages from pollutants. Differences in this choice reflect different research questions and will include/exclude different dimensions of environmental justice. For example, differential pollution concentrations across population groups may ignore differential abilities to adapt to pollution across these groups, which impact health outcomes. Studies focusing on characterizing disparities in concentrations and exposure (Colmer et al. 2020; Currie, Voorheis, and Walker 2020) calculate the exposure gaps as the difference in pollution *concentrations* (weighted or unweighted) across demographic groups. Studies characterizing exposure gaps in *damages* calculate the differences in hospitalizations, mortality, and morbidity by race or income groups (Gillingham and Huang 2021).

For some of the environmental hazards being studied, notably air pollution, human health and socioeconomic impacts are expected from long term exposure, rather than short term shocks (Isen et al. 2017, Aizer et al. 2018, Aizer and Currie 2019). Further, people are mobile, and their location choices may change over time. In these cases, understanding disparities in human health impacts from environmental hazards necessitates tracking pollution exposure by people over time, incorporating changes in residential locations. Recently, the availability of long panel data has made such research designs possible.

In several first-of-their-kind studies,[3] Voorheis and co-authors use newly linked survey and administrative records to create long panel data that facilitate longitudinal studies of pollution exposure (Colmer and Voorheis 2020; Voorheis 2017b, 2017c). Voorheis (2017a) connects these administrative records to satellite measurements of ground level concentrations of fine particulate matter to study longitudinal trends in pollution exposure from 2000 to 2014. The work confirms previous trends found in the literature -- cross-sectional environmental inequality has been declining -- but finds that this result masks longitudinal patterns. On average, pollution reductions over this period are larger among whiter and richer individuals than they are for minority and poorer individuals. Long panel data also allows for the study of intergenerational pollution exposure. Voorheis (2017b) uses administrative data to study the impact of pollution exposure at birth on outcomes as an adult, finding that pollution exposure at birth has significant effects on high-school completion, college attendance, and incarceration. Voorheis and Colmer (2020) develop a data set that links parents and children, finding that regulation-induced air quality improvements in utero increase second generation college attendance, a result which appears to stem from parents' resources and investments rather than biological channels.

These longitudinal studies, made possible through the application of newly linked long panel data, provide novel insights into the intergenerational effects of pollution exposure, opening the door for further research into intergenerational consequences of environmental injustice.

C. Discussion

A key development in the last decade of work in this area regards the documentation of underlying selection and bias in off-the-shelf data sources. Pollution monitors, for example, can be strategically located or have systematically less coverage across minority or poor communities (Grainger and Ruangmas 2018; Hausman and Stolper 2020). Improvements in satellite data availability and the use of atmospheric transport models have allowed researchers to use finer-scale pollution exposure measures, without being limited to the administrative geographic units of strategically placed pollution monitors. Economists are well versed in the perils of selection in biasing estimation and need to continue to apply these fundamental tools to

[3] Other papers have also used administrative data to study longer term pollution exposure effects, though without a focus on distributional impacts by race and income, for example, Bishop et al. (2021) and Deryugina et al.(2019).

estimation in the environmental justice arena. Likewise, administrative agencies can play a role in refining state and federal reporting requirements to promote either more comprehensive, or when not possible, a randomized data collection process. Research has also demonstrated the pitfalls of aggregating sociodemographic characteristics to larger geographic boundaries (Baden, Noonan, and Turaga 2007). And recent increases in data availability have allowed researchers to make use of finer scale pollution and demographic data, overcoming at least some of aggregation issues in earlier work. Further, the recent availability of longitudinal pollution and demographic data have allowed for burgeoning work in intergenerational pollution exposure.

Meanwhile, the literature continues to lack consensus on the objective function in environmental justice policy-making, likely in part due to the difficultly of connecting pollution exposure to individual measures of welfare. Studies have instead taken an array of approaches to defining environmental inequality and disparities in pollution exposure. Some calculate the average difference across minority groups or income levels (Currie, Voorheis, and Walker 2020; Fowlie, Holland, and Mansur 2012) while others have calculated the concentration distribution of pollution exposure across demographic groups using inequality indices like the Gini coefficient or the Atkinson index. Studies using inequality indexes estimate the extent to which existing pollution concentrations deviate from equality in pollution concentrations (Bouvier 2014; Boyce, Zwickl, and Ash 2016; Clark, Millet, and Marshall 2014; Goodkind, Coggins, and Marshall 2014; Holland et al. 2016). Notably, Clark et al. (2014) find that the inequality in pollution exposure to NO_2 is larger than the income inequality in the United States, and Boyce et al. (2016) show that the Gini coefficient for toxic exposure in 2010 was higher than that of income. Moreover, analyzing inequality coefficients in pollution exposure can yield different policy implications than when looking at average pollution exposure across groups. Holland et al. (2016) find large differences in inequality of damages associated with different pollution sources – when comparing the Gini coefficients, damages from gasoline vehicles are more concentrated compared to damages of electric vehicles. Mansur and Sheriff (2021) use alternative methodologies derived from the income inequality literature to estimate the distributional impacts of a cap-and-trade program in Southern California. Using generalized Lorenz curves and equally distributed equivalents, the authors rank policies in terms of pollution distributions across groups, demonstrating a methodology that allows for a preference structure to be attributed to the decision maker, who can characterize a tradeoff across different policies.

Much of the recent literature studies environmental justice in the context of air pollution, with less research on other media (water pollution being one notable example). Several studies have found that the impacts of exposure to water pollution are large, particularly for infants (Currie et al. 2013; Currie, Greenstone, and Meckel 2017; Flynn and Marcus 2021). To our knowledge the impacts of water pollution on environmental justice remains a gap in the literature. Linking water pollution to affected communities is difficult as it requires modeling the catchment area of rivers, streams, and sources of drinking water. Keiser & Shapiro (2019) and Andarge (2020) use the National Hydrography Dataset, which delineates a network of all surface waters in the United States and describes the flow direction of rivers and streams, which allows the authors to characterize whether a location is upstream or downstream from rivers and streams. Hill and Ma (2021) create a novel dataset from several administrative data sources to study the impact of fracking on water quality. These empirical approaches offer guidance to future research studying disparities in water access and quality. Policy makers and state and federal agencies can also help here –expanding the data collection processes on air pollution to other media would offer a pathway for the next decade of research to study other environmental hazards.

Studies measuring pollution impacts to disadvantaged communities often associate pollution exposure based on individuals' place of residence. Depending on the occupation and commuting patterns for work and school, location of residence may be a poor indicator of total pollution exposure. Yet, filling in the research gap characterizing differences in exposure to pollution at home, school, and work, is stalled by data availability. As these differences can have important implications for anticipating the effects of place-based policy, the research community would do well to work with regulators on methods to fill in these gaps.

The EPA has also developed methods for assessing environmental justice, publishing a Technical Guidance for Assessing Environmental Justice in Regulatory Analysis in 2015, which describes methodological practices to consider when assessing environmental justice concerns. Among other contributions, the guidance proposes a set of best practices, which relate to several topics discussed throughout this paper such as the selection of a comparison group, the selection of the geographic unit of analysis, the measurement of cumulative impacts, and other methodological decisions to examine environmental justice in EPA decisions.

Conclusion

The last 10 years have seen a marked increase in the documentation of many dimensions of environmental justice, as well as improvements in data collection and methodologies. Increasingly sophisticated pollution transport models have allowed for improvements in linking pollution sources to receptors. And the use of administrative records to observe location decisions over time as well as more sophisticated spatial equilibrium models have both been key advancements in connecting residential choices to pollution exposure. Yet, empirical researchers can only study what they observe, and much of the work in this review studies air pollution given the availability of data, with environmental justice research in water pollution, for example, notably lagging. Expanding pollution monitoring across space and media would be a straightforward way to make progress on EJ goals in the near term. Finally, a small but growing share of the recent literature connects disparities in pollution exposure to causal mechanisms. Analyzing the impacts of future policies on the environmental justice will require a continued focus on understanding where the injustice comes from.

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