UCLA Luskin Center for Innovation

Informing effective and equitable environmental policy

What Defines a Plastic-Burdened Community?

AN ENVIRONMENTAL JUSTICE FRAMEWORK FOR IDENTIFYING EXPOSURE DISPARITIES AND INFORMING MITIGATION INVESTMENT

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REPORT

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GLOSSARY OF KEY TERMS

Abbreviation	Meaning
CalEnviroScreen (CES)	The California Communities Environmental Health Screening Tool, an index that uses 21 indicators of environmental, public health, and socioeconomic conditions to assess burdens among Californian communities at the census tract level
CalRecycle	The California Department of Resources Recycling and Recovery, the primary agency tasked with implementing SB 54
Downstream	The stage of the plastic life cycle during which items reach the end of their life and escape into the environment or are disposed of via various methods
GIS	Geographic information systems, software that enables spatial mapping of data
GHG	Greenhouse gases, compounds that have warming potential when emitted to the atmosphere and contribute to climate change
Microplastics	A small piece of plastic typically less than 5 mm in length
Midstream	The stage of the plastic life cycle where fossil fuels are refined into plastic resins and plastic items are manufactured, bought, and used
Nanoplastics	A subcategory of microplastics that are especially small, 1-1,000 nm in length
Plastic Life Cycle	The entire process by which a plastic product is made (including the production of raw materials), used, and disposed of. Includes three major stages: upstream (extraction), midstream (manufacturing and use), and downstream (final disposal)
PPMF	The Plastic Pollution Mitigation Fund established by SB 54, which state agencies are tasked with using to remediate and lessen the impacts of plastic in California
SB 54	California's comprehensive plastic legislation enacted in 2022, also known as the California Plastic Pollution Prevention and Packaging Producer Responsibility Act
Upstream	The stage of the plastic life cycle where feedstocks — crude oil and natural gas — are extracted, transported, stored, and initially refined

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EXECUTIVE SUMMARY

California, and the global community at large, are facing a plastic pollution crisis. Recycling has proven ineffective as a strategy to address the plastic crisis, with only a small fraction of global plastic ever being recycled. This report shows how plastic, while ubiquitous and utilized in all aspects of the economy, disproportionately impacts lower-income communities and communities of color. Plastic-related pollution is, therefore, an environmental justice issue.

Building on prior efforts to address plastic pollution, California's latest response to the plastic crisis is the Plastic Pollution Prevention and Packaging Producer Responsibility Act (SB 54) enacted in 2022. This law aims to improve recycling outcomes and significantly decrease the amount of plastic waste generated in the state. Furthermore, it establishes the Plastic Pollution Mitigation Fund (PPMF), an investment fund that state agencies will use to remediate and mitigate harmful plastic impacts in the state beginning in 2027. The PPMF will deploy up to $5 billion over 10 years, representing a significant opportunity to address impacts in the communities disproportionately affected by plastic production, use, and disposal.

To aid Californian policymakers and agency administrators in effectively addressing these exposure risks, this report develops *The Three-Part Framework for Identifying Plastic-Burdened Communities* — an environmental justice tool to better measure inequitable patterns of plastic-related exposure. This framework characterizes overall exposure risk by focusing on the three general types: 1) site-based (impacts related to industrial sites and waste facilities), 2) dietary (inadvertent consumption of plastic or related contaminants via food and drink), and 3) consumer goods (dermal contact with products, services, and packaging containing or using plastic). With proper development of data-driven indicators to assess a community's exposure risk across the three risk vectors, Californian agencies will be able to use this framework to more intentionally target PPMF investment to address specific exposure risks in a given community.

Prior research has established that communities facing cumulative environmental burdens — which are disproportionately lower income and non-White — experience compounding harms, including from plastic exposure risks. Recognizing the effects of these existing patterns of environmental injustice is crucial to maximizing the benefits of plastic impact mitigation efforts. We discuss how the framework can be used by policymakers to synthesize both plastic exposure disparities and preexisting and co-occurring vulnerabilities when prioritizing mitigation funds to achieve maximum environmental justice benefits.

As a first step toward realizing the potential of this framework, this study includes a spatial analysis of downstream sites in California — those involved in processing and disposing of plastic waste — and how associated exposure risks are distributed throughout the state. Our analysis shows that exposure risk from plastic-related waste sites constitutes a significant environmental justice issue. We identified strong links between the areas of California experiencing the highest level of plastic-related waste site exposures and those experiencing high levels of other preexisting and co-occurring vulnerabilities, including lower income and higher poverty rates, poorer health outcomes, lower educational attainment, and larger portions

of the population who are non-White. Communities with high levels of impact are more likely to be designated as disadvantaged under California law, but we found that a large number of the highest-impacted communities are not (though these communities may have other resources not available to disadvantaged communities that ameliorate impacts from plastic). The plastic-burdened communities framework should be used to ensure that all heavily impacted areas are included in mitigation investment efforts. This tool will help to identify geographic hotspots for focusing mitigation efforts and investments to serve the communities most impacted by the plastic pollution crisis.

This report concludes with a number of policy recommendations aimed at making the administration of PPMF moneys more effective and transparent, as well as several important near-future research needs that will keep California on the cutting edge of plastic policy. These include utilizing *The Three-Part Plastic-Burdened Communities Framework* to align PPMF investments with specific community-level exposure risks and to develop new data sources to track microplastic pollution and other proxy measures of plastic exposure risk.

The report is accompanied by an interactive map readers can use to further examine the associations between one aspect of plastic pollution — plastic waste-related facilities — and communities. A policy brief summarizing the key points is also available.

1. BACKGROUND: THE PLASTIC CRISIS AND ITS ENVIRONMENTAL JUSTICE IMPLICATIONS

Environmental injustice is the propensity for communities of color and low-income communities to be disproportionately impacted by environmental hazards. Historical race-based redlining and zoning restrictions led to placing toxic facilities in communities of color at higher rates, a trend documented across diverse environmental issues throughout the United States. This report examines the link between environmental injustices and plastic-related pollution in California in order to contribute to the policy calculations involved in administering the Plastic Pollution Mitigation Fund established by Senate Bill 54. While environmental justice considerations have shaped important California environmental policy, public officials have not yet systematically applied the environmental justice lens to the many issues associated with plastic pollution. This report seeks to recenter environmental justice in the plastic pollution discussion and present a framework for understanding the plastic burden across different exposure risks.

1.1. The Global Plastic Crisis

Plastic is one of the greatest environmental challenges of our time. Decades of mass production of cheap, lightweight synthetic polymers has created a global plastic crisis. Since the development of the first completely synthetic plastic — Bakelite — in 1907 and the ballooning of plastic production beginning in the 1930s, plastic has become a staple of the broader economy. Plastic resins are now an inescapable component of the consumer goods market, found in everything from high-value durable goods like vehicles and furniture to toys and consumer electronics. Of particular concern is the way cheap plastic has facilitated the "throwaway economy" — an economic operational model in which short-lived goods, disposable items, and copious amounts of cheap packaging material create a pipeline that produces large amounts of waste and other externalities. The widespread use of this model in many industries is, in large part, responsible for the proliferation of plastic waste, which can often escape into the environment and persist for many years. However, use of plastic generally (not only in disposable or single-use contexts) is also associated with negative environmental and human health impacts related to the extraction and refining of fossil fuel feedstocks and the use of toxic chemical additives in polymer manufacturing. Risks related to plastic manufacturing, use, and waste are now pervasive. This problem is both local and global. As plastic production has increased, recycling rates have remained low (approximately 9% of plastic is recycled in the U.S.), and historically most plastic captured for recycling has been sent overseas, predominantly to countries with low recycling capacity. The result is a widespread dispersal of plastic waste throughout all corners of the globe, and constant exposure via food, drinking water, and consumer products.

A growing body of research has documented the worldwide pervasiveness of microplastics: small plastic particles created through weathering and physical degradation of plastic items, as well as the plastic pellets that are created in the intermediate stage of plastic manufacturing and recycling.[1] These pollutants have been found in every conceivable environment on Earth, from the bottom of the ocean to the highest mountains. Numerous studies have begun to document microplastics' ability to infiltrate the human body, identifying microplastic contamination in human blood, tissue, organs, and brain matter — a trend with serious and concerning ramifications. Curbing the risk of ingestion or inhalation of microplastic, along with chemicals or contaminants it can carry, is now one of the most significant environmental and public health challenges facing policymakers today.

Exposure to chemicals within plastic also poses serious health risks. Toxic additives, such as brominated flame retardants and plasticizers like bisphenol A (BPA), are often intentionally added to plastic during manufacturing for performance reasons. However, these chemicals can subsequently leach from the plastic material during use or be introduced into the environment when littered or via waste disposal. Other pollutants can be airborne in nature, posing an inhalation risk to workers and nearby residents. Examples include volatile organic compounds (VOCs) that can be emitted during plastic manufacturing or from fossil fuel extraction and refining operations, and dioxins and other toxic compounds created and released from plastic waste incineration. Plastic can also adsorb (hold molecules as a thin film on the inside or outside) other pollutants, including heavy metals, potentially contaminating post-consumer goods when recycled and allowing microplastics to act as a vector for additional exposure risks. Combined with the aforementioned ubiquity of microplastic pollution, chemical exposure risks are pervasive on a global scale.

Plastic is also a potent contributor to climate change. Greenhouse gas emissions occur at every stage of the plastic life cycle. The plastic industry is the fastest-growing source of industrial greenhouse gases in the world. Plastic generates 4% of total global greenhouse emissions, but could be responsible for as much as 19% of global greenhouse emissions by 2040, under a business-as-usual scenario (United Nations Development Programme, n.d.). Transportation, pipeline leakage, and even recycling of plastic waste creates greenhouse gases (Shen et al., 2020). Plastic pollution and a warming climate interact in alarming ways: "Rising temperatures and moisture alter plastic characteristics, contributing to waste, microplastic generation, and release of hazardous substances" (Wei et al., 2024).

For a more in-depth discussion of plastic-related exposure pathways and the environmental justice implications of plastic-related impacts, see the section *The Three-Part Plastic-Burdened Communities Framework: An Environmental Justice Tool*.

1.2. Plastic Policy Action in California: A Brief History

Historically, most policies aimed at curbing plastic impacts in California have been small-scale efforts targeted at specific products. Until recent years, many of these were municipal or county laws regulating expanded polystyrene (EPS) products (often called Styrofoam, though the two

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[1] Extruded plastic pellets — the intermediate form for synthetic polymer resins from which final plastic items are made — are a major form of microplastic pollution. These are not the result of weathering or degradation, but are intentionally manufactured and introduced to the environment via mismanagement.

are different). EPS items, such as coffee cups, disposable food trays, and coolers, were early targets of regulation due to their highly visible tendency to fragment into small particles, low recycling potential, and health concerns in food packaging contexts.

In the last decade, some Californian city and county governments have moved beyond EPS-focused regulations to policies targeting a broader set of single-use plastics (SUPs). Strategies have included efforts to reduce reliance on SUP food service ware (e.g., mandates on reusable dine-in ware), decrease the use of extraneous plastic items (e.g., “upon request” food service policies for optional items like utensils), and ensure local government purchasing power does not go toward disposable plastics.

Though these policies — including those enacted by some of the most populous cities and counties in the state — have likely reduced plastic waste to some degree, they are inherently limited by questions of scale. A patchwork of slightly different policy requirements across cities and counties can create confusion and inconsistency for consumers and complying companies, and more far-reaching policy goals necessitate a system-level approach. Bans at the city or regional level may be limited due to loopholes or low compliance by the food service industry; a widespread state policy with adequate funding for regulatory oversight is likely to be more effective.

At the state level, California has been an early adopter of plastic policy instruments and continues to chart new territory, informed by lessons learned. The state’s 2014 plastic bag ban is an instructive example. The law was enacted by the California legislature in 2014, and reaffirmed through a 2016 referendum vote. It banned SUP bags at grocery stores and retail checkout lines, but a loophole in the law allowed stores to charge consumers a small fee for “reusable” bags, including high-density polyethylene plastic bags, which companies argued could be reused. The result was the proliferation of thicker plastic bags that ended up in landfills and generated a total net increase of plastic bag waste volume, from 4.08 tons per 1,000 people in 2014 to 5.89 tons in 2021 (CalPIRG, 2024, p. 14). Some states and cities across the country learned from and avoided this loophole in the plastic bag bans they adopted. In September 2024, Governor Newsom signed a bill into law closing the legal loophole on plastic bag waste, banning all single-use plastic bags in checkout lines by 2026.

In 2022, California’s legislature accelerated its plastic reduction efforts by adopting SB 54 — also known as the Plastic Pollution Prevention and Packaging Producer Responsibility Act — which pursues transformative plastic policy goals backed by the weight of one of the largest economies in the world. SB 54 constitutes the most ambitious policy effort to date to address plastic waste in the United States. It includes provisions to bolster plastic recycling and requires the adoption of a Producer Responsibility Organization (PRO) to represent plastic manufacturers and achieve statutory requirements for plastic source reduction and recycling.

The most notable feature of the law from an environmental justice perspective is the establishment of a Plastic Pollution Mitigation Fund (PPMF). Beginning in 2027 and for 10 years thereafter, this fund will be supported through $500 million remitted annually by the PRO. Funds are required by law to be used by a select number of state agencies to mitigate and remediate the environmental and human health impacts of plastic, with minimum investment thresholds for efforts directly and primarily benefitting residents of disadvantaged and low-income communities.[2] However, SB 54 has been criticized by many environmental justice organizations for not providing sufficient clarity on how funding should be distributed to and spent by agencies, as well as for giving outsized control to the PRO.

In September 2024, California's attorney general took the remarkable step of suing ExxonMobil, alleging the company misled consumers about the utility of plastic recycling. The suit argues that the myth of effective recycling helped increase plastic usage, and points to ExxonMobil as a leader in producing key components of SUPs. These actions reflect California's ongoing commitment to improve on state-level plastic governance and lead on delivering solutions for the global plastic pollution crisis.

1.3. An Opportunity for Equity to Inform Plastic Policy

The primary motivation of this report is to conceptualize a framework for how the legislature and PPMF-administering agencies can identify "plastic-burdened communities." California has historically centered its legal definition of disadvantaged communities on the California Communities Environmental Health Screening Tool (CalEnviroScreen, or CES). CES, currently in version 4.0 after more than a decade of refinement, uses a broad array of environmental, public health, and sociodemographic indicators to identify which regions of California experience the greatest cumulative burdens. Census tracts identified as being in the top 25% of cumulative burdens make up the core of Californian communities legally defined as "disadvantaged."

CES, though rigorously data-driven, is, therefore, a broad measure that captures many different types of effects beyond those pertaining to plastic. Thus, though the minimum investment requirements of SB 54 — which rely heavily on CES — are laudable, there is room to improve the methodological precision with which PPMF moneys are dispensed. Building on CES with *The Three-Part Plastic-Burdened Communities Framework* will help agencies target investments more intentionally toward areas where impacts can be directly linked to plastic-related exposures. Doing so will improve the efficacy of PPMF-supported projects, address concerns from advocates that the law does not provide enough guidance on how agencies should make funds available to environmental justice groups and communities and produce greater positive externalities and co-benefits by tackling problems at their source.

[2] Under the law, 40% of fund moneys "shall be expended by the Dept of Fish and Wildlife, the Wildlife Conservation Board, the State Coastal Conservancy, the California Coastal Commission, the Ocean Protection Council, the Department of Parks and Recreation, the Natural Resources Agency, and the California Environmental Protection Agency to monitor and reduce the environmental impacts of plastics on terrestrial, aquatic, and marine life and human health, including to restore, recover, and protect the natural environment," at least 50% of which shall benefit residents in disadvantaged, low-income, or rural communities. The remaining 60% "shall be expended by the Strategic Growth Council, the California Environmental Protection Agency, the Natural Resources Agency, and the Department of Justice to monitor and reduce the historical and current environmental justice and public health impacts of plastics," 75% of which must benefit residents of disadvantaged or low-income communities.

2. UNDERSTANDING THE PLASTIC LIFE CYCLE IN CALIFORNIA

Plastic-related exposures can occur in many different forms across the entire life cycle of a plastic product. A product's life cycle encompasses not only the narrow phase when it is bought and used by consumers, but also how it is produced and disposed of. The production and disposal stages are especially important to consider in the case of plastic, given the pollution challenges and other risks associated with their creation as a fossil fuel-based product and the aforementioned issues related to plastic waste proliferation. Understanding the nature of plastic-related exposures, therefore, requires a general understanding of plastic's life cycle stages and the magnitude of its component industries' footprint in California.

2.1. The Stages of the Plastic Life Cycle

The plastic life cycle is typically broken down into three stages: upstream, midstream, and downstream.[3] The term upstream refers to activities during the plastic production stage. This involves extraction of the feedstocks — crude oil and natural gas — from which plastic is derived. In the upstream stage, prospective oil and gas sources are identified ("exploration") and extraction operations (e.g., drilling, fracking) remove crude oil and gas from the earth. This stage includes transportation and storage of oil and gas feedstocks in the intermediate phase before they are refined and processed, as well as pipeline operations and the transport of feedstocks via trucks, rail, or tanker ships, along with interim storage.

Midstream activities refer to the stage of design, manufacture, packaging, distribution, and use of plastic products. These activities involve manufacturing facilities, transportation routes, and consumer use of plastic products in many different commercial, residential, and industrial contexts. The refining process for crude oil and natural gas produces a broad array of petrochemicals, including materials which are used to create synthetic polymers. Polymer resins are extruded into small plastic pellets — an intermediate form that can then be transported to manufacturing facilities where they are used to create the many diverse types of plastic products and packaging. Given the vast variety of ways in which plastic is used in the consumer goods market, consumers' interactions with plastic also vary, as do the time frames in which plastic components are used. Plastic could be part of a durable component in a long-lasting product (e.g., a car), the primary material in a cheap, short-lived product (e.g., a toy), or packaging or other single-use material that is immediately discarded.

The *downstream* portion of the plastic supply chain refers to the end-of-life management of plastics that involve segregation, collection, sorting, recycling, and disposal. Once plastic reaches the disposal stage, several possible outcomes can occur. Among OECD countries,[4] the

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[3] This language often refers to points of the plastic lifecycle in which specific policies are being targeted, according to the United Nations and stakeholders in the Intergovernmental Negotiating Committee for the creation of a global plastic treaty (2022-2024). See https://www.undp.org/plastics-101. See also Environmental Investigation Agency (2022).

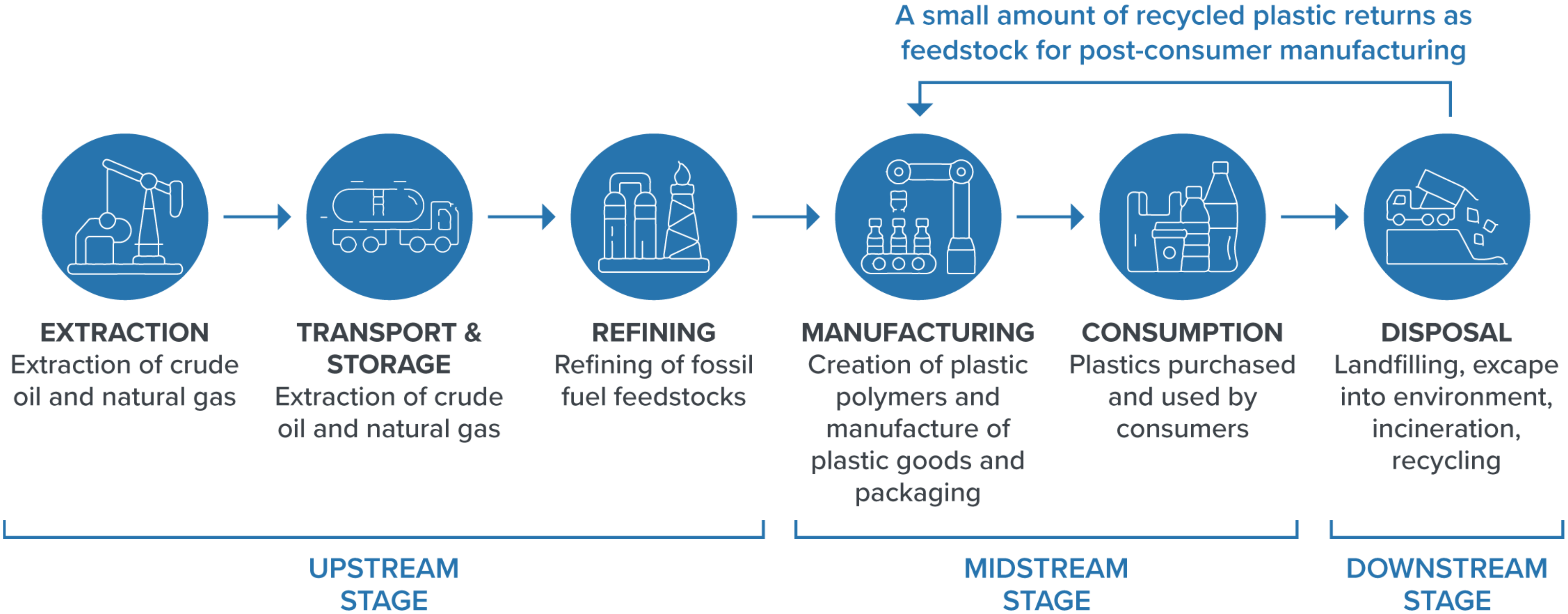
[4] The Organisation for Economic Co-operation and Development, an intergovernmental organization of 38 countries that collectively represent a majority of global GDP. The United States is a member.

most common outcome for plastic waste is landfilling (50%), followed by escape from the waste system, or leakage (22%),[5] incineration (19%), and recycled (9%) (OECD, 2022). This phase of the life cycle also includes accompanying processes, such as the transportation and processing of plastic waste.

[5] This category includes disposal in uncontrolled dumpsites, open pit burning, and escape into the environment.

FIGURE 1

Plastic life cycle; communities can face exposure risks at each stage



2.2. California's Plastic Supply Chain Footprint

Plastic is a significant component of California's economy, from upstream fossil fuel extraction to midstream plastic manufacturing. This section briefly reviews the size of California's fossil fuel industry, examining its plastic manufacturing footprint and data on shipping trends pertaining to the passage of plastic material through California's major ports.

Despite its status as a leader in decarbonization, California continues to host major fossil fuel extraction operations. Although its natural gas production is quite small (<1% of national output), the state produced 112 million barrels of crude oil in 2023 — the seventh-highest state total, making up nearly 2.5% of national production (U.S. EIA, 2024). California is also home to 14 active petroleum refineries, which account for approximately one-tenth of national refining capacity — the third most of any state — and which depend on foreign crude oil imports for a majority of their feedstock (U.S. EIA, 2024). Absent other changes, the portion of impacts on Californian residents from these facilities attributable to plastic is likely to increase as plastic continues to grow as a portion of the global fossil fuel industry.

With respect to plastic manufacturing, it is worth contextualizing the United States' global profile. As of 2022, the U.S. produced 17% of global plastic — 125.5 billion pounds (Statista, 2024). Several of the world's largest plastic manufacturers are based in the U.S., including Dow Chemical and ExxonMobil's chemical division, contributing to plastic manufacturing's position as the third-largest domestic manufacturing industry with more than 1 million employees in 2019 (Statista, 2024). California is one of the largest plastic manufacturing states by employment, alongside Ohio, Texas, and Michigan (Statista, 2024).

Using macroeconomic data from the U.S. Economic Census, we can quantify the size of California's plastic manufacturing[6] profile in relation to the country as a whole (Table 1), as well as to the state's broader manufacturing economy (Table 2). California contains 10.5% (1,748) of the nation's plastic manufacturing establishments, 7.2% (78,658) of its related employees, and 7% (nearly $23 billion) of the economic value pertaining to product sales. Within the state, plastic manufacturing has a slightly lower profile than in the national context, making up 4.6% of its manufacturing establishments, 6.7% of employees, and only 4% of sales value. However, post-2020 investment in the plastic sector by oil and gas corporations, continued growth in demand for packaging, and the global trend of increasing plastics manufacturing make it likely these numbers will grow in absolute terms.

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[6] The U.S. Economic Census is the five-year official measure of American business and the economy. Plastic products manufacturing encompasses processing new or recycled plastic resins into intermediate or final products, including single-use plastic (e.g., packing materials, bags, pouches, films, bottles) and industrial or multiuse consumer products. U.S. Economic Census Data Code 3261 Plastics Product Manufacturing includes the following subcategories: 32611 Plastics Packaging Materials and Unlaminated Film and Sheet Manufacturing; 326111 Plastics Bag and Pouch Manufacturing; 326112 Plastics Packaging Film and Sheet (including Laminated Manufacturing); 326113 Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing; 326121 Unlaminated Plastics Profile Shape Manufacturing; 326122 Plastics Pipe and Pipe Fitting Manufacturing; 326130 Laminated Plastics Plate, Sheet (except Packaging) and Shape Manufacturing; 326140 Polystyrene Foam Product Manufacturing; 326150 Urethane and Other Foam Product (except Polystyrene Manufacturing); 326160 Plastics Bottle Manufacturing; 32619 Other Plastics Products Manufacturing; 326191 Plastics Plumbing Fixture Manufacturing; 326199 All Other Plastics Product Manufacturing.

TABLE 1

California vs. national plastic manufacturing activity

	Plastic Manufacturing Establishments (#)	Plastic Manufacturing Employees (#)	Plastic Manufacturing Sales, Value of Shipments, or Revenue ($1,000)
California	1,748	78,658	$22,854,585
U.S. Total	16,614	1,083,514	$331,833,523
CA % of National Activity	10.5%	7.2%	7.0%

Source: U.S. Economic Census Data (2021, 2017), downloaded July 2024

TABLE 2

Plastic manufacturing vs. total manufacturing activity in California

	Establishments (#)	Employees (#)	Sales, Value of Shipments, or Revenue ($1,000)
Plastic	1,748	78,658	$22,854,585
All Manufacturing	37,887	1,083,514	$331,833,523
Plastic % of State Activity	4.6%	6.7%	4.0%

Source: U.S. Economic Census Data (2021, 2017), downloaded July 2024

Within California's broader plastic manufacturing sector, single-use plastic (SUP) makes up a large component (Table 3). By establishments and employees, SUP constitutes 18.6% and 18.3% of the state's plastic manufacturing, but a disproportionate 27.1% of sales and revenue — over $6 billion annually. Of the various categories of items that fall under the SUP umbrella, only one — plastic bottles — is generally accepted as recyclable, although the recycling rates for these are low. Thus, the vast majority of SUP manufacturing in California — amounting to over 23% of the state's total plastic manufacturing value — produces items that have almost no chance of being recycled and will quickly become part of the plastic waste stream.

TABLE 3

Single-use plastic manufacturing activity in California

Product Type	Establishments (#)	Employees (#)	Sales, Value of Shipments, or Revenue ($1,000)
Plastic Packing Materials and Unlaminated Film and Sheets	132	5,454	$2,382,183
Plastic Bag and Pouches	48	1,982	$1,451,093
Plastic Bottles	54	3,533	$907,312
Plastic Packaging Film and Laminated Sheets	41	1,402	$734,227
Polystyrene Foam Products	51	2,060	$716,191
Totals and % of State Plastic Manufacturing	326 (18.6%)	14,431 (18.3%)	$6,191,006 (27.1%)

Source: U.S. Economic Census Data (2021, 2017), downloaded July 2024

Finally, time-series data on the international import and export of plastic waste to and from California and nationwide offers an interesting look into industry trends, especially where recycling is concerned (Table 4). Until the last decade, the United States exported large amounts of plastic waste under the auspices of recycling.[7] Prior to the 2017 enactment of National Sword — a stringent set of restrictions on the import of plastic waste — China was the primary importer of plastic waste exported from the U.S. California played an outsized role in this activity, being the site of more than a quarter of national exports by value. However, plastic waste exports have declined precipitously since 2015, both in the state and nationally, due in large part to China's new restrictions. U.S. exports are now approximately a quarter of their peak in the early 2010s, while California's share of the national total has dropped to approximately 11% as of 2023. However, imports have not experienced similar disruption, with state totals remaining fairly constant since 2010, while national imports have slightly increased.

[7] Exported plastic waste, mostly shipped overseas to less developed countries, historically contained large amounts of contaminated or valueless material that was never recycled, despite domestic recycling programs gathering much of it.

TABLE 4

Plastic waste import/export activity in California and the United States, 2010-2023

Year	California		United States	
	Exports ($)	Imports ($)	Exports ($)	Imports ($)
2010	262,736,907	25,553,569	948,446,825	202,676,598
2011	289,784,380	25,782,013	1,053,745,276	199,006,980
2012	245,823,283	33,413,103	947,500,589	206,508,353
2013	242,592,216	40,625,391	869,411,203	241,909,134
2014	258,630,461	40,153,324	953,036,078	263,535,720
2015	226,706,673	27,927,501	816,778,101	212,015,251
2016	193,317,808	23,249,514	733,864,419	212,528,372
2017	161,542,079	24,266,084	636,865,964	221,287,245
2018	103,295,536	24,398,378	446,450,542	245,066,413
2019	56,994,745	22,330,788	278,241,011	223,628,999
2020	47,476,168	30,464,134	225,550,525	209,336,550
2021	61,581,645	27,283,663	301,084,854	336,881,556
2022	49,690,008	29,899,138	288,520,439	340,158,488
2023	28,566,279	24,316,184	249,274,280	274,295,574

Source: U.S. Economic Census Data: USA Trade Online, downloaded July 2024. All figures reported in US$. All figures report Harmonized Code 3915: waste, parings, and scrap, of plastics.

These trends suggest that in recent years, more of California's plastic waste is disposed of within the state through means such as landfilling and incineration, while material retained for recycling is more likely to be shipped domestically out of state.[8] The lack of shift in California's plastic waste imports could be explained by relatively low levels of in-state recycled goods manufacturing, but this a hypothetical that requires more research to substantiate. Interestingly, in 2023, the U.S. imported more plastic than it exported for the first time, perhaps indicating feedstock supply challenges for domestic recycled goods manufacturing.

[8] See the Luskin Center for Innovation's 2020 report Plastic Waste in L.A. County, which includes information from waste industry professionals to this effect.

3. THE THREE-PART PLASTIC-BURDENED COMMUNITIES FRAMEWORK: AN ENVIRONMENTAL JUSTICE TOOL

Environmental injustice is the disproportionate exposure of communities of color and low-income communities to environmental toxins. A 1987 landmark study by the United Church of Christ's Commission for Racial Justice found that 3 out of 5 Black and Hispanic communities were in proximity to uncontrolled toxic waste (Commission for Racial Justice, 1987). This study was part of a larger movement for environmental justice that has become an explicit part of federal and state level policy for the U.S. Environmental Protection Agency and state counterparts. Insights from the environmental justice movement have influenced important California environmental policies, including the development of CalEnviroScreen and the creation of the California Climate Investments initiative. However, while much research has documented the links between low land value, environmental toxins, and disadvantaged communities, the environmental justice lens has not been adequately applied to the issue of plastic pollution.

The *plastic burden* is the cumulative impact of the plastic supply chain on a community's health, environment, and economy. While the impacts of plastic production, use, and disposal are widespread and highly dispersed, some communities are more exposed to plastic-related contamination, and therefore, experience a greater plastic burden than others. In this section, we discuss how the plastic burden is an environmental justice issue as plastic is disproportionately impacting lower-income communities and communities of color. California's policy efforts to mitigate and remediate plastic impacts on its communities[9] must be understood in relation to their uneven distribution across California's populations in order for mitigation investments from the PPMF to achieve equitable outcomes.

To support this, we propose *The Three-Part Plastic-Burdened Communities Framework* that focuses on the three main vectors of plastic-related exposure: site-based, dietary, and consumer goods (Figure 2). For each of these parts of the framework, we review existing research that connects plastic-related exposures to specific harms and their disproportionate occurrence in low-income communities and communities of color. This framework is based, in part, on research showing that the three main routes of human exposure to microplastics are ingestion, inhalation, and dermal contact, with ingestion considered to be the vector of greatest concern, followed by inhalation, and then dermal (Prata et al., 2020a, pp. 2–3).

Readers familiar with contemporary research into plastic pollution will note that ambient airborne exposure risk from microplastic particles is not included in the discussion below. There are two reasons for this: Firstly, it is likely that generalized airborne microplastic pollution is linked, in part, to the same types of sites identified as notable sources of pollution. Therefore,

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[9] California has historically defined "communities" for purposes of environmental justice investment as individual census tracts. Therefore, when discussing specific community characteristics in this report, we are referring to census tract-level data.

policy action to address localized site-based exposures will produce co-benefits by reducing microplastic prevalence. Secondly, this is a relatively novel and dynamic research area, and there is not yet sufficiently robust data available to incorporate it into the framework.

FIGURE 2

Where and how plastic exposures occur

	SITE-BASED EXPOSURES	DIETARY EXPOSURES	CONSUMER GOODS EXPOSURES
WHERE	**Site-based exposures** are related to sites and facilities in the plastic supply chain, such as fossil fuel refineries, plastic manufacturers, and landfills. These fall heaviest on nearby residents and workers.	**Dietary exposures** occur from consuming food and drinking water contaminated with microplastics, related toxins that can be carried by microplastic particles, or chemicals in plastic that can leach from the material. Contamination is especially prevalent in plastic bottled water and ultraprocessed, packaged foods.	**Consumer goods exposures** are experienced through contact with plastic-containing or contaminated goods and packaging, and the use of services that utilize such items. Products intended for skin application, such as beauty care products, are of particular concern.
HOW	Inhalation, ingestion, or dermal contact of/with pollutants from living and working near plastic supply chain facilities	Inadvertent ingestion of microplastics and plastic-related pollutants through food and drink, and dermal contact with food packaging	Exposure to microplastics and plastic-related contaminants through everyday use of retail products, services and packaging, primarily via dermal contact

3.1. The Three Exposure Risk Types and Associated Environmental Injustices

3.1.1. Site-Based Exposure

Site-based exposure occurs from living or working in close proximity to facilities associated with the plastic supply chain. These facilities' operations create localized impacts — including generating many different types of pollutants that can be inhaled, ingested, or absorbed through the skin — that affect workers and residents of fenceline communities located close to the sites in question. In many cases, contaminants can spread beyond the immediate area around the facility over time. For example, waste disposal site pollutants that escape into a local waterway can then migrate to the ocean. Even in such cases, exposure risk and magnitude remain higher closer to the facilities in question, and from a policymaking perspective, addressing extant point sources serves to reduce both localized impacts and migratory contaminants.

The specific exposure mechanisms and risks associated with plastic supply chain-related sites vary greatly depending on their operational nature. Therefore, we organized our discussion of site-based exposures around the stages of the plastic supply chain from the prior chapter.

Upstream Sites. Upstream sites in the plastic supply chain are those related to the production of plastic manufacturing feedstock, its transportation and storage, and eventual refining and the creation of virgin plastic. The primary activity in these stages is the extraction and refining of crude oil into the precursor materials for plastic item manufacturing — primarily ethylene and propylene (Wong, 2010, pp. 14–15). Plastic accounted for 6% of global oil production as of 2016, and is expected to use 20% by 2050 (Ellen MacArthur Foundation, 2016, p. 7).

Sites associated with the initial stages of the plastic supply chain — most notably oil wells, fracking sites, and refineries — expose workers and nearby communities to a multitude of pollutants that pose risks to human health and the environment. Oil drilling sites directly emit various harmful air pollutants, including volatile organic compounds (VOCs) such as benzene, particulate pollution, nitric oxides, and sulfuric acid (Johnston et al., 2019, p. 193). Extraction operations also introduce pollutants into soil and water through transport activities, leaks, spills, or wastewater discharge (Johnston et al., 2019, p. 195). Soil and water contaminants may include hydrocarbon compounds (especially polycyclic aromatic hydrocarbons, or PAHs), heavy metals, naturally occurring radioactive materials, chloride, and arsenic (Johnston et al., 2019, p. 195–196). Many of these compounds, including VOCs, particulate matter, hydrocarbons, and chlorine, have also been identified in petroleum refinery emissions (PREs) (Otitolaiye & Al-Harethiya, 2022, pp. 71–72). Extraction and refining exposures have, in turn, been linked to numerous health harms for workers and nearby residents, including respiratory and cardiovascular diseases, mutagenic and carcinogenic impacts, organ damage, neurological impairments, and reproductive health harms (Johnston et al., 2019, pp. 191–196; Otitolaiye & Al-Harethiya, 2022, pp. 72–76). Additionally, local environmental impacts from extraction and refining operations can threaten flora and fauna, degrading ecosystems and creating secondary exposures via activities like agriculture and fishing (Johnston et al., 2019, p. 196). These impacts may create additional equity concerns due to the disproportionate representation of certain groups in affected industries (e.g., Latino farmworkers).

When discussing what portion of the impacts from California's fossil fuel industry can be attributed to plastic, it is important to remember that oil and natural gas are fungible commodities — interchangeable goods bought and sold on a global market. Thus, it does not matter exactly how much of the fossil fuels produced and refined *in California* go toward the production of plastic because feedstocks can be readily imported or exported across state lines, and any shift toward or away from plastic production from California-produced oil will be offset elsewhere. The growing global percentage of oil and natural gas used for plastic production is the determinative factor.

Midstream Sites. Once feedstocks are refined, facilities in the midstream of the plastic supply chain produce plastic resin pellets, and subsequently other plastic items and packaging, from refined precursors. Exposures from these sites arise from emissions of toxic substances during the manufacturing process. Plastic manufacturing sites have been identified as sources of VOC and PAH emissions (Adekanmbi et al., 2024, p. 233; Lu et al., 2020, p. 1; Ren et al., 2024, pp. 3–5). Exposure to these substances is linked to health risks including increased cancer risk, as well as contributing to creation of ground-level ozone (Lu et al., 2020, p. 1; Ren et al., 2024, p. 5). Plastic manufacturing sites are also a major point source of microplastic pollution in the form of plastic resin pellets (Karlsson et al., 2018, pp. 55–57). Microplastics, including pellets, are increasingly a pollutant of concern due to their global ubiquity and demonstrated ability to adsorb other toxins, acting as an additional exposure vector (Andrady, 2011, p. 1601; Ashton et al., 2010, p. 2054; Aslam et al., 2019, pp. 8–9; Mato et al., 2001, p. 1). Microplastic-associated harms are discussed further in the section *Mapping Plastic Waste-Related Site-Based Exposures in California: Data and Methods.*

Downstream Sites. At the end of the plastic supply chain, downstream sites are those associated with disposal, determining the end-of-life outcome for plastic items. These are the facilities involved in collecting, transporting, processing, and ultimately disposing of plastic waste. Plastic waste that does not escape into the environment (which accounts for 32% of global plastic packaging) is transported to transfer and processing stations before being landfilled (40%), incinerated (14%), or recycled (14%) (Ellen MacArthur Foundation, 2016, p. 13).[10] Problematically, the industrial processes and associated impacts of plastic recycling are highly similar to those of virgin plastic manufacturing.

The most serious incinerator impacts relate to airborne emissions of toxic substances, many of which are used directly in the manufacture of plastic materials or have been found in plastic as contaminants. These include flame retardants and metal contaminants (N. A. O. Morin et al., 2017, p. 128; National Research Council (U.S.) Committee on Health Effects of Waste Incineration, 2000, pp. 85, 87, 89, 91). Other highly toxic pollutants are created specifically through burning plastic, including dioxins and polychlorinated biphenyls (PCBs) (Alabi et al., 2019, p. 4). Taken together, these exposures are linked to numerous health harms, including carcinogenic and mutagenic effects, neurological damage, cardiovascular and respiratory disease, and disruption of bodily systems (Verma et al., 2016, p. 704).

In contrast, the most problematic exposures from landfills pertain to pollutants in leachate — liquid that filters through interred wastes and becomes contaminated with chemicals and particles before escaping. Living near landfills is associated with exposure to carcinogenic chemicals and heavy metals and increased incidence of health conditions such as skin and respiratory conditions (Khoiron et al., 2020, pp. 64–65). Landfill leachate often contains microplastics, along with the various contaminants they can potentially adsorb (P. He et al., 2019, pp. 40–41; Kabir et al., 2023, p. 2).

Generally, disposal sites are also associated with relatively minor, but common, day-to-day disruptions and impacts that degrade quality of life for nearby residents. These “disamenities”

[10] The figure of 14% of plastic packaging being recycled somewhat oversells the actual outcomes. Of that 14%, 4% is lost during processing, and 8% is recycled into lower-value products, or “downcycled.” Only 2% is recycled in a closed-loop fashion.

can include increased traffic and accompanying air pollution, debris or waste products escaping the facility, noise, and odors.

Plastic debris, litter, and bottles that escape the waste stream can accumulate in the environment in and around communities. These can be considered a source of site-based exposures, as living or working in heavily plastic-littered areas or near informal plastic dump sites can harm mental health and decrease quality of life.

For a more detailed discussion of site-specific disposal stage exposures, see the section *Mapping Plastic Waste-Related Site-Based Exposures in California: Data and Methods*.

Environmental Injustices from Site-Based Exposure. Past research has shown clear patterns of inequity in the location of harmful, polluting industrial infrastructure. This is especially true in the case of fossil fuels, where "pollution and public health hazards disproportionately impact Black, Brown, Indigenous, and poor communities" (Donaghy et al., 2023, p. 1). Historic patterns of zoning ordinances, redlining, and segregation have resulted in higher rates of hazardous waste and other toxic facilities in poor and minority communities (Taylor, 2014). Studies have found that toxic air exposures are shaped by racial disparities in California (Pastor et al., 2005, p. 143), even controlling for other factors such as income. Illegal waste dumping from external entities looking to offload garbage cheaply is more likely to occur in communities of color and low-income communities (Hohl et al., 2023, p. 2).[11] While prior environmental justice research documented these disparities for a range of environmental issues, this study sought to identify the connection between plastic-related waste sites and community characteristics. In the section Mapping Plastic Waste-Related Site-Based Exposures in California: Results and Analysis, we show how plastic-related waste site exposures in California have a higher rate of siting in communities with higher percentages of non-White residents and lower-income households.

3.1.2. Dietary Exposure

Dietary exposure occurs through inadvertently eating and drinking foods and liquids contaminated with micro- and nanoplastics and/or plastic-related chemicals and contaminants. The primary concern of dietary exposure is the health impact of ingesting these contaminants, but risks from dermal contact with packaging are also a concern. In some cases, dietary exposure risk may be related to site-based exposures, such as in a case where pollutants from a plastic-related industrial facility contaminate a rural community's drinking water supply.

Ingestion is thought to be the most significant route of human exposure to plastic (Prata et al., 2020b, p. 2). Widespread contamination of the food supply chain means people are frequently exposed to microplastics through consumption of food and liquids. Data suggests that microplastics will continue to be found in most, if not all, items intended for human consumption

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[11] See for example, "Illegal dumping has plagued Watts for decades. Residents are fed up," Los Angeles Times, May 7, 2023.

for the foreseeable future.[12] Researchers estimate that meeting about 15% of a person's caloric intake is associated with the intake of up to 52,000 microplastic particles annually (Cox et al., 2019, p. 7073). Seafood — one of the most well-studied food types with respect to microplastic contamination — is a major vector for exposure (Cox et al., 2019, p. 7071). Sugars, terrestrial meat, fruits, and vegetables are likely to contribute to exposure, as do salts, tap water, and alcohol to a lesser degree (Cox et al., 2019, p. 7071; Dietz & Herth, 2011).

Food Preparation and Packaging. Beyond contamination of the food supply, food preparation and packaging play a role in dietary exposure as well. Processes such as meal preparation (e.g., with the use of a plastic kitchen items), reheating (e.g., lunch reheated in the microwave in plastic containers), or cooking (e.g., brewing tea bags) can greatly increase microplastics exposure. On the packaging front, research suggests that food wrapped in plastic packaging materials (PPMs), processed foods, and fast-food take-out meals may increase microplastic exposure (Al Mamun et al., 2023, p. 9). PPMs contain endocrine-disrupting chemicals (EDCs) that can migrate to food under the right conditions (e.g., microwave heating, storage, degradation over time) (Ong et al., 2022, p. 960; Sewwandi et al., 2023, pp. 5, 10). Take-out food and street food wrapped in plastic were shown to have higher rates of microplastics in studies (Sewwandi et al., 2023, p. 2), and fast food has also been shown to have plasticizers as it interacts with microplastics at different stages of food preparation, storage, and heating (Edwards et al., 2022). It is estimated that individuals have a higher risk of ingesting 12-203 microplastic particles per week if they consume food from take-out containers 4-7 times a week (Sewwandi et al., 2023, p. 10).

Plasticizer[13] Contamination. Plasticizer risk is generally higher for processed foods, with greater plasticizer content per calorie than more minimally processed food. Processed foods also have more vectors for microplastics exposure: more sugars, salts, and additives (all of which are vectors for microplastics), a greater number of potential interactions with plastic in the food preparation and storage stage, and plastic packaging requirements. Compared to nonmanufactured food, processed foods are more likely to be contaminated during the manufacturing and packaging processes (Lin et al., 2022, p. 2). These risks are elevated for children (Lin et al., 2022, p. 8).

Plastic Bottled Water. Plastic bottled water is a particularly notable vector for microplastic exposure. Bottled water consumption can lead to microplastic intake 22 times higher than drinking the same amount of tap water (Cox et al., 2019, p. 772).[14] Plastic bottled water likely has high levels of microplastics because multiple contamination routes exist: contaminated water

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12 Studies have begun to document the microplastic content of frequently consumed foods and liquids. Bisphenol A and bis (2-Ethylhexyl) phthalate were the most frequently reported both in food and beverage (Sewwandi et al., 2023, p. 1).

13 Plasticizers are chemicals added to polymers during manufacturing to change their performance properties, usually by making the material softer and more flexible.

supply, plastic packages, and microplastics introduced during the filling and capping of bottles (Lin et al., 2022, p. 6).

Environmental Injustices from Dietary Exposure. Evidence suggests that families who derive higher percentages of their daily diet from processed foods, plastic packaged foods typical of take-out food and street food, or that rely on bottled water as primary sources of drinking water ingest higher levels of microplastics. Ultraprocessed food makes up a large percentage of the U.S. daily diet across the general population and has increased from 53% to 57% of total intake from 2001 to 2018. Higher ultraprocessed food consumption is significantly associated with mid-low or mid-level educational attainment and lower income/poverty ratios (Dicken et al., 2023, p. 28). U.S.-born individuals consume over 12% more ultraprocessed food than foreign-born persons on average, but these differences are most significant among persons with lower income and/or educational attainment. Notably, Hispanic, Asian, and Asian-American populations were less likely to be in the highest quantile of ultraprocessed food intake (Dicken et al., 2023, p. 28).

It is also likely that households living within food deserts — areas where people have limited access to healthy and fresh food — are more exposed to microplastics. Food deserts are historically prevalent in neighborhoods of color where gas stations, fast food, and dollar stores replace grocery stores; here, food has a higher ratio of plastic packaging to products (Walker-Franklin & Jambeck, 2023, p. 80). Food deserts are also correlated with low-income communities in rural areas throughout the U.S. Nearly one million Californians, 45% of whom are low income, live without access to nearby supermarkets or large grocery stores.[15]

Additionally, children who eat free or reduced-cost meals at school in California may be getting a large amount of their daily nutritional content from foods with higher concentrations of microplastics. These meals are often highly processed and packaged in plastic and made in schools without kitchens, reliant instead on heating the food in ovens and microwaves inside its plastic packaging. Most studies of microplastic exposure via food underscore the higher risk to children versus adults, due to lower weight and a vulnerability to endocrine disruptors during developmental periods in youth. These risks are broad, but heightened among groups facing greater levels of socioeconomic disadvantage. More than 56% of all U.S. children and adolescents receive free or reduced lunch, with higher rates for Black (66.2%) and Latino (64.4%) students, heightening their exposure risk compared to their White or Asian peers (Morbility and Mortality Weekly Report, 2023).[16]

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[14] Drinking bottled water led to microplastic intake of 205, 349, 174, and 255 particles for male children, male adults, female children, and female adults, as compared to drinking only tap water, which led to intakes of 9, 16, 8, and 11 for those same categories of people, respectively. Averaged across demographic groups, annual microplastic particle intake from drinking water was 90,000 if consuming only bottled water and 4,000 if only tap water is consumed, a 22-fold difference (Cox et al., 2019, p. 7072).

[15] https://agri.assembly.ca.gov/system/files/2024-04/ab-2090-ag-comm-analysis.pdf. See USDA's Economic Research Service identifying 6,500 food desert tracts in the U.S.

[16] 56.6% of all U.S. children and adolescents. National Center for Health Statistics, National Health Interview Survey, 2021, posted on CDC.gov.

Drinking water is also a factor in disproportionate dietary exposure. Bottled water intake is highest among low-income, Black, and Latino households across the U.S. (Jaffee, 2024), increasing the plastic exposure of these communities. Disinvestment in public water infrastructure, the uneven distribution of drinking water quality problems, and significant distrust of public tap water among low-income residents and communities of color has driven increased reliance on costly bottled water among these groups (Jaffee, 2024, p. 7). Perversely, some state programs that offer testing for well water used for drinking will provide bottled water to residents with contaminated wells, effectively trading one set of contaminants for another.

Taken together, research in this space suggests that low-income families with adults who have lower educational attainment, and Black and Latino households are being disproportionately exposed to microplastic and other plastic-related contaminants via ingesting processed food, take-out food, and/or bottled water. Exposures to microplastic is likely to co-occur for families who have higher poverty rates and lower access to medical care and preventative and primary care. For a brief discussion of how these patterns can inform California's policy strategy for plastic impact remediation, see *Key Findings, Recommendations, and Future Research Needs*.

3.1.3. Consumer Goods Exposure

Consumer goods exposure occurs through exposure to microplastic and plastic-related contaminants through the everyday use of retail products, services, and packaging. Microplastic- and nanoplastic-related interactions with the skin and consequent health impacts are the primary vector of concern in this context (Prata et al., 2020b, pp. 2–3), alongside chemical contaminants.[17] However, some inadvertent ingestion or inhalation can occur, such as in the case of cosmetics and beauty products.

Many consumer products are frequently made from plastic or are exposed to plastic during their production cycle. The greatest plastic-related risk lies with products where skin contact is typically frequent, prolonged, and sometimes invasive; examples include skin care and personal beauty products and synthetic clothing. While more research is needed to disentangle these complex impacts, this report identifies key factors raised in prior research related to these "dermally most proximate products."

Microplastics and Nanoplastics. The degree of harm resulting from potential microplastic presence in a personal care product varies depending on the specific type of microplastic. Microplastics are typically defined as solid, insoluble particles of plastic smaller than 5mm.[18] However, even smaller particles called nanoplastics or particles that are liquid soluble are found in many types of beauty care products. One study showed that nanoplastics of up to 200 nm could enter the human body through the skin's furrows, lipid channels, and vellus hair follicles,

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[17] Research suggests that cosmetics, clothing, medicine, and dust are primary potential pathways of exposure to particle toxicity for microplastics in the human body via the dermal vector (Prata et al., 2020b, p. 6).

[18] Nanoplastic often defined as 100 nanometers or less in size, although definitions vary.

although research on human samples is rare and more information is needed (Aristizabal et al., 2024, pp. 769–770). Based on existing evidence, it has been speculated that particles under 100 nm in size could transverse the dermal barrier.[19] Moreover, nascent research suggests the mouth and scalp hair act as important passive receptors of microplastics (Aristizabal et al., 2024, p. 770).

Features of plastics— such as size, shape, and chemical makeup — ultimately determine the degree of particle toxicity, with the implication that if toxicity increases with decreasing particle size, then nanoplastics are more toxic than larger particles (Aristizabal et al., 2024; The Plastic Soup Foundation, 2022, p. 16). Beyond the resin itself, dermal exposure is also a risk factor for plastic additives such as endocrine disruptor bisphenol A (BPA) and phthalates (Prata et al., 2020b, p. 3).

Cosmetics and Skin Care. Synthetic polymers — which include water-soluble, liquid, or semi-liquid materials — are the main constituent of plastic and are widely used in the cosmetics industry as ingredients and as packaging materials (Aristizabal et al., 2024, p. 768).[20] Despite their ubiquity, prolific use of these materials has largely gone unregulated. Policy efforts such as the 2015 U.S. ban on microbead usage notwithstanding, nanoplastic and water-soluble polymers are still prevalent. It is estimated that 23,700 tons of soluble, semisolid, and liquid polymers enter the wastewater system in Europe annually due to cosmetic products, along with 922 tons of solid synthetic polymers (The Plastic Soup Foundation, 2022, p. 15). One study finds that the cosmetics industry uses 8,700 tons of microplastics each year; were microplastics defined less narrowly, this number would likely be much higher (The Plastic Soup Foundation, 2022, p. 13).[21] Although there are efforts to broadly assess microplastic presence in the cosmetics industry — the Beat the Microbead database, for example, documents the wide array of microplastic found in different cosmetics — more research is necessary to explore the extent of nanoplastic contamination.

Clothing. Synthetic textiles are another major vector for dermal plastic exposure. Microplastic fibers (microfibers) are the most abundant form of microplastic found in the environment, released in massive numbers from textiles during home laundering via sewage effluent (Acharya et al., 2021).[22] Consequently, millions of microfibers are released each day to the aquatic environment, causing environmental pollution that creates secondary risks of microplastic ingestion (e.g., via contaminated food and drinking water) and inhalation. These risks are primarily a consequence of land or sea dumping or agricultural use of microplastic contaminated sewage sludge (Acharya et al., 2021, p. 2147).

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[19] Studies have demonstrated that chemical enhancers like oleic acid and ethanol in products can enhance the transdermal transport of nanoparticles (Aristizabal et al., 2024, p. 769).

[20] See also https://www.unep.org/news-and-stories/story/whats-your-bathroom-hidden-plastics-your-beauty-products.

[21] Water-soluble, semi-soluble, and liquid polymers are excluded from this definition.

[22] See also https://www.theguardian.com/fashion/2024/feb/12/the-hidden-plastics-in-our-clothes-and-how-to-avoid-them.

Environmental Injustice and Consumer Goods Exposure. While the cosmetics and beauty care industries use a number of concerning toxins, nanoplastics, and plasticizers, the negative health impacts are not distributed evenly across the population. Generally, women 18-34 years old are the most likely to be "heavy buyers" of such products, purchasing more than 10 types per year (Zota & Shamasunder, 2017). Researchers have documented the disproportionate exposure that Black women and women of color have to personal care products with toxic ingredients. Studies argue that Black women experience disproportionate pressure to adhere to European beauty standards promoting, for example, lighter skin or straighter hair, which exposes women of color to ingredients with higher levels of toxicity and at higher frequency of use (Collins et al., 2023, p. 293; Zota & Shamasunder, 2017, p. 419). Black women use hair relaxers and straighteners at higher rates, and Latina women are the fastest-growing ethnic beauty market segment (especially for makeup); globally, dark-skinned women use skin-lightening face creams at higher rates (Collins et al., 2023, pp. 293–294; Zota & Shamasunder, 2017, p. 419). Studies stress that hormonally active chemicals found in many personal care products (e.g., hair relaxers) create disproportionate harms to women of color, particularly young Black girls (James-Todd et al., 2021, p. 477). Income may also play a factor, as less costly, lower-quality brands (especially imported brands) are more likely to be produced in a less-regulated setting using lower-quality materials, which may increase the risk of contamination or chemical leaching.

Organizations such as the Campaign for Safe Cosmetics have documented that beauty products marketed to Black women can contain the most toxic ingredients used by the cosmetics industry and that they are associated with endocrine disruption, reproductive harms, and increased cancer incidence. The Campaign for Safe Cosmetics' Non-Toxic Black Beauty Project identifies 480 chemicals of concern on the Black Beauty Red list (Campaign for Safe Cosmetics, 2023, p. 16). The connections between identified toxins and plastic are complex and merit more attention. For example, phthalates – a class of plasticizers commonly found in plastic products and their packaging – are endocrine disruptors associated with developmental and reproductive toxicity and heightened cancer risk. They are on the Campaign for Safe Cosmetic's "Red List" of most concerning toxins.

Despite the growth of the multibillion-dollar "clean" beauty industry, which aims to address concerns over toxins in beauty products, cleaner products largely cater to White consumers and offer limited options to women of color, the latter group tending to use such products more often. Groups such as "Clean Beauty Justice" are campaigning to reduce the prevalence of toxic chemicals in products aimed at these consumers — such as those for darker skin tones and curly, coily hair — but more research and advocacy around plastic-related exposure risks in cosmetics will be necessary to reduce disproportionate personal care product exposure among women of color.

Women of color also face outsized compounding risks from environmental burdens (e.g., from place-based pollution or high traffic density) and/or poorer health care outcomes (e.g., high rates of breast cancer or lower maternal health) (Dayo et al., 2023). This increases the potential harms from co-occurring chemical and nanoplastic exposures related to beauty products (Collins et al., 2023, pp. 293–294; Zota & Shamasunder, 2017, p. 419). Women who work in the beauty care industry are even more likely to be impacted; beauty care workers are predominantly women of color and immigrant women who often labor under ad hoc workplace safety standards (Zota & Shamasunder, 2017, p. 418). Disproportionality in microfiber exposure risk across demographics is understudied and requires more research. It is plausible low-income families with constrained budgets may have higher rates of synthetic fiber exposure at home via lower-quality, inexpensive synthetic clothing and textiles. Laundering and drying habits of such items are also a major factor, as these processes release microplastic in consumers' homes. Further research is needed on how microfiber generation is affected by usage of older, secondhand synthetic clothing. Relatedly, the textile supply chain creates many release points for microfibers via microshedding. More work is needed to identify how and where this supply chain creates additional exposure risk in communities impacted (Henry et al., 2019, p. 487).

Regardless of how micro- and nanoplastic enter a person's body, research has clearly established a link between microplastic and reproductive health harms. Of the more than 13,000 chemicals associated with plastic and plastic production, 7,000 have been screened for hazardous properties, and 3,200 have been identified as having "carcinogenicity, mutagenicity, reproductive toxicity, and endocrine disruption." As microplastic has risen globally, so has the concurrent decline in global fertility rates. Microplastic is shown to be toxic to reproductive organs and associated with ovary, uterus, and placenta disruptions (Wang et al., 2024). Women of color suffer from greater overall disparities in maternal health (Dayo et al., 2023). It is important to further consider the reproductive health harms to these communities from micro- and nanoplastic exposure.

3.2. Identifying Plastic-Burdened Communities: Considering Total Exposure Risks and Preexisting Vulnerabilities

For mitigation investments from the Plastic Pollution Mitigation Fund (PPMF) to achieve equitable outcomes, agencies must be mindful of both the nature of exposures and the patterns in which they occur. We posit that the first step for doing so in a just and transparent fashion is to identify plastic-burdened communities based on two pillars:

1. Whether a community is at disproportionate risk for any of the three exposure types, and to what degree.
2. Whether a community experiences coinciding exposure risks, and the combined severity of those risks.

The second pillar is straightforward in nature but difficult to put into practice. Our approach identifies the plastic burden as more than just exposure to polluting facilities, but rather as one where multiple impacts — from site-based, dietary, and consumer goods — can create a compounded plastic burden for some communities. Figure 3 shows how communities can be assessed based on each of their relative exposure risks, synthesizing the different measures into an overall measure. Some communities face high levels of risk across more than one exposure vector and are "triply-impacted" (Figure 3A) or "doubly-impacted" (Figure 3B) —

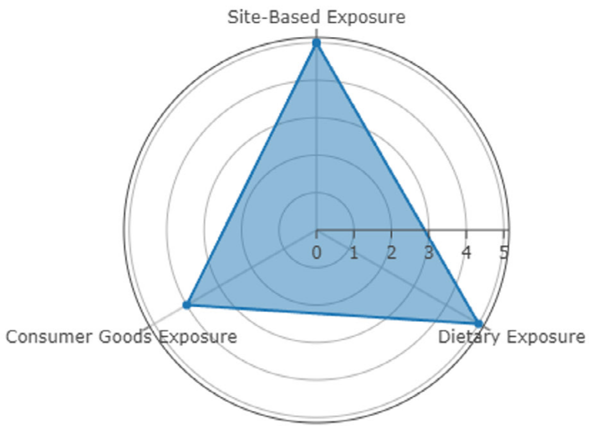
others may have more limited exposure (Figure 3C). Relative size of the colored area in Figure 3 indicates the overall level of exposure risk for the example communities. Those with higher risk — the triple and double burdened communities — should be higher priority for investments from SB 54 mitigation monies.[23]

[23] Ideally, future efforts will develop data-driven indices for each exposure type and appropriately weight them, such that policymakers and administrators cannot only prioritize funds for the communities experiencing the greatest overall impact, but also identify the greatest sources of their exposure risk and develop targeted solutions.

FIGURE 3

The Three-Part Plastic-Burdened Communities Framework; shows relative impact for the three exposures on a 0-5 scale for three hypothetical

3A. A triple-burdened community. **3B. A double-burdened community.** **3C. A single-burdened community.**

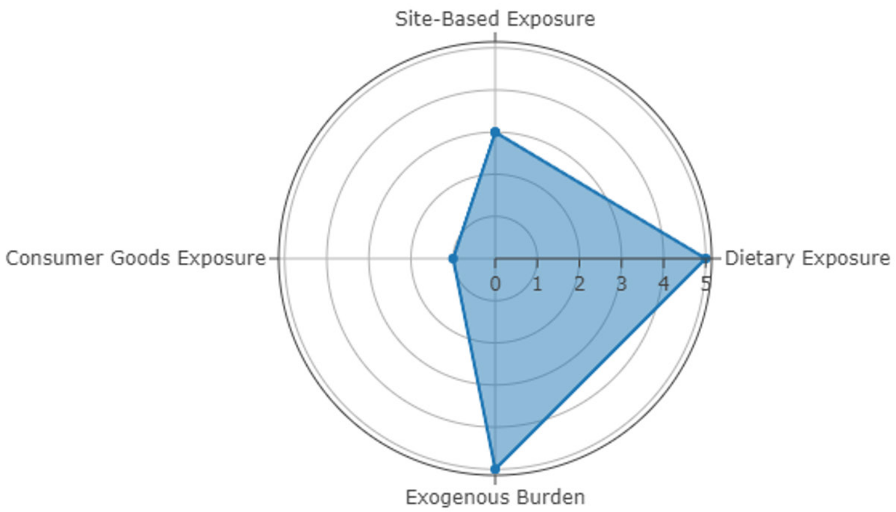


This methodology could be supplemented by considering what nonplastic-related burdens the community is already facing, as additional plastic-related exposures will fall hardest on communities already struggling with other pollution, health, or socioeconomic challenges. Figure 4 shows how these preexisting and co-occurring vulnerabilities (termed "exogenous burden") can help decision-makers prioritize between two hypothetical communities facing similar levels of plastic burden. The overall level of exposure risk indicated by the colored area indicates that the community with higher exogenous burden (Figure 4A) should be higher priority for funding than the other (Figure 4B).

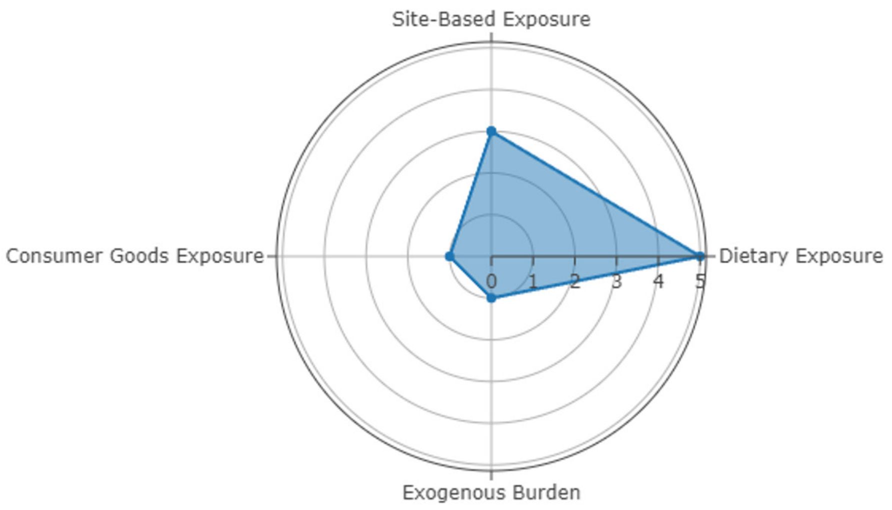
FIGURE 4

***The Three-Part Plastic-Burdened Communities Framework*, supplemented by also considering preexisting and co-occurring vulnerabilities not related to plastic impact (exogenous burden)**

4A. Community with high levels of nonplastic-related burden.



4B. Community with low levels of nonplastic-related burden.



The three exposures we identify should be examined carefully with respect to how they impact low-income communities and communities of color. These communities are more likely to face preexisting exogenous burdens such as reduced access to preventative health care, living in closer proximity to food deserts, and exposure to negative environmental externalities at home and work. Below, we present a summary of evidence from other research that the plastic pollution burden is an environmental justice issue facing low-income communities and communities of color, but more research and measurement strategies need to be adopted to make these associations across California's populations.

4. MAPPING PLASTIC WASTE-RELATED SITE-BASED EXPOSURES IN CALIFORNIA: DATA AND METHODS

In the prior chapters, we provided an overview of the plastic life cycle in California and the magnitude of its supply chain, discussed the exposure risks facing people across the life cycle's different stages, articulated a conceptual framework for identifying plastic-burdened communities to better inform mitigation investments, and explained how plastic exposures are an environmental justice concern. We will now show how we illustrated a portion of our framework, focusing on one stage of the life cycle (downstream/disposal) and one type of exposure (site-based). Below, we detail our approach to creating a spatial map of plastic waste-related site-based exposures in California and our analysis of the results, including a more detailed discussion of exposure impacts tied to specific types of waste facilities.

We prioritized this component of the framework because site-based exposure risk lends itself to spatial analysis, and public data on the locations of plastic-related waste sites is readily available. Future research has the opportunity to expand this approach to other stages of the supply chain and other exposure risks. This initial mapping exercise provides evidence that the plastic burden is an environmental justice issue, as we find that exposure risks from plastic-related waste disposal facilities are more closely linked to communities of color, low-income communities, and communities with greater environmental and health vulnerabilities.

Visuals of the resulting map tool and key findings can be found in the following chapter, *Mapping Plastic Waste-Related Site-Based Exposures in California: Results and Analysis*. The interactive map tool is publicly available at https://innovation.luskin.ucla.edu/mapping-impacts-from-plastic-disposal-sites-in-california/.

4.1. Data Sources

For identifying the nature and location of waste infrastructure involved in the processing of plastic waste we rely primarily on three public data sets available from the California Department of Resources Recycling and Recovery (CalRecycle):

- Solid Waste Information System (SWIS) "Site Activity" and "Site Waste" datasets
- Recycling and Disposal Reporting System (RDRS) data, filtered by "Active" site status as of March 20, 2024.

Locations of three currently operating or recently closed municipal waste incinerators in the state were identified via community partner engagement, with additional information provided by City of Commerce Environmental Services Division.

4.2. Data Processing and Classification

With the above data sources, we took measures to remove entries not relevant to this study (e.g., not located in California, not engaged in plastic waste processing) or where the available data did not inform the physical location of an operational site (e.g., P.O. box addresses). The facilities were then consolidated into a single dataset and classified. See Appendix 1 for a detailed description of this process.

4.3. Mapped Facility Descriptions

Following the above data classification procedures resulted in four plastic-related waste facility types that could be mapped within the state:

1. Incinerators: Facilities that combust mixed solid waste. In California, incinerators have historically operated as waste-to-energy facilities (WEF). WEF incinerators have been linked to numerous health and environmental risks through the creation and emission of harmful contaminants produced in the combustion process. Unlike in other categories, we include two nonoperational facilities because of their long operation times and resulting cumulative impacts.
2. Plastic-Related Recyclers: Facilities that receive and recycle plastic waste. Plastic waste is typically recycled through a process that washes, shreds, melts, and extrudes plastic pellets for use in new applications. Plastic recycling operations have been linked to health and environmental harms, including toxic emissions and creation of microplastic pollution.[24]
3. Solid Waste Disposal Sites and Landfills: Facilities that sequester solid waste in a tract of land. Landfilled plastic waste can result in toxic exposure to workers and residents, escape of contaminated leachate, and release of plastic pollution debris. Plastic is estimated to be 13.7% of California's waste stream. We designated large facilities as those with a throughput of 1,000 tons/day or more, and small facilities as those that receive less than 1,000 tons/day or for which no throughput data is available.[25]
4. Transfer and Processing Facilities: Facilities that receive solid waste for purposes of storing, handling, and/or processing it prior to transfer to another facility. Transfer and processing facilities are linked to increased local pollution and other disamenities that negatively affect quality of life for nearby residents. Large facilities are designated as "large" in CalRecycle database classifications; "small" facilities are all others.

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[24] As detailed in Data Processing and Classification, facilities classified as plastic-related recyclers are those that appear in the RDRS database as "Recycler/Composter," which we could not exclude as unlikely to process plastic in their intended operations. However, the database does not provide sufficient detail on facility operations such that we can be fully confident that all such facilities have been excluded. Thus, it is likely that our assessment of plastic-related recyclers currently overcounts these facilities in California, and that there is some variance among the facilities in terms of the exact nature of their day-to-day operations that affects the localized impacts they produce.

4.4. Determining Distance of Impact Zones

To create a spatial rendition of plastic-related impacts across California, we identified "impact zones" within distances specific to each of four facility types. To determine the distance within which localized impacts are felt around plastic waste-related facilities, we relied solely on figures established in existing environmental and public health literature.

The buffer distances for each facility type are shown in Table 5. In one case (incinerators), we applied a concentric, two-tiered buffer to reflect differential impacts identified in the literature. For two other facility types (solid waste disposal sites and landfills and transfer and processing facilities), we applied different buffers depending on the facility's size category.

TABLE 5

GIS buffer distance specifications by facility type

Facility Type	Buffer Distance
Incinerators (Near)	5 km
Incinerators (Far)	30 km
Plastic-Related Recyclers	0.9 km
Solid Waste Disposal Sites and Landfills (Large)	5.23 km
Solid Waste Disposal Sites and Landfills (Small)	3 km
Transfer and Processing Facilities (Large)	3.3 km
Transfer and Processing Facilities (Small)	2.86 km

Our sources and justification for the specifications shown in Table 5, by facility type, follow below:

5. **Incinerators**

When determining buffer distances to represent areas of impact around incinerators, we primarily relied on National Research Council (U.S.) Committee on Health Effects of Waste Incineration (2000). In its discussion of environmental transport and exposure pathways of emitted contaminants from incinerators, NRC cites three sources that provide specific distance guidance on the promulgation of incinerator-related pollutants. When estimating ambient air pollutant concentrations related to waste incineration, NRC relies on air unit concentrations from Cullen (1995), the distributions for which extend to a maximum distance of 30 kilometers — hence our less conservative, lower-impact zone distance.

[25] Under CalRecycle's classification scheme, solid waste disposal sites are distinguished from landfills in that they only inter waste produced by the operator on site. Thus, it is possible that among the facilities included in our analysis are some solid waste disposal sites where plastic waste is not a major component of the interred waste, depending on the nature of on-site operations.

In discussing more proximate impacts, NRC cites Collett et al. (1998) and Carpi et al. (1994), both of which illuminated the presence of hazardous substances in areas around waste incinerators as a result of operations. The former identified lead in soil samples within 5 kilometers of a Scotland-based incinerator directly related to atmospheric emissions from the facility, while the latter examined bioaccumulation of mercury in moss and grass samples within 5 kilometers of a New Jersey waste incinerator (Carpi et al., 1994; Collett et al., 1998). We elected to use this 5-kilometer radius as the buffer for the zone of higher impacts from California's incinerator sites.

6. **Plastic-Related Recyclers**

In our review of literature on impacts of plastic recycling plants, we identified only one study that provided specific distance figures within which impacts were assessed. Xin & Tsuda (2017) examined impacts from a plastic recycling facility's air pollution on nearby residents within 500 meters and 900 meters of the site, compared to a reference group located 2.8 kilometers away (Xin & Tsuda, 2017). Health effects were identified at distances of both 500 and 900 meters, albeit with greater magnitude for residents closer to the facility. Therefore, we opted to use 900 meters as the buffer for plastic-related recycling facilities.

7. **Landfills and Solid Waste Disposal Sites**

Numerous studies have examined the impacts of landfills and hazardous waste sites on proximate communities. We identified 3 kilometers as the base buffer distance for small landfills and other solid waste disposal sites in our analysis, based on its presence in multiple studies and, in particular, its predictive value as noted by Ham et al. (2013). In a study of landfill disamenity impacts as reflected in housing valuation, the authors found 3 kilometers was the best predictive distance band for active landfill impacts on home prices (Ham et al., 2013). Other research on the effects of living near some types of hazardous facilities has also used 3 kilometers as the threshold for defining an impacted "host neighborhood" (Mascarenhas et al., 2021). Other studies used a more restrictive two-kilometer band to assess landfill impacts on home prices and health impacts on residents living near Superfund sites (Currie et al., 2011; Du Preez & Lottering, 2009). However, because of the findings of Ham et al. (2013) and the inherent limitations of hedonic pricing method studies,[26] we elect to use the larger 3-kilometer distance. In the case of large landfills, we used a buffer distance of 5.23 kilometers (3.25 mi) — the threshold of analysis used by Hite et al. (2001) — to reflect the more widespread impacts that come with greater operational scale (Hite et al., 2001).

[26] Hedonic pricing method studies use statistical analysis to estimate the economic value of a variable of interest — such as the presence of a nearby landfill — based on market behavior (i.e., home prices). Because such studies rely on market behavior made in response to the variable, they are inherently limited in that hidden or unperceived impacts on the people in the market are not reflected in the outcome.

8. **Transfer and Processing Facilities**

   Compared to other facility types, transfer and processing facilities are relatively understudied in the literature. In contrast to the numerous studies identified in our review focused on the impacts of waste-related sites, we identified only one study — Eshet et al. (2007) — that specifically focused on proximate impacts of transfer and processing facilities. Among the four facilities examined in this study, the average distance for the spatial extent of impacts was 2.86 kilometers, while those of the largest facility reached 3.3 kilometers. We, therefore, used these distances as impact buffer specifications for small and large facilities, respectively.

4.5. Determining Relative Exposure Risk Levels

To provide a rough relative map of the environmental and public health impacts these facilities have on nearby Californian communities, we adopted an ordinal impact scale, assigning each facility type a number based on its associated negative impacts as compared to other facilities. We examined four factors: airborne exposure, liquid leachate, long-term accumulated post closure impacts, and disamenities. These factors impact nearby residents' lives in different ways, some more noticeable than others, and on different time scales. Some factors considered (e.g., microplastic pollution and liquid leachate) are highly dynamic areas of research. Others may vary based on characteristics of individual facilities, such as quality of maintenance, adherence to occupational safety practices, and local es, such as quality of maintenance, adherence to occupational safety practices, and local environmental conditions. Future research could build on our assessment to produce a more comprehensive measure of localized impacts (see Recommendations and Future Research Needs).

Below, we identify four impact categories that negatively affect the health and quality of life of workers and nearby residents and create environmental harms. They are listed from the most to least impactful.

1. **Airborne Exposure**

   Does research link the facility type to airborne emissions of substances that cause severe health risks, such as carcinogenic or neurological impacts, respiratory disease, and/or exposure to highly toxic substances like heavy metals, dioxins, and volatile organic compounds (VOCs)?

2. **Liquid Leachate or Effluent Exposure**

   Does research link the facility type to contamination of soil and/or water through the escape of liquid leachate or effluent, which may carry microplastic particles and/or toxic compounds such as flame retardants, plasticizers, and heavy metals?

3. **Long-Term Accumulated Post-Closure Impacts**

   Is there evidence that the facility type — either through intentional interment of waste or via buildup of released contaminants — results in accumulated environmental contamination that is likely to cause persistent impacts for years, even after operations cease?

4. **Disamenities**

   Does the facility type create disamenities — such as additional visual, noise, or odor pollution or increased traffic and vehicle emissions — that degrade the quality of life for nearby residents?

Table 6 below shows our assessment of each facility type with respect to the above criteria based primarily on a review of scientific literature on waste facility impacts. The final impact weighting used for the spatial impact analysis is also included.

TABLE 6

Impact criteria assessment and impact scale determinations by facility type

Facility Type*	Impact Criteria				Impact Rating
	Airborne Exposure	Liquid Leachate or Effluent Exposure	Long-Term Accumulated Post-Closure Impacts	Disamenities	
Incinerators (Near)	3	0	1	1	5
Incinerators (Far)	2	0	1	1	4
Recyclers	1	1	0	1	3
Landfills	0	2	1	1	4
Transfers	0	0	0	1	1

*Facility type names abbreviated for legibility

The sources and logic used to formulate these impact ratings are discussed below. It should be emphasized that much of the research on impacts related to waste infrastructure does not solely focus on those impacts that can be attributed to the plastic portion of the waste stream, nor does it attempt to disaggregate this portion from the larger whole. However, in our judgment these sources are still valuable in assessing plastic-related impacts, based on a few considerations.

First, plastic plays an outsized role in determining a facility's impacts, even when it comprises only a subset of the waste the facility processes. A growing body of research has identified plastic waste as a source of numerous toxic contaminants or as a vector of other contaminants via accumulation. Additionally, plastic debris and microplastic that escapes the waste stream persists in the environment in a manner that other common waste materials do not.

Second, plastic impacts related to operations (e.g., emissions from vehicles transporting waste) are commensurate with their share of the waste stream by mass, which is substantial. All other factors equal, these impacts will decrease as reliance on SUPs and disposal items lessens and less solid waste is generated.

Third, while patterns of distribution vary by contaminant type, we assume that existing research on the spread of contaminants from waste facilities is generally representative of the spread of plastic-related contaminants. Given the light weight of many single-use plastic items, plastic films, and microplastic fragments, plus the ability of plastic materials to persist for long periods of time in the environment, this approach is likely conservative.[27]

1. **Airborne Exposures**

   To reiterate, we rated facilities as having notable impacts related to airborne exposures if they were linked in the literature to a substantial risk of airborne exposure to highly toxic substances that pose severe health risks — that is, their airborne emissions went beyond those associated with foul odors or traffic emissions. We found no evidence in the literature that landfills and solid waste disposal sites or transfer and processing facilities meet this criterion, and therefore rated them both as "0."

   Plastic recycling operations have been linked to a plethora of harmful environmental releases, but evidence of airborne contamination is more limited. The most common airborne exposure factor for such facilities is volatile organic compounds (VOCs) released via the plastic extrusion process (Z. He et al., 2015; Salhofer et al., 2021, p. 8; Yorifuji et al., 2012). Workers and nearby residents exposed to VOCs from recycling operations have higher incidence of respiratory and skin conditions (Z. He et al., 2015; Yorifuji et al., 2012). There are also concerns about the escape of microplastic dust created and aerosolized during processing, which can act as a vector for other dangerous contaminants (Salhofer et al., 2021, p. 8). Thus, while there are clear concerns about airborne exposures created by plastic recycling operations, their relative severity and the level of documentation on them is somewhat low, meriting a rating of "1."

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[27] This discussion comes with the important caveat that our classification method is a simplified, generalized assessment that does not necessarily reflect the many factors that can affect any one facility. Site-specific factors and practices — such as ventilation, proper use of protective equipment, the specific types and amounts of plastic waste being processed, and maintenance — can affect the nature of contaminants and the degree to which they escape. Future research can build on our work to further differentiate among different types of plastic waste-related operational sites and the externalities they generate.

2. **Liquid Leachate or Effluent Exposure**

The escape of contaminated liquid leachate or effluent from a facility is not a risk factor identified in the literature for incinerators or transfer and processing facilities. We rated both facility types a "0."

In the case of plastic recycling operations, recycling facilities' role as point sources of plastic debris pollution, especially microplastic, is a concern (see the Microplastic and Associated Harms sidebar). Operational processes such as the washing of plastic feedstock items can create effluent contaminated with microplastic particles (Marie Mahon et al., 2017). Large amounts of microplastic particles can be released via wastewater or sludge from recycling operations, escaping to aquatic or marine environments, or becoming entrained in sewage sludge (Kallenbach et al., 2022; Le Tran et al., 2023; Marie Mahon et al., 2017). Microplastic in sewage sludge may later be introduced into the environment via agricultural fertilizer application, creating risks for food supply chain contamination (Marie Mahon et al., 2017). The introduction of microplastic — including recycled plastic pellets themselves — into the local environment also contributes to direct environmental and ecological harms and creates the risk of second-order public health risks via dietary exposure (see sidebar). Given these factors, we ranked plastic-related recyclers a "1."

The risk mechanism for landfills and solid waste disposal sites is similar to that of plastic-related recyclers, but with heightened risk as a consequence of time and volume. The most severe health effects linked to landfill exposure are those related to chemical exposures, which can have carcinogenic, neurological, endocrine-disrupting, and other impacts (Khoiron et al., 2020; Lakhouit & Alsulami, 2020). Many of these chemicals, notably brominated flame retardants and plasticizers, are directly linked to plastic materials (N. Morin et al., 2015; N. A. O. Morin et al., 2017; Panni, 2023). Buildup over time has been shown to create large accumulations of brominated flame retardants in landfills, which can later escape the site (N. A. O. Morin et al., 2017). Likewise, large amounts of plasticizers like bisphenol A (BPA) and phthalates make their way into landfills, whereafter they often escape into the environment. One study found that landfilling constituted the single greatest source of environmental emissions of BPA — up to 13% of the amount landfilled (Arp et al., 2017). Plasticizer contaminants were also found in the leachate escaping from 5 out of 5 landfills examined in a 2017 study, including a remediated site five years post-closure (Wowkonowicz & Kijeńska, 2017). In 45% of the samples from said study, levels of Di(2-ethylhexyl) phthalate (DEHP) — the most common of a class of plasticizer additive called phthalate acid esters (PAEs) — exceeded European Union and World Health Organization drinking water limits. Other research has identified toxic levels of BPA in landfill leachate (N. Morin et al., 2015). Plasticizer contamination poses a pronounced public health risk; in all forms (including those beyond the landfill context), the aggregate health impacts of the three most common plasticizers in the U.S. — polybrominated diphenyl ether (PBDE), BPA, and DEHP — is estimated to be equivalent to $920 billion (Landrigan et al., 2023).

Alongside chemical contaminants, landfill leachate can facilitate the escape of microplastic produced through weathering of plastic debris, along with contaminants carried by the particles (Wan et al., 2022). The long time periods for which plastic waste is interred in a landfill setting create more opportunity for physical breakdown of items into microplastic and additional time and opportunity for particles to be exposed to potential contaminants in the mixed waste environment. Mismanagement and natural disasters such as flooding can heighten the risk for pollutant escape (Laner et al., 2009; Yadav et al., 2020).

Taking all these factors into account, we rated landfills and solid waste disposal sites at a "2."

3. **Long-Term Accumulated Post-Closure Impacts**

We identified no clear evidence in the literature that plastic-related recyclers or transfer and processing facilities produce long-lasting environmental contamination that outlasts facility operations. Therefore, these facility types are rated as "0."

In the case of landfills and solid waste disposal sites, the operational model of such facilities — interring waste in the ground — inherently creates a long-term post-closure impact. This is especially true for nonbiodegradable plastic. However, research has also established that contaminant escape continues to be a risk for years after a landfill is closed (Wowkonowicz & Kijeńska, 2017). Therefore, we rated landfills and solid waste disposal sites a "1."

MICROPLASTICS AND ASSOCIATED HARMS

Microplastic contamination has reached a point of global ubiquity, being found in groundwater, drinking water, and environmental samples, among other contexts (Andrady, 2011; Aslam et al., 2019; Panno et al., 2019). Plastic particles consumed by organisms in the environment can cause direct health and reproductive harms and, although technically bio-inert, can accumulate toxic substances such as heavy metals and persistent organic pollutants, becoming a toxic vector (Andrady, 2011; Aslam et al., 2019; Pirsaheb et al., 2020). Tainted microplastics, thus, compound dietary exposure risks if they contaminate groundwater, well water, or other drinking water sources. Recycled plastic pellets — a potential form of microplastic pollution themselves — contaminated with toxic classes of chemicals are also of concern (Brosché et al., 2021). Pellets may, therefore, create exposure risks through direct chemical leaching as microplastic pollution or heighten consumer goods exposure risk when used in the manufacture of recycled content plastic items.

For incinerators, the presence of non-degrading and, in some cases, bioaccumulative toxins (e.g., heavy metals), the multidecadal operation spans of the facilities in question, and the evidence of contaminant settling in soil, plants, and water constitute a clear long-lasting impact (Alabi et al., 2019; National Research Council (U.S.) Committee on Health Effects of Waste Incineration, 2000). We rated incinerators a "1."

4. **Disamenities**

"Disamenities" constitute the myriad ways in which residents' quality of life is degraded by living near a plastic waste-related facility. Unsurprisingly, we rated all four facility types as creating disamenity impacts in some fashion.

Compared to other facility types, transfer and processing facilities are relatively understudied in the literature. In contrast to the numerous studies identified in our review

EXPLAINING EXPOSURE RISK RATING (ERR)

ERR is the numerical value our analysis uses to describe the overall relative exposure risk a given area experiences from proximity to plastic-related waste sites.

ERR values are simplified groupings of the raw impact values produced by our analysis. For more information on how these groupings were created, see Appendix 3.

ERR = 0

Impact value is 0. The area does not have any nearby plastic-related waste sites.

ERR = 1. Low exposure risk

Impact value is 0.1-2. The area is only affected by transfer/processing stations, and no more than two of them.

ERR = 2. Moderate exposure risk

Impact value is 2.1-5. The area typically lies within the impact zone of a single higher-risk site, such as an incinerator or landfill.

ERR = 3. High exposure risk

Impact value is 5.1-9. The area is affected by 1-2 higher-risk sites and may be affected by additional transfer/processing stations.

ERR = 4. Very high exposure risk

Impact value is 9.1-14. The area is affected by 2-3 higher-risk sites and additional transfer/processing stations. Almost all of these areas are those affected by both Los Angeles-area incinerators.

ERR = 5. Extremely high exposure risk

Impact value is 14.1-25. The area is affected by at least three higher-risk sites and additional transfer/processing stations. Almost all of these areas are affected by both Los Angeles-area incinerators, plus one or more local landfills or recyclers.

focused on the impacts of waste-related sites, we identified only one study — Eshet et al. (2007) — that specifically focused on proximate impacts of transfer and processing facilities. The authors used a hedonic pricing method analysis to assess impacts of waste transfer and processing facilities on nearby communities, as manifested in home prices. All noted impacts are incidental to waste processing operations, and include noise and visual pollution, litter, foul odors, and greater incidence of litter and vermin, among other perceived discomforts (Eshet et al., 2007). The environmental impacts of traffic and related emissions from waste transport vehicles were found to be most associated with larger facilities (Eshet et al., 2007). Unsurprisingly, these impacts were found to negatively affect nearby home prices, with a greater magnitude of impact on homes located closer to the facility (Eshet et al., 2007).

Living near a landfill brings with it many disamenities, but it can be difficult to gauge how closely some of these (e.g., foul odors) are related to plastic waste. However, landfills are at inherent risk of allowing plastic debris to escape and become litter in the surrounding community, whether through incidental operational loss or via mismanagement, biotic (i.e., animal) or anthropogenic interference, environmental processes, flooding, or fires (Laner et al., 2009; Yadav et al., 2020). Like transfer and processing facilities, landfills also create additional visual, noise, and air pollution via the comings and goings of heavy-duty waste transport vehicles.

In the case of plastic-related recyclers, the clearest example of local disamenities is odorous pollution generated from the process. Post-consumer plastic can often retain malodorous substances, to the point where some processes integrate steps to decontaminate and remove odors from feedstock plastic (Strangl et al., 2019, p. 1). Additionally, the aforementioned VOCs produced during plastic recycling that pose an airborne exposure risk can also cause foul smells in the surrounding area (Cabanes et al., 2020, pp. 1, 4; Fuller et al., 2020, pp. 1–2).

Lastly, incinerators are associated with numerous disamenities impacting nearby community members, including vehicle exhaust and mismanaged ash outside the facility (Fuhrmann, 2021, pp. 7–8).

4.6. Spatial and Statistical Methods

In order to map waste site-based exposures using the above specifications, we used the geographic information system (GIS) program ArcGIS Pro to map the locations of waste facilities in California, show the corresponding impact zones around each site, and essentially "add up" the overlapping impact values. For example, an area where the impact zones of a single landfill and a single transfer/processing station overlap would have an impact value of "5." Because of the complexity of the waste site landscape in California, this step resulted in a broad range of unique impact values, from "0" to "25." To facilitate the legibility of the public-facing mapping tool that accompanies this report, we categorized these values into a simplified scale, termed exposure risk rating (ERR), with values between "0" and "5" (see sidebar).

We used ArcGIS Pro to calculate the average ERR value within each census tract in the state. Because ERR values are rasterized — meaning each pixel on the digital map is assigned a value indicating the exposure risk in that particular real-world area — each census tract's average ERR is determined by looking at the total value of all pixels that fall within its physical area and averaging them.

To study the links between these impact values and measures of environmental and socioeconomic disadvantage, we performed a series of statistical tests: Pearson's correlation tests, simple linear regressions, and in one case, a two-tailed t-test. These tests aim to address the question: If we were to compare two Californian communities with different levels of exposure risk from plastic-related waste sites, how would we expect those communities to look different? Thus, we treat ERR as the independent variable in our analysis and examine its relationship to each individual measure in a vacuum, apart from all others.

Table 7 shows the indicators we examined with brief descriptions and sources.

TABLE 7

Select indicators analyzed for relationship with census tract-level average impact, with sources and definitions

Indicator	Source*	Description
Median Household Income	U.S. Census Bureau American Community Survey, 2010**	Median annual income ($) of households in the census tract
CalEnviroScreen Score	CalEnviroScreen 4.0	Absolute burden score calculated using the CalEnviroScreen 4.0 index.[28]
Poverty	CalEnviroScreen 4.0	% of population living below two times the federal poverty level
Unemployment	CalEnviroScreen 4.0	% of population age 16+ that is unemployed and eligible for the labor force
Low Educational Attainment	CalEnviroScreen 4.0	% of population age 25+ with less than a high school education
Non-White Population %	CalEnviroScreen 4.0	% of population not classified as White in CalEnviroScreen demographic data
Asthma	CalEnviroScreen 4.0	Spatially modeled, age-adjusted rate of emergency department visits for asthma per 10,000 people (average 2015-2017)
Low Birth Weight	CalEnviroScreen 4.0	Percent of infants born weighing less than 2.5 kg (average 2009-2015)

*Indicates direct source from which data was accessed. In some cases, CalEnviroScreen indicators are derived from other sources, including the U.S. Census Bureau American Community Survey and other state agencies. See the CalEnviroScreen 4.0 report for indicator data sources.
**2010 median household income values were used because the current version of CalEnviroScreen uses 2010 census tracts.

In addition to the non-White population percentage indicator, we examined each racial group included in CalEnviroScreen 4.0's demographic data individually using the same approach. These groups are:

- Hispanic
- White
- African American
- Native American
- Other / Multiple races
- Asian American and Pacific Islander (AAPI)

For a detailed, technical description of our analytical methods, see Appendix 3.

[28] More information is available at https://oehha.ca.gov/calenviroscreen.

5. MAPPING PLASTIC WASTE-RELATED SITE-BASED EXPOSURES IN CALIFORNIA: RESULTS AND ANALYSIS

Our analysis shows that lower-level exposures from plastic-related waste sites are common throughout California, with pockets of more intense impact interspersed throughout the state. The greatest levels of impact are those occurring proximate to the three operational or recently shuttered waste incinerators in the vicinity of Modesto and the Los Angeles area. There is strong evidence that these exposures fall hardest on communities already facing public health and socioeconomic challenges and may be placing sensitive populations and sites at undue risk. However, we found that a large portion of the highest-impacted communities are not designated as disadvantaged, suggesting some degree of disconnect between the state's broad definition and plastic-related impacts, specifically.

5.1. Mapping Results

Figures 5-7 show the results of the spatial mapping procedures detailed in the previous chapter at three key stages: mapping of plastic-related waste sites by type and (where applicable) size, the visualization exposure risk rating (ERR) in facility impact zones, and ERR at the census tract level. The most significant impact zones are those in the Modesto and Los Angeles areas, driven by the presence of municipal waste incinerators. However, smaller high-impact zones can be seen in many areas of the state, including the south Bay Area, the San Bernardino area east of Los Angeles, and the San Diego area, among others. These zones are generally driven by the presence of landfills and/or plastic-related recyclers.

The interactive map set, along with underlying data features, can be found at https://innovation.luskin.ucla.edu/mapping-impacts-from-plastic-disposal-sites-in-california/.

FIGURE 5

Locations of plastic-related waste sites and facilities used in waste site impact analysis, by type

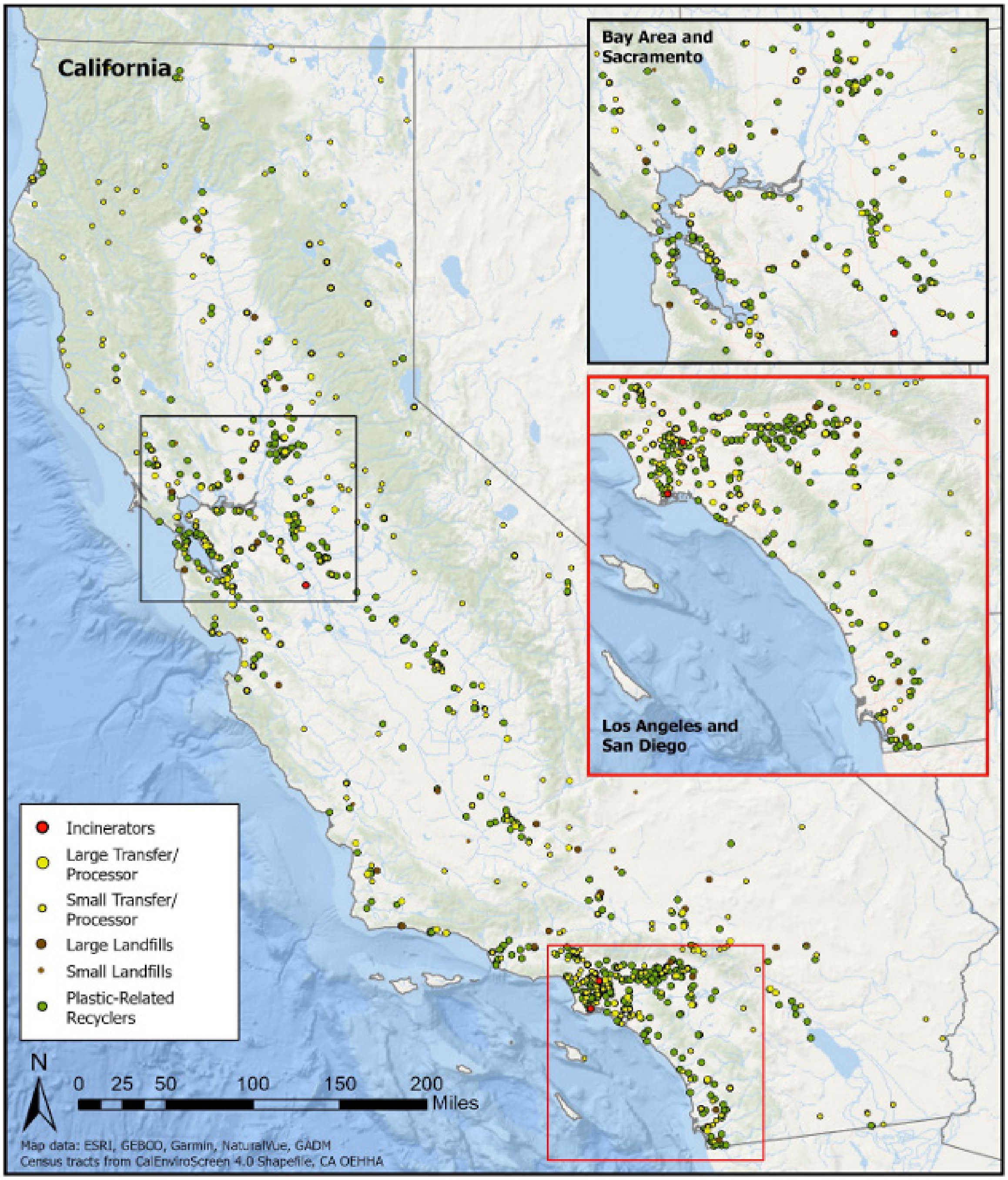


FIGURE 6

Visualization of exposure risk rating (ERR), representing the spatial distribution of cumulative plastic-related waste site impacts in California

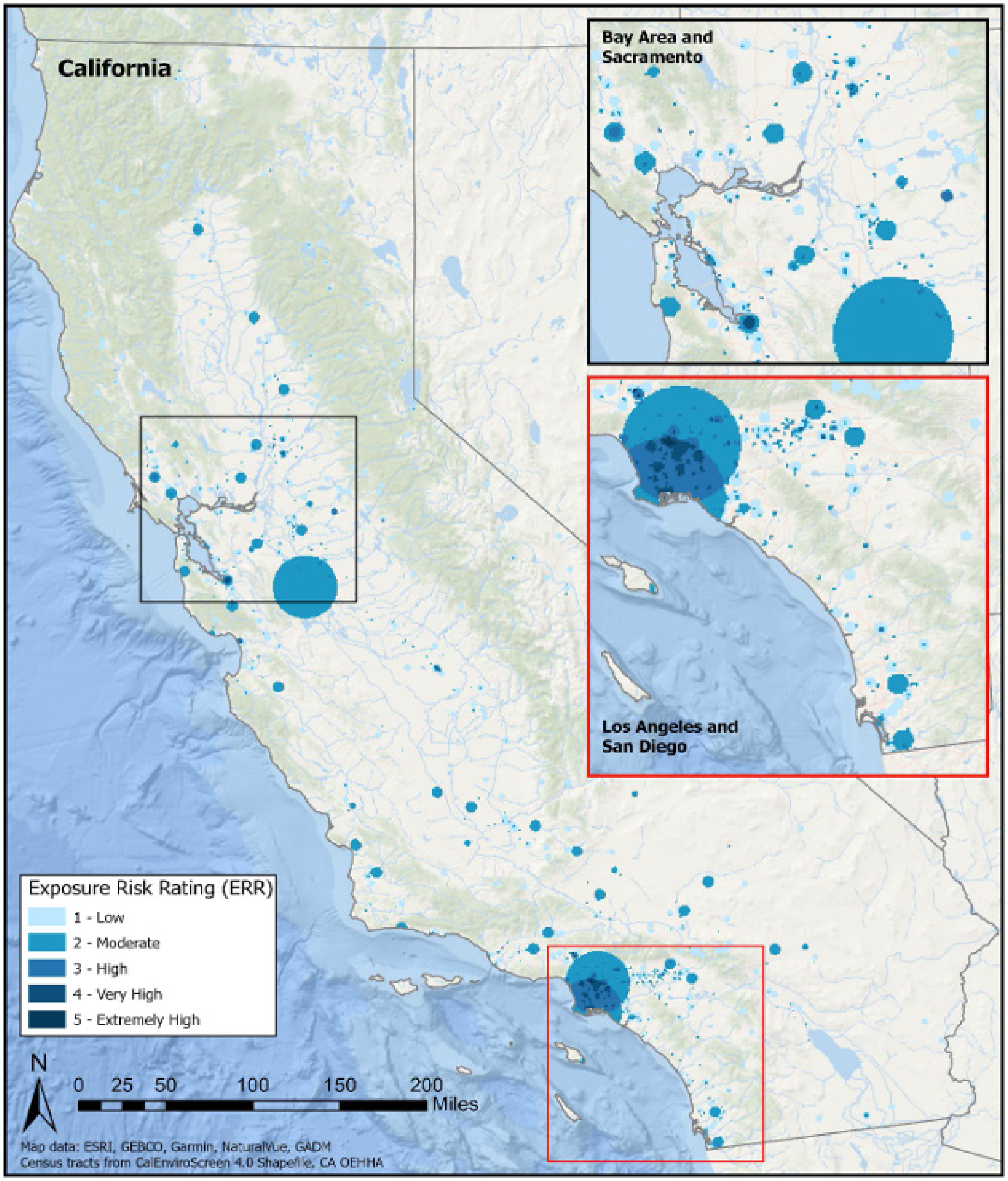
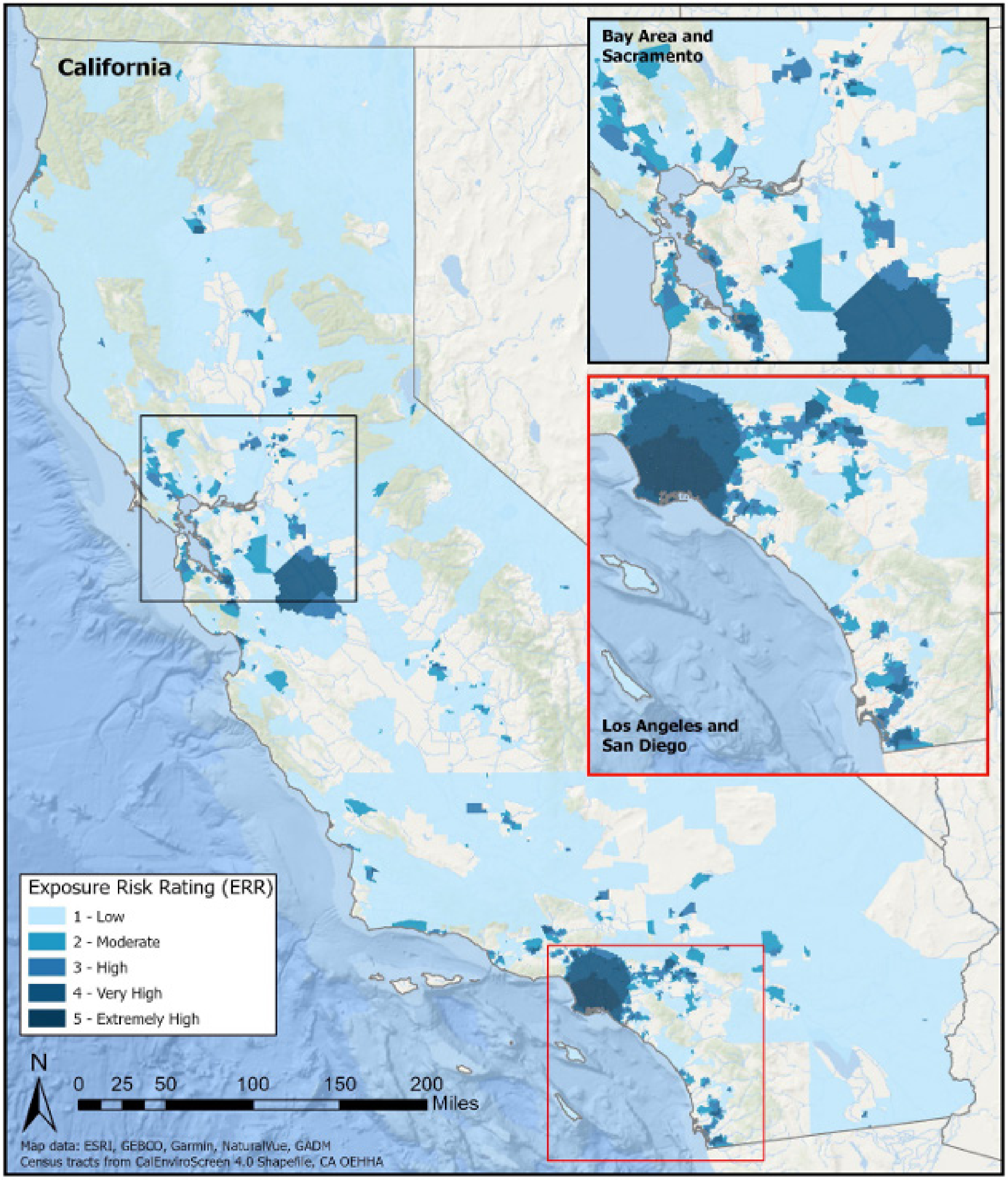


FIGURE 7

Census tract-level average exposure risk rating (ERR) from plastic-related waste sites



5.2. Statistical Analysis Results

We identified statistically significant linkages between census tract-level average impact and all but one of the indicators we analyzed (Table 8). "Statistically significant" means that the odds of the outcome occurring by random chance are very small — typically less than 5%. In most cases, the chance of our findings occurring randomly are much smaller, as indicated by the p-value.[29] When examining population composition by individual racial group, all groups showed a statistically significant relationship, with notably high positive coefficients for Hispanics and African Americans (meaning more people from these groups live in higher-impact areas) and negative coefficients for Whites and Other/Multiple Races (meaning fewer people from these groups live in higher-impact areas).

[29] Probability value of findings being due to random chance, as a percentage in decimal form. For example, a p-value of <0.01 would indicate a less than 1% chance of the observed relationship occurring randomly.

TABLE 8

Pearson's correlation test results for census tract-level average impact and select indicators. The correlation coefficient indicates the strength of the relationship (-1 to 1), sample size is the number of census tracts included in the analysis,[30] and p-value is the chance the observation occurred randomly (see footnote)

Indicator	Correlation Coefficient	Sample Size	p-Value*
Median Household Income	-0.188	7,973	<0.001
CalEnviroScreen Score	0.441	7,932	<0.001
Poverty	0.192	7,960	<0.001
Unemployment	0.021	7,700	0.070
Low Educational Attainment	0.297	7,932	<0.001
Non-White Population %	0.390	8,011	<0.001
Disaggregated Racial Group %		8,011	
• Hispanic	0.305		<0.001
• White	-0.390		<0.001
• African American	0.198		<0.001
• Native American	-0.034		0.002
• Other / Multiple Races	-0.203		<0.001
• Asian American or Pacific Islander	0.061		<0.001
Asthma	0.073	8,024	<0.001
Low Birth Weight	0.157	7,808	<0.001

*Indicates result is not statistically significant

Table 9 shows the simple linear regression results for all examined indicators, excluding unemployment given its lack of a statistically significant relationship. To reiterate, the "Regression Coefficient" indicates the predicted change in the corresponding indicator if the census tract's average waste site exposure rating increased by 1. P-values for these findings are identical to those for the corresponding correlation tests and are, therefore, not repeated.

[30] Some census tracts lack data for certain indicators in CalEnviroScreen and were, therefore, excluded.

TABLE 9

Simple (single-variable) linear regression results for census tract-level exposure risk rating (ERR) (independent variable) and select indicators (dependent variable)

Indicator (dependent variable)	Regression Coefficient for ERR
Median Household Income	-4,931.27
CalEnviroScreen Score	6.278
Poverty	3.032
Low Educational Attainment	3.742
Non-White Population %	8.733
Disaggregated Racial Group %	
• Hispanic	6.942
• White	-8.733
• African American	1.465
• Native American	-0.065
• Other / Multiple Races	-0.429
• Asian American or Pacific Islander	0.819
Asthma	1.934
Low Birth Weight	0.214

Table 10 provides a descriptive overview of the highest-impact tracts, showing the average values for each of the above indicators for 90th-percentile (average impact “3” or higher) and 75th-percentile (average impact “2” or higher) tracts. It also includes the percentage and number of highest-impacted tracts that are currently designated as disadvantaged by California law.

TABLE 10

Average indicator values and disadvantaged status breakdown for tracts with the highest levels of average waste site impact (90th and 75th percentile)

Indicator	90th Percentile ERR	75th Percentile ERR	Statewide Average
Designated Disadvantaged %	66.44 (584 of 879)	51.74 (1,084 of 2,095)	28.75 (2,310 of 8,034)
Median Household Income	$53,795	$58,042	$89,870 (2023, Statista)
CalEnviroScreen Score	44.29	38.34	28.32 (Tract-level average)
Poverty	39.08	35.63	31.34 (Tract-level average)
Low Educational Attainment	28.05	22.77	19 (OEHHA)
Non-White Population %	83.32	75.44	65 (2022, U.S. Census)
Asthma	62.97	52.02	51.98 (Tract-level average)
Low Birth Weight	5.71	5.32	5.00 (Tract-level average)

Lastly, we found a statistically significant ($p<0.001$) difference in average census tract-level waste site impacts between tracts designated as disadvantaged under California law versus non-disadvantaged ones (Table 11).

TABLE 11

Two-tailed t-test results examining average tract-level waste site impact among disadvantaged versus non-disadvantaged tracts

Status	Average Impact	Impact Standard Deviation	p-Value
Disadvantaged	1.531	1.373	<0.001
Non-disadvantaged	0.584	0.081	

6. KEY FINDINGS, RECOMMENDATIONS, AND FUTURE RESEARCH NEEDS

Our initial analysis provides compelling evidence that plastic supply chain impacts manifest disproportionately among certain Californian communities, and contamination from site-based exposures may pose a significant risk to susceptible populations and areas of recreational and environmental importance. We propose a number of recommendations to help inform the actions of CalRecycle, agencies administering PPMF moneys, and policymakers with respect to plastic impact mitigation investment and refining the state's approach to addressing the environmental justice elements of the plastic crisis, which our analysis illustrates.

6.1. KEY FINDINGS

Our spatial analysis of impacts from plastic-related disposal sites clearly shows that these site-based exposures are inequitably distributed throughout California. To a large degree, waste site impacts follow well-established patterns of environmental and socioeconomic disadvantage. However, a large portion of the communities with the highest levels of these impacts currently fall outside the state's legal definition of "disadvantaged" — a factor with ramifications for how administering agencies dispense mitigation funds.

Our statistical analysis (Table 9) shows that, on average, a community whose **average Exposure Risk Rating** was "1" higher than another (for example, the difference between having no plastic waste-related sites nearby and living near a transfer/processing station, or the difference between a community with one nearby landfill versus one with two) would have:

- Nearly **$5,000** less in annual median household income
- A CalEnviroScreen score more than **6 points higher**
- 3% more of the population living in poverty (less than two times the federal poverty line)
- Nearly **4% more** of people 25 or over without a high school education
- A population who is approximately **7% more Hispanic and 1.5% more African American** while being nearly **9% less White**[31]
- **1.9 more** annual emergency department visits for **asthma**, per 10,000 people
- **0.2%** more infants born low weight (under 2.5 kg)

These findings are mirrored by the examination of the highest-impacted tracts (Table 10). Compared to the state average, the typical community in the top 10% of plastic-related

[31] Other racial group composition would change less than 1%, on average.

disposal site impacts would have:

- Over **$36,000 less** in annual median household income
- A CalEnviroScreen score nearly **16 points higher**
- Almost **8% more** of the population living in poverty
- **9% more** of people 25 or over without a high school education
- A population who is **18% less White**
- **11 more** annual emergency department visits for **asthma**, per 10,000 people
- **0.7%** more infants born low weight

Communities defined by the state as disadvantaged have a significantly higher average waste site impact rating than non-disadvantaged communities (1.53 versus 0.58), but also show much greater variability (standard deviation of 1.37 versus 0.08). This suggests that disadvantaged status alone may not be the most reliable indicator of disposal site-based exposure. Moreover, a sizeable number of the highest-impact tracts are non-disadvantaged (Table 10, row 1). Nearly one-third of the top 10% of tracts and almost half of the top 25% fall into this category.

6.2. Recommendations and Future Research Needs

Given the multifaceted nature of plastic exposures facing Californian communities and our findings illustrating how plastic exposure risk is an environmental justice issue, we recommend a number of actions for the California legislature and personnel in CalRecycle and other state agencies tasked with administrating the Plastic Pollution Mitigation Fund (PPMF). These actions will improve the efficacy with which the PPMF makes investments to address plastic-related exposure risks, improve accountability and transparency around fund administration, and improve California's ability to inform future plastic policy action with current data and research.

- **Adopt the three-part plastic exposure framework**, based on data-driven indicators, for use by agencies administering the PPMF to inform and justify targeted investments
- Agencies should be able to **clearly articulate how investments target exposure risks**, identifying specific exposures facing a community and showing how mitigation efforts directly address these
- Use the **three-part plastic exposure framework** as the primary means of targeting PPMF investments outside the statutory minimums required for disadvantaged communities (DACs) to non-DACs with high levels of plastic-related exposure risk
- **Fund and develop new research and resources** to aid in better evaluation of exposure risks (see below)

One of California’s historic strengths has been in the creation of high-quality public datasets in areas such as pollution risk and public health. Access to these resources enables researchers to better study patterns of vulnerability among the state’s communities, and informs public action by state agencies. However, the complexity and relative novelty of the plastic crisis requires innovative new efforts to track plastic-related exposures and develop specific indicators for the plastic exposure framework. Among the most acute research needs are:

- Large-scale tracking of **microplastic pollution** and associated contaminants, especially via widespread sampling and testing of drinking water and natural bodies of water
- Studying and mapping **plastic-burdened populations** and proxy measures, such as living in food deserts, reliance on bottled water due to drinking water insecurity, and prevalence of plastic-wrapped, ultraprocessed foods in K-12 schools
- Improved database tracking of fossil fuel and other **plastic-related industrial operations**, especially industrial operations that create localized pollution risks, that is publicly accessible
- Expanding the scope of **site-based exposure mapping** to include the midstream and upstream components of the plastic supply chain and refining impact assessment methods
- Targeted study of **plastic-related occupational exposures** and their impacts on the health and safety of Californian workers, including examining disproportionate representation of members of low-income communities and communities of color in these jobs

APPENDIX 1. DATA PROCESSING AND CLASSIFICATION

Our methods for how CalRecycle datasets were consolidated, cleaned, and classified follows below:

1. CalRecycle Data Cleaning and Consolidation

By default, the Recycling and Disposal Reporting System (RDRS) dataset did not include latitude/longitude coordinates. We edited the address field to follow a format of "#### street name, city, state," then geocoded the entries in ArcGIS Pro. This process resulted in 1,457 matched locations, 24 similar locations, and 844 unmatched locations. Facilities located outside California, with incomplete or missing address data, and P.O. Box addresses were removed.

Within RDRS, we excluded entries where there was a weak linkage between registered address and localized environmental or public health impacts, where the operations were likely not related to the processing of plastic waste, or where there was a lack of clarity on the types of waste being processed by a facility class and we could not be confident that plastic waste made up a major component of their intake. Thus, we excluded facilities based on "Reporting Entity Activity" matching the types identified in Appendix 2.

Within the broad "Recycler/Composter" activity type in RDRS, we excluded facilities that, with reasonable confidence based on the information available, did not process plastic waste or did so only incidentally. We removed facilities based on keyword matching in the "Organization/Site: and "Reporting Entity Activity Name," using keywords identified in Appendix 2. The primary goal of this process was to remove facilities from our analysis that are engaged in composting operations or the recycling of nonplastic materials (e.g., wood, metals). This data processing step was taken after the RDRS and SWIS datasets were consolidated (see below); thus, Recycler/Composter facilities were only excluded based on keywords if they did not appear in Solid Waste Information System (SWIS). The resulting set of facilities were classified as "Plastic-Related Recyclers."

The SWIS dataset, being more detailed, provided data for the types of waste materials facilities processed in the "Waste Types" field. We restricted our analysis to sites processing at least one waste type that was primarily plastic or likely to include plastic waste. We retained facilities with at least one of the waste types noted in Appendix 2 and excluded all others.

We joined the resulting dataset of SWIS facilities processing plastic waste to SWIS site activity data using facility-specific SWIS numbers, such that plastic-related facilities were matched to public data figures for capacity, throughput, and acreage, when available. In cases where a single SWIS site conducted more than one plastic-related activity (e.g., transfer/processing AND solid waste disposal), we created two separate entries for said site, one for each activity type.

Since SWIS data already includes geographic coordinates, additional geocoding was unnecessary. A point layer was created from the existing coordinate data using ArcGIS' "XY Table to Point" tool.

We then consolidated the modified RDRS and SWIS datasets. When facilities appeared in both datasets — indicated by duplicate facilities with identical SWIS numbers — we eliminated the duplicate from RDRS, retaining the more detailed SWIS data. We repeated this process when a facility in the RDRS dataset had no SWIS number, but shared a similar or exact name and an exact address with a facility from the SWIS dataset.

For geospatial presentation, we further consolidated two categories of facilities from the RDRS/SWIS dataset. Facilities with SWIS Activity designations of “Solid Waste Disposal Site” and “Solid Waste Landfill” and those with RDRS Reporting Entity Activity (REA) designations of “Landfill” were grouped together under the designation “Solid Waste Disposal Sites and Landfills.” Facilities for which throughput data was available from SWIS and equaled or exceeded 1,000 tons/day were designated as “Large,” all others as “Small.”

Facilities with SWIS Activity designations including “Direct Transfer Facility,” “Large” or “Medium Volume Transfer/Processing Facility,” “Limited Volume Transfer Operation,” and “Small Volume Transfer Station,” and those with RDRS REA designation of “Transfer/Processor” were grouped under the designation “Transfer/Processing Facilities.” Because CalRecycle’s size-related

BEVERAGE RECYCLING CENTERS

In addition to the four facility types included in our spatial analysis, we considered a fifth: beverage recycling centers, which serve consumers directly as collection points for beverage bottles. Polyethylene terephthalate (PET) plastic bottles are the most common type of product processed at these facilities, and CalRecycle maintains a relatively high-quality dataset showing their locations throughout California. However, there is little research on the localized impacts of beverage recycling centers. There is evidence consumers generally prefer the convenience of curbside pickup to utilizing a beverage recycling center, suggesting that recycling center usage creates unnecessary traffic and commensurate air emissions (Beatty et al., 2007). Additional research has found that curbside collection points are preferable to beverage recycling center models with respect to both greenhouse gas (GHG) emissions and human toxicity potential (Simon et al., 2016), and the operational model of such facilities makes waste mismanagement and the creation of plastic litter inevitable. However, even in the case of such a clear-cut problem as litter, it is difficult to gauge to what degree those impacts propagate. The spread of plastic debris is affected by a multitude of factors, including shape, wind, slope, and surface use (Khoeriyah & Sembiring, 2023; Mellink et al., 2022).

Thus, because of the nebulous nature of how beverage recycling centers create localized impacts and the difficulty in assessing their severity, we did not include them in our spatial impact analysis.

terminology did not match any clearly delineated activity measures in SWIS (e.g., throughput, capacity), we elected to use the agency's designations to assign size categories. Any facilities labeled as "Large" in CalRecycle's classification were designated as "Large," with all others being classified as "Small."

APPENDIX 2. SUPPLEMENTAL WASTE SITE DATA CLASSIFICATION INFORMATION

Recycling and Disposal Reporting System (RDRS) "Reporting Entity Activity" exclusions:

- Broker/Transporter
- Contract Hauler
- Food Waste Self Hauler
- EMSW Conversion
- Other Disposal (Specify)
- Transformation

RDRS Recycler/Composters with no Solid Waste Information System (SWIS) entry "Organization/Site" and "Reporting Entity Activity Name" keyword exclusions:

- Agri
- Alloy
- Asphalt
- Bark
- Battery
- Bio
- Biological
- Biosolids
- Cattle
- Cement
- Cemex
- Compost (except as part of generic recycler/composter; entity-specific operational info sought to inform whether to exclude)
- Concrete
- Construction
- Crush
- Dairy
- Farm
- Fertilizer
- Fiber
- Gravel
- Grinding
- Gypsum
- Landscape
- Meat
- Metal
- Mushroom
- Nursery
- Nutrient
- Organic
- Pallet
- Paper
- Quarry
- Ranch (except as part of proper name)
- Rock (except as part of proper name)
- Sand
- Saw Dust/Sawdust
- Soil
- Steel
- Wood (except as part of proper name)
- Water
- WWTP

SWIS Waste Types included within “Plastic-Related” designation:

- Mixed Municipal
- Tires/Tires, Shreds/Passenger/Cut/Truck/Baled
- Mattresses
- Engineered Municipal Solid Waste
- Other designated

APPENDIX 3. TECHNICAL METHODS FOR CENSUS TRACT-LEVEL SPATIAL AND STATISTICAL ANALYSIS

A3.1 Spatial Impact Mapping Methods

To create a spatial visualization of waste site-based exposures using the above specifications, we created a rasterized (pixel) impact layer in ArcGIS Pro. Buffer zones were assigned to each facility type, matching the corresponding impact distance parameters, set to "overlapping" (as opposed to "dissolve"). New polygons were created for each area where impact zone buffers overlapped using the ArcGIS Pro Union Tool. A new field, "Impact," was assigned to each polygon with an initial placeholder value of "1."

In areas of overlapping impact from a single facility type (e.g., an area within the impact zone of two or more landfills), overlapping areas were manually classified to reflect the cumulative impacts of multiple sites. For sites with an impact rating greater than "1," the impact value was calculated by tallying the number of overlapping sites for a given polygon, then multiplying that value by the site type's impact rating.

We created the rasterized impact layer using the ArcGIS Pro Polygon to Raster Tool on the four site-specific layers. Raster values were calculated using the "Impact" field; thus, all polygons in the impact areas were classified as their impact value. The resulting raster was reclassified to include zero values for the remaining area of the entire state not within any impact zone. We then used the ArcGIS Pro Raster Calculator to find the sum of all six raster values (four facility types, plus small/large classifications for two types of sites). The final raster was clipped to the state boundary using the USA States Generalized Boundaries shapefile, filtered to California.

Resulting rasterized impact values were in the range of 0-25. For legibility, we symbolized the raster in five levels using a system called natural breaks. Referred to as "jenks," natural breaks groups data into clusters in a way that maximizes the similarity of data points within each cluster and the differences between clusters. For more information on natural breaks, see https://pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm. The data grouping produced the following value "bins:"

0. Only 0 values
1. 1-2
2. 2-5
3. 5-9
4. 9-14
5. 14-25

Thus, each pixel on the map was assigned a value from 0-5, 0 indicating no impact and 5 being extremely high impact.

To translate the impact visualization into census tract-level values that can be compared to CalEnviroScreen data, we used the ArcGIS Pro Zonal Statistics as Table tool to assign impact values to each census tract in the CES 4.0 shapefile. The tool uses two inputs — the boundaries (census tracts) from the CES shapefile[32] and the raster (the impact value sum from the raster calculator) — to output the average impact value of the pixels within each polygon. Essentially, the tool examines every pixel within the shape of each census tract on the map and calculates the average value, based on the weighting scale above. Each census tract, therefore, receives an impact rating between 0 and 5.

Outputs were matched to the correct census tract using the FID field. The output value was classified as a new field, "Zonal Stat Impact."

A3.2 Statistical Methods

To assess potential linkages between waste site exposure levels and existing measures of environmental and socioeconomic disadvantage, we conducted a series of Pearson's correlation tests alongside simple linear regression models. Respectively, these statistical tests essentially test how strong the relationship is between two values[33] and, if one of the values changes, how large the expected change in the other will be.[34] Importantly, these tests do not establish whether one thing does or does not cause the other, merely whether they tend to co-occur. We performed these tests for a select set of indicators where a relationship with waste site exposure was plausible (Table 7). We also described the highest-impact communities — census tracts in the 90th (top 10%) and 75th (top 25%) by average impact rating — by calculating average values for said select indicators within these populations and examined the difference between tracts defined by the state as disadvantaged versus non-disadvantaged using a two-tailed *t*-test.

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[32] CalEnviroScreen 4.0 uses 2010 census tract boundaries.

[33] Correlation tests result in a value from -1 to 1, where -1 indicates a perfectly related negative relationship (i.e., one value increasing means the other will always decrease), 0 indicates no relationship, and 1 indicates a perfectly related positive relationship (i.e., one value increasing means the other will always increase).

[34] This value is indicated by the coefficient on the X variable. For example, if the resulting regression takes the form Y = 3X, then an increase of 1 in X would be expected to produce an increase of 3 in Y.

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