Social Science & Medicine 297 (2022) 114834

Contents lists available at ScienceDirect

Social Science & Medicine

journal homepage: www.elsevier.com/locate/socscimed

Distributive justice in environmental health hazards from industrial contamination: A systematic review of national and near-national assessments of social inequalities

Di Fonzo Davide [a,b,*], Fabri Alessandra [a,c], Pasetto Roberto [a,c]

[a] Unit of Environmental and Social Epidemiology, Department of Environment and Health, Istituto Superiore di Sanità, Viale Regina Elena 299, 00161, Rome, Italy
[b] School of Hygiene and Preventive Medicine, Department of Medicine, University of Parma. Via Volturno 39, 43125, Parma, Italy
[c] WHO Collaborating Centre for Environmental Health in Contaminated Sites, Istituto Superiore di Sanità, Viale Regina Elena 299, 00161, Rome, Italy

ARTICLE INFO

Keywords:
Environmental justice
Environmental distributive justice
Environmental Health
Social Disadvantage
Social Determinants of Health
Health inequalities
Contaminated sites
Industrial pollution

ABSTRACT

Communities where polluting human activities are sited often show disadvantage in terms of social and economic variables. Environmental distributive justice studies seek to identify common characteristics in exposed populations and highlight the presence of environmental inequalities.

We have conducted a review of the existing literature about justice in the distribution of health hazards from industrial pollution. We included papers investigating associations between social disadvantage and contamination through assessments at national or macro-area level. From each study we extracted: indicators for the social determinants of exposed communities (classified according to PROGRESS-plus categories); definition and measurement of environmental hazard (as either proximity to contamination sources, exposure to emissions or health impacts from pollutants); study design and methods; significant results.

We retrieved 45 eligible articles. Most publications were from USA and had a nationwide scope with data at municipal/sub-municipal scale. Socioeconomic position and race/ethnicity were the social determinants most often explored, followed by occupation and education; air pollution was the commonest sort of contamination, while proximity prevailed as measurement of hazard. All papers found significant associations between social dimensions and health hazard from industrial contamination: the majority of associations supported an increased burden on vulnerable categories, especially ethnic minorities and unemployed – however, several relationships were found in the opposite direction or in both ways, particularly with wealth and education, reflecting a mixed reality where potential discrimination in siting decisions coexists with socioeconomic benefits for nearby communities due to industrial development. Assessments of environmental distributive justice are lacking in most countries and those that are conducted show vast methodological heterogeneity. We recommend consistency in models and indicators, the inclusion of female-led households among indicators of social disadvantage, and the adoption of a small scale to elicit significant findings and provide meaningful policy action.

1. Introduction

1.1. Rationale and objectives

The 2017 Conference of the ministries of the Environment and the Health sectors of the WHO European Region included “contaminated sites and waste management” in a list of seven priorities for policy action, with a focus on contrasting the harms from pollution on disadvantaged communities and groups (WHO Regional Office for Europe, 2019). Therefore, in order to pinpoint vulnerable communities bearing a disproportionate burden of contamination, countries and comparable administrative regions are expected to assess the distribution of environmental health hazards in their territories with respect to socioeconomic determinants. However, there are yet no reference procedures nor pre-existing guidelines about the research questions to be addressed and the methods to be adopted: this contributed to the great heterogeneity in both analyses and findings in the studies conducted thus far (Köckler et al., 2017).

The current review explores the existing literature about national/macro-area assessments of inequalities in the distribution of health

* Corresponding author. School of Hygiene and Preventive Medicine, Department of Medicine, University of Parma. Via Volturno 39, 43125, Parma, Italy.
E-mail address: davide.difonzo@studenti.unipr.it (D.F. Davide).

https://doi.org/10.1016/j.socscimed.2022.114834
Received 9 March 2021; Received in revised form 19 January 2022; Accepted 16 February 2022
Available online 18 February 2022
0277-9536/

hazards from polluting facilities, examining and comparing the choice of indicators and analytic methods as well as the overall results. The aim is to evaluate the state of the art, highlight strengths and weaknesses, and provide key recommendations for large-scope (i.e., at national or macro-area level) environmental distributive justice (EDJ) assessments, so that they may provide high-quality, consistent evidence appropriate for use in national policymaking. Although previous reviews have been conducted on the overall EDJ literature (Althor and Witt, 2020), and the evidence of combined effects of environmental and social pressures on health (WHO, 2010), to our knowledge this is the first critical review with a focus on EDJ large-scope assessments relative to contaminated sites.

1.2. Background

Environmental justice can be defined as the "fair treatment and meaningful involvement of all people regardless of race, skin color, national origin and income with respect to the development, implementation and enforcement of laws, regulations and environmental policies" (EPA, 2014). It is usually intended as a goal: one of its objectives is environmental distributive justice (EDJ), which is intended as a fair distribution of risks and benefits from polluting economic activities (Agyeman et al., 2003). Other components are also included, most notably procedural justice which pursues the democratic participation and fairness in the decision-making processes that affect said distribution (Walker, 2012).

The concept was introduced in the 1980s from civil right activism in the USA against the disproportionate location of sources of contamination in the proximity of deprived communities, especially those with a higher proportion of African Americans and Hispanics (Bullard and Johnson, 2000). Many cases around the world have been found and mapped (EJAtlas, 2021) of harmful structures, locally unwanted land uses and environmental hazards sited next to socially disadvantaged communities.

EDJ encompasses equality in risks (i.e., the distribution of hazards) as well as outcomes. Although industrial plants can often increase the prosperity of their surroundings, the communities most exposed to pollution from economic activities may inadequately benefit from the wealth which is generated (Brulle and Pellow, 2006): from a global perspective, this is particularly evident in many poor countries hosting extractive activities, which are burdened with the environmental externalities while most of the profits are allocated elsewhere (Faber, 2017; Agyeman et al., 2003). Marginalised individuals are also more vulnerable than the general population to health impacts from contamination because of concomitant pressures due to social disadvantage – e.g., poor health literacy, lack of healthcare access (WHO, 2010). Furthermore, the quality of life in communities residing near polluting industrial complexes is in fact undermined, and the potential exposure to contaminants helps create uncertainty, psychosocial anxiety and distress impairing health and well-being (López-Navarro et al., 2013).

A universal definition of EDJ does not exist, since what constitutes justice depends on the context and circumstances. Also, any claim of injustice implies a conceptual frame for which patterns of disparity emerging from evidence are identified as "discriminatory" and "unfair" rather than "overall acceptable" or even "inevitable" (Walker, 2012): the adoption of such a frame may vary across societies and among stakeholders, depending on the beliefs in different theories of justice (Liu, 2001) and their perception of the balance between health risks and economic benefits (Phillimore and Moffatt, 2004; Pellow, 2000). Nevertheless, the need to identify and address environmental inequalities has been recognised for many years by governmental and international bodies such as the US EPA, the European Environmental Agency and the WHO.

There is debate on the mechanisms behind inequalities in the distribution of environmental health hazards from industrial contamination (EHHIC). A company may decide to locate a polluting site in a marginalised community (*disparate siting*) because it would face weaker organised resistance, or even be welcome for the desirable prospective of economic development (Phillimore and Moffatt, 2004); low land price, presence of other complexes, cheap workforce and discriminatory regulations can also play a role (Liu, 2001; Mohai and Saha, 2015b; Banzhaf et al., 2019). On the other hand, a new undesirable activity may increase the deprivation in an area because of residential mobility (*post-siting demographic change*): while the wealthiest families can move away, the worse-off are forced to stay, and the flow and clustering of more disadvantaged people is facilitated – e.g., through cheaper housing (Liu, 2001; Mohai and Saha, 2015b; Banzhaf et al., 2019). Clearly, all these mechanisms coexist and intersect with one another, and their role varies in different contexts.

Post-siting change can also include positive socioeconomic effects of an industry (e.g., reduced unemployment). Some authors (Dinda, 2004; Stern, 2018) claim that the relationship between average income and environmental quality is better represented as an inverted-U-shaped curve called *environmental Kuznets curve*: according to this hypothesis, increasing per capita income (x axis) is initially associated with worsening pollution (y axis), indicating a positive correlation between industrial development and wealth; then, beyond a certain point, the trend is reversed for higher incomes, reflecting the lower risk of exposure in more affluent communities.

Overall, the distribution of EHHIC is determined by the complex interaction of many socioeconomic factors, with important differences both between and within countries. National and subnational EDJ assessments should aim to measure the common characteristics at country level (amenable with legislation) while also reporting peculiarities at local level which can be addressed by the appropriate jurisdictional authorities – e.g., townships (Pasetto et al., 2019).

2. Materials and methods

A search was performed for original studies investigating inequalities in exposure to toxic industrial hazards (defined as proximity to contamination sources, or exposure to emissions) and/or the related health risk, with a national or near-national extent.

The research strategy was adapted from a previous systematic review on environmental justice in industrially contaminated sites by Pasetto et al. (2019) focused on studies analysing distributive justice and procedural justice limited to the WHO European Region and without distinction between local and national assessments.

The search in literature electronic databases was built up considering the three dimensions of 'socioeconomic and sociodemographic characteristics', 'inequalities and inequities', and 'industrial contamination/pollution'.

The key words proposed by Dreger et al. (2019) for a set of systematic reviews, limited to studies carried out in the WHO European Region, on social inequalities in exposure to environmental hazards/benefits and the associated health risk, were considered for the two dimensions of 'socioeconomic and sociodemographic characteristics' and 'inequalities and inequities'.

For the dimension of 'industrial contamination/pollution', general terms referred to industrially contaminated sites, and specific terms related to the sources of contamination were considered. Three topics were chosen to select the terms related to specific sources of contamination: 1. main heavy industries producing chemical contamination (i.e., metallurgic, chemical, petrochemical, oil refining, steel, gas, and power plants—excluding nuclear plants); 2. mines and quarries; and 3. waste, incinerators, and landfills (i.e., waste industry). These sources were selected considering evidence from the last survey of the European Environment Agency on industrial pollution in Europe (European Environment Agency, 2019).

The three strings representing the three dimensions were combined into one query showed in Table 1, which was adapted for PubMed,

Table 1
Search query for PubMed.

#1 socioeconomic and sociodemographic characteristics	("sociological factors" [MeSH Terms] OR disadvantaged [All Fields] OR disadvantage [All Fields] OR deprived [All Fields] OR social [All Fields] OR socio*[All Fields] OR "vulnerable populations" [MeSH Terms] OR vulnerable [All Fields] OR vulnerability [ALL Fields] OR psychosocial [All Fields] OR psycho-social [All Fields] OR "socioeconomic factors" [MeSH Terms] OR socio-economic [ALL Fields] OR deprivation [All Fields] OR socio-demographic [All Fields])
#2 inequalities and inequities	(inequality [Title/Abstract] OR inequity [Title/Abstract] OR inequities [Title/Abstract] OR inequalities [Title/Abstract] OR unequal [Title/Abstract] OR "environmental justice" [Title/Abstract] OR "environmental injustice" [Title/Abstract])
#3 industrial contamination/ pollution	("industrial pollution prevention and control sites" [Title/Abstract] OR IPPC [Title/Abstract] OR "european pollutant emission register" [Title/Abstract] OR "contaminated land" [Title/Abstract] OR "contaminated site*" [Title/Abstract] OR "industrial site*" [Title/Abstract] OR "industrial pollution" [Title/Abstract] OR "industrial water pollution" [Title/Abstract] OR "industrial air pollution" [Title/Abstract] OR "industrial soil pollution" [Title/Abstract] OR superfund [Title/Abstract] OR "industrial facilities" [Title/Abstract] OR (("industry * " [Title/Abstract] OR site [Title/Abstract] OR "plant * " [Title/Abstract]) AND (steel [Title/Abstract] OR iron [Title/Abstract] OR "metallurgic * " [Title/Abstract] OR "chemical * " [Title/Abstract] OR "petroleum * " [Title/Abstract] OR "petrochemical * " [Title/Abstract] OR "oil refinery" [Title/Abstract] OR gas [Title/Abstract] OR "power plant" [Title/Abstract] OR mining [Title/Abstract] OR "quarr*" [Title/Abstract] OR waste [Title/Abstract] OR "incinerator*" [Title/Abstract] OR "landfill*" [Title/Abstract])))
	#1 AND #2 AND #3

Scopus and Web Of Science search engines. The results were limited to the 2010–2020 time period.

Since the U.S. Environmental Protection Agency (EPA) has an online repository dedicated to environment and health – i.e., the Health and Environmental Research Online (HERO) – analogous research was carried out on HERO (which however does not allow for complex search strategies), combining the keywords: *"industrial" (match all words)* and *"justice, injustice, equality, equalities, inequality, inequalities, disparity, disparities, equity" (match any word)*.

A further search for relevant articles was performed by consulting the bibliography of the articles identified through the search strategies and included for review.

The eligibility criteria, specified following the objectives of this review, were:

1. Articles in English
2. Observational and population studies (i.e., excluding reviews, commentaries and any other article not including original contributions)
3. Perspective under a lens of environmental distributive justice (i.e., fairness in the distribution of sources and outcomes of environmentally noxious activities)
4. Statistical analysis of the relationship between the burden from industrial pollution and the sociodemographic/socioeconomic characteristics of the exposed communities
5. Assessment with a national or near-national scope.

"Near-national" macro-areas were defined as regions that, by extension and population, are representative of the country they are in, so that their situations should reflect countrywide issues that require remediation through legislative action. No strict definition of these macro-areas was specified, rather deciding on a case-by-case basis by agreement between reviewers; as a rule of thumb, both small territories with a large, highly concentrated population (i.e., megacities), and vast but sparsely inhabited regions were excluded. Macro-areas examined in the studies include high-level administrative divisions (states, provinces), unofficial geographic regions, or ad hoc operative portions of a country's land.

All publications resulting from the database research were screened separately by two reviewers (DD and AF) according to relevance and eligibility criteria. Any disagreement was resolved by discussion and mediation with a third reviewer (RP). Additionally, the bibliography of every included paper was scanned and any relevant citation was screened for inclusion.

As a template for the research, the following PECO (Dekkers et al., 2019) was formulated and applied:

- *Population:* general population in a country or macro-area
- *Exposure:* social disadvantage (SD), defined as a value corresponding to vulnerability (e.g., low income, ethnic minority) in at least one indicator measuring a social determinant of health from the PROGRESS-Plus framework
- *Contrast:* absent or reduced SD within the same determinants
- *Outcome:* environmental health hazard from industrial contamination (EHHIC), defined as proximity to sources of contamination, or exposure to emissions, or health impacts of pollutants

The PROGRESS-Plus framework, an instrument to identify factors that stratify health outcomes and opportunities, was used to categorise determinants of social disadvantage (O'Neill et al., 2014). The acronym stands for: **P**lace of residence, **R**ace/ethnicity/culture/language, **O**ccupation, **G**ender/Sex, **R**eligion, **E**ducation, **S**ocioeconomic position, **S**ocial capital; the "plus" category refers to other personal characteristics or relationships potentially leading to discrimination.

Indicators of environmental health hazard were classified into proximity, exposure and health impact measures. **Proximity** indicators were defined as any measure relative to the mere presence of facilities and their toxic emissions in the area. They can be divided into spatial coincidence and distance-based methods (Chakraborty, 2017). Among the first, *unit-hazard coincidence* methods evaluate the presence or absence of a polluting facility in a community, or the number of facilities in a large area (Mohai and Saha, 2015b). Alternatively, spatial coincidence can be expressed as the *volume of emissions* – either total or restricted to some pollutants, either crude or weighted for the toxicity of each component – as declared by the firms in an area and registered in an inventory of toxic releases. *Distance-based analyses* rely on the geolocation of pollution sources: proximity can be represented as either buffers of circular or polygonal shape around facilities (discrete measurement) or the distance between the facilities and the centroid of the territorial unit (continuous measurement) (Jarup and Best, 2008). Next, **exposure** assessments were defined as deterministic or stochastic modelling of the emission distribution, or estimates of the average toxic dose per capita, or data from monitoring systems. Finally, **health impact** indicators were distinguished as metrics of relationships and interactions between measured health outcomes, environmental contamination and social disadvantage.

It is worth noticing that some studies measured the environmental hazard dimension as the exposure/contrast variable and the social disadvantage dimension as the outcome variable: these papers would be included nonetheless since the relationship between the two dimensions was still investigated.

All eligible articles were examined in full text by the above two reviewers, who performed the data extraction and synthesis following a predisposed form (Table 2). For each study the research questions were:

Table 2
Retrieved information from studies. SD = social disadvantage; EHHIC = environmental health hazard from industrial contamination.

Fields	Description
Reference	–
Country	–
Type of contamination	–
Scope	Nationwide or limited to a macro-area
Methods	Study design and statistical methods of analysis
Unit of analysis	–
SD measurement	Indicators of social disadvantage (PROGRESS-Plus)
EHHIC measurement	Indicators of proximity/exposure/health impact
Findings	Assessment of the relationship between environmental health hazard and social disadvantage
Evaluation of socioeconomic consequences	Assessment of beneficial and detrimental effects of facilities on social determinants

1. Choice and definitions of indicators for the social disadvantage (SD) dimension
2. Contamination sources, choice and definitions of indicators for the dimension of environmental health hazard from industrial contamination (EHHIC)
3. Study design, scope of the assessment, geographical unit of analysis, statistical methods
4. Findings of the assessment (significant statistical associations between SD and EHHIC)
5. Supported EDJ concept, whether as an equal distribution of environmental health hazards or as a fair balance of environmental hazards and socioeconomic effects

Due to the great heterogeneity of the selected papers concerning study discipline and study design, no standardised quality assessment tool across studies could be applied.

The review is compliant with the PRISMA standard (Moher et al., 2009) and its Equity expansion (Welch et al., 2012) where applicable. The COSMOS-E model (Dekkers et al., 2019) was also followed as guidance.

3. Results

The selection process is resumed in the PRISMA flowchart (Fig. 1). Database search was performed on November 28, 2020. Forty-one articles met the eligibility criteria on screening; 5 were excluded after reading the full text for not fitting into the established PECO inclusion scheme; 9 more publications were retrieved through citation scanning and searching on HERO website, for a final total of 45 articles. Detailed summaries for each article are available in the supplementary material.

Table 3 summarizes the basic characteristics of the papers concerning the research questions expressed in the previous section.

The great majority of assessments were made in high-income countries (as per the World Bank classification – World Bank, 2020): the United States of America alone were the subject of more than half of the studies (24); 10 assessments were conducted in European countries (UK: 3; France: 3; Czech Republic, Italy, Germany and Austria: 1 each), and 3 in Australia, South Korea and Canada. Of the remaining publications, 5 are about upper middle-income countries (People's Republic of China: 4; Peru: 1) and 3 about lower middle-income countries (India: 2; Ghana: 1).

3.1. Social determinants

Each of the domains specified in the PROGRESS-Plus framework was investigated in at least one study. A large predominance of measures for

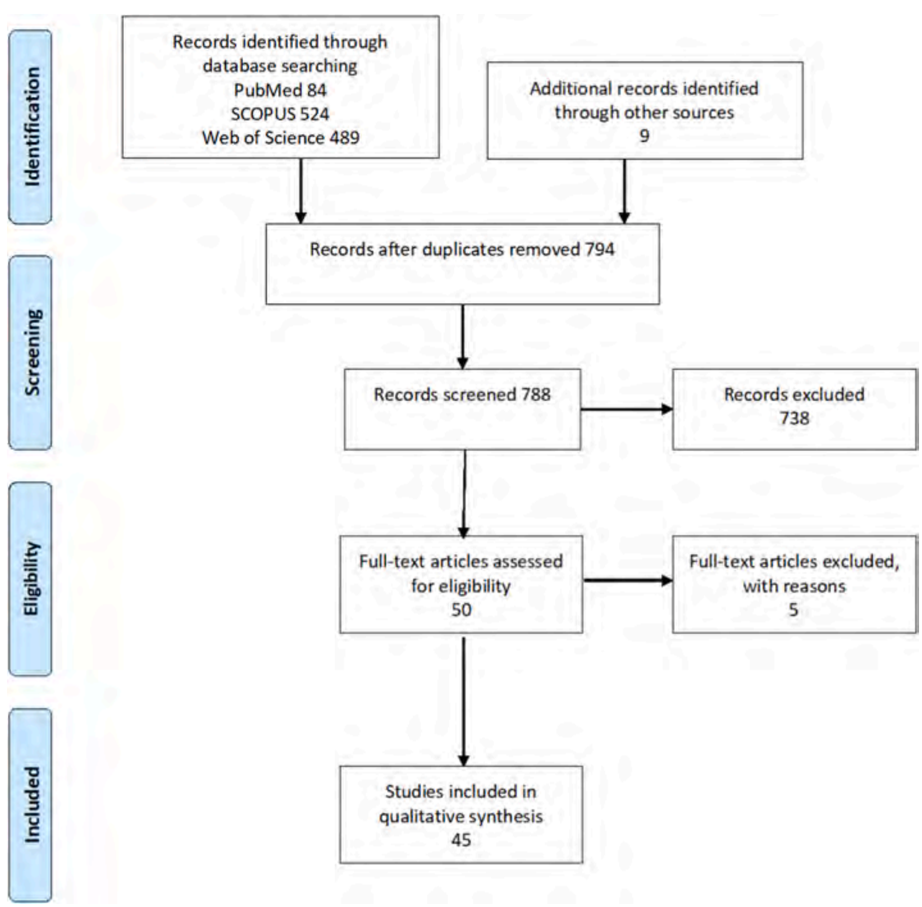

Fig. 1. PRISMA flowchart.

Table 3
Summary of results. EHHIC = environmental health hazard from industrial contamination.

Field	Study characteristics	N	%
Environmental health hazard	***Source of contamination***		
	Air pollution	27	60.0%
	Generic pollution	9	20.0%
	Soil and water pollution	4	8.9%
	Mining	2	4.4%
	Waste disposal	3	6.7%
	EHHIC measurement		
	Proximity	29	64.4%
	Exposure	18	40.0%
	Health impact	3	6.7%
Methods	***Study design***		
	Comparative	2	4.4%
	Ecological	26	57.8%
	Point source	5	11.1%
	Cross-sectional	5	11.1%
	Longitudinal	7	15.6%
	Scope of the assessment		
	National	29	64.4%
	Macro-area	16	35.6%
	Scale of territorial data availability		
	Regional	10	22.2%
	Municipal	9	20.0%
	Sub-municipal	26	57.8%
	Statistical analysis		
	Bivariate regression	6	13.3%
	Other uni/bivariate analysis	11	24.4%
	Multivariate regression	38	84.4%
	Other multivariate analysis	3	6.7%
Evaluation of socioeconomic consequences	*Total*	15	33.3%
	Kuznets curve	5	
	Post-siting demographic changes	4	
	TOTAL	**45**	

race/ethnicity, socioeconomic position, education and occupation can be seen (Fig. 2). Six papers relied on composite indexes of deprivation encompassing more than one determinant (e.g., Carstairs index in the UK, Massachusetts' definition of environmental justice community).

Interest in the **race/ethnicity** component of EDJ is particularly widespread in studies from the United States (22 out of 25 have taken at least one measure of racial composition or segregation, often as the main variable of interest). In Western European countries there is a substantial juxtaposition between ethnic minorities and immigrants – hence, in publications from these countries, the proportion of foreigners was considered as an indicator of ethnic minority prevalence, albeit with caveats; on the other hand, in the 4 papers from China and the one from the Czech Republic the proportion of **migrants** refers to citizens moving within areas of the same country, regardless of their ethnical affiliation which is reported in a different variable – therefore, this variable was included in the "Plus" domain (i.e., miscellaneous conditions potentially leading to discrimination).

Socioeconomic position (SEP) is measured with many different indicators, depending in part on the characteristics of the country's census: the most widespread indicator is average household income, followed by poverty rate; other proxies for wealth are based on individual assets (e.g., property value, car ownership, house crowding) or eligibility for welfare benefits. Several studies gather more than one indicator to capture SEP, sometimes combining them into composite indexes of deprivation. In publications from India, social status is codified as caste.

Educational attainment is investigated in more than half of the papers, all but one also exploring SEP. In high-income countries, education is mostly expressed as the proportion of residents with a tertiary degree or above, while in other countries it can also be measured in terms of years of school completed or with literacy rate. **Occupation** is mostly evaluated as the percentage of **unemployment**; three studies, which focused on the distribution of economic benefits from industries, instead analysed the workforce composition. Data about **gender** was reported either as a population's sex ratio or as the proportion of female-headed households – the latter being more relevant in terms of disadvantage. **Age** is frequently included in the data, but only in a few studies it is appraised as a potential determinant of disadvantage. Few papers collected data on the **place of residence**, specifically on characteristics of the area suggesting deprivation (green spaces, amenities, life quality).

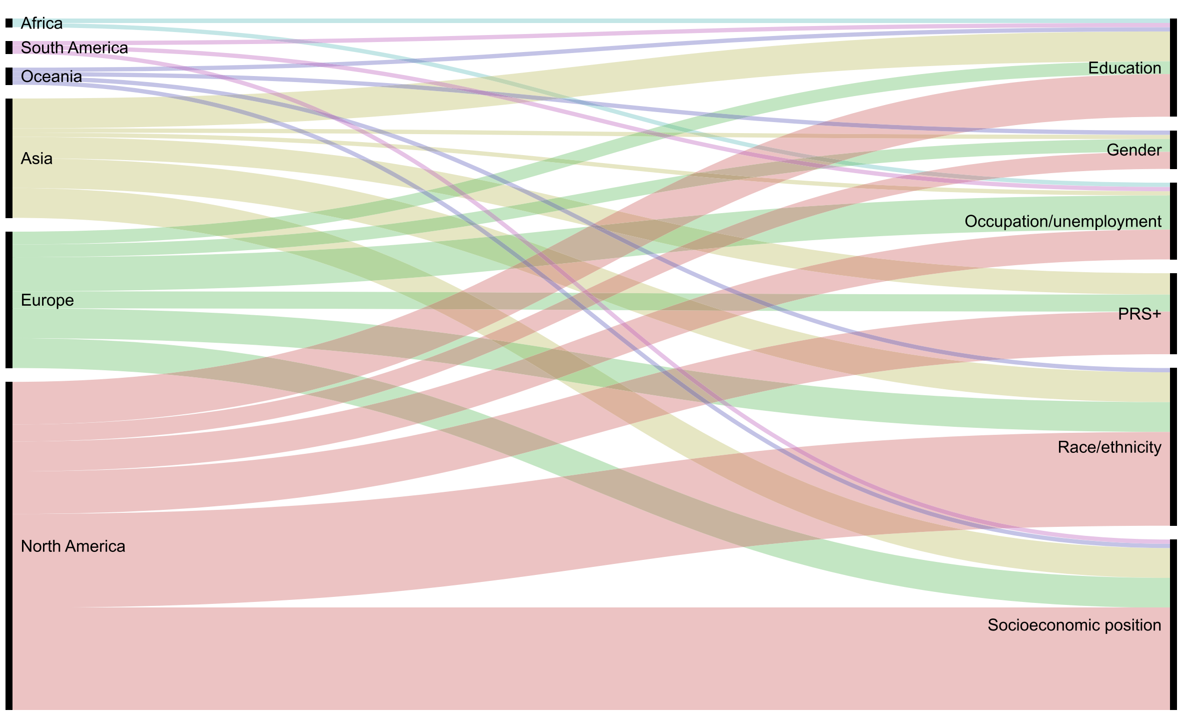

Fig. 2. Alluvial diagram showing the distribution of selected articles by continent and socioeconomic dimensions assessed by each article; chart created using RAWGraphs (Mauri et al., 2017).

Information about **social capital** and cohesion (including political engagement) was reported in 5 publications; furthermore, 6 addressed **family structures** (percentage of one-person households etc.) as another indicator of disadvantage. Finally, **religion** as a determinant of EDJ was investigated in one publication.

3.2. Environmental health hazard

With regards to the **sources of contamination** analysed, there is a net prevalence for *air pollution*: studies about aerial emissions make the bulk of the many papers from the USA (18 out of 24), and more than half of European publications (6 out of 10). *Soil and water pollution* was the subject of 4 studies, including 1 from Ghana and 3 from the USA. Pollution from *waste disposal* and *mining* (which affect both air quality and the soil/water matrix) was explored in 3 and 2 publications, respectively. Finally, 9 papers (including all of the 4 from China) delved on *generic industrial emissions* having toxic properties.

A variety of **indicators of environmental hazard** were found, with some articles utilizing more than one. *Proximity* measurements (as proxies of toxic exposure) were the most widely used. *Exposure* assessments were only found for industrial air pollution: one (Chaparro et al., 2018) was based on data from air quality monitoring, while 17 more used estimates from dispersion models (plume-based analysis) interpolated with social determinants data from census unit boundaries (e.g., Collins et al., 2016). The majority of US studies of this kind relied on EPA's Risk Screening Environmental Indicators (RSEI) which maps cumulative toxic exposure for the entire country in a grid of 1 km^2 square cells, accounting for the emission plume, the chemical decay of each pollutant, its toxicity, and even the average inhaled dose per capita adjusted by age and sex composition of the exposed communities (Chakraborty, 2017).

Health impacts were investigated in 3 publications, using different methods: one estimated the increase in aggregated mortality attributable to emissions (Mayfield et al., 2019), another was based on individual self-reported health status from a previous survey (Riva et al., 2011), and the last included individual data on biomarkers of effect from a pre-existing cross-sectional study (Chaparro et al., 2018).

3.3. Methods

In all papers the **study design** was observational. The vast majority were *ecological studies* – i.e., they searched for a correlation between aggregated data related to populations within a specified administrative or census division (census tracts, cities etc.). Five more are classified as *point source studies*, which have a similar design except that the boundaries for observed populations are mapped areas of pollution exposure (e.g., circular buffers around a facility, or air dispersion plotting) rather than administrative units (Jarup and Best, 2008). Two papers were based on aggregated data but did not explore a correlation between variables, rather looking for statistically significant differences between populations: hence, they were classified as *comparative studies*. The remaining publications relied at least in part on samples, including surveys providing individual data, rather than entirely on census values: 5 of these articles were classified as *cross-sectional studies* and 7 more were *longitudinal studies*.

In 29 out of 45 papers, the **scope** of the assessment was nationwide, while the remaining 16 evaluated a macro-area. Populations ranged from 5 million inhabitants in Scotland to 1.4 billion people in China.

The **scale** of the analyses varied considerably among publications. Twenty-six assessments delved in data at *sub-municipal* (neighbourhood) resolution, which included territorial units encompassing populations of hundreds to thousands – such as US block groups and census tracts or Scotland's CATTs, as well as point-source buffers. Two studies utilised schools as territorial references (Grineski and Collins, 2018; Batisse et al., 2018). Nine papers were based on *municipalities* or equivalent – that is, the lowest administrative division in a country. On the other hand, ten studies analysed data from jurisdictions at a higher administrative level: such *regions* often have a considerable extension and a population of up to millions. Some papers might include data at both small and large scale, either for controlling or for lack of more granular information on some variables.

The **statistical techniques** utilised varied considerably in type and complexity, with several studies employing two or more analyses. The lion's share goes to *generalised linear models*, especially multivariate regression allowing to control at least in part for possible confounders. Univariate and bivariate analyses (simple linear regression, *t*-test, z-test and others) were used as well, but only 7 studies relied entirely on them (e.g., Ash and Boyce, 2011; Koester and Davis, 2018).

3.4. Findings

All papers reported one or more statistically significant association between EHHIC and SD. In most studies, at least one relationship consistent with distributive injustice was traced. However, several associations in the opposite direction (i.e., more hazard associated with less deprivation) were also highlighted, often in the same studies for different measures of disadvantage or, less commonly, hazard, or as a result of the application of different statistical models (Fig. 3). Two papers found exclusively relationships between EHHIC and SD in the direction against inequality (Loayza and Rigolini, 2016; He et al., 2019); conversely, in 28 out of the remaining 43 studies, significant associations were exclusively towards support for environmental injustice.

The greatest consistency can be seen in relationships with **race/ethnicity**, which are overwhelmingly in support of unfairness against minorities. Such skewness appears to be mostly driven by US studies: 21 out of 22 papers measuring the racial component found support for higher EHHIC in non-white populations (especially African Americans and, to a lesser extent, Hispanics). In other countries, the evidence is more mixed: among the 4 studies conducted in China, EHHIC showed a positive association with ethnic minorities in one (He et al., 2017), a negative association in one (Schoolman and Ma, 2012), and no significant relationship in two (Ma, 2010; He et al., 2019); in the two studies from India, one (Kopas et al., 2020) found a non-monotonic association of exposure with minority tribes (i.e., townships with a higher proportion of minorities had a higher average exposure, however municipalities where minorities prevailed were excluded from industrial development, hence spared from pollution), whereas the other (Basu and Chakraborty, 2016) did not highlight a significant relationship; a significantly higher EHHIC could also be seen for native minorities in Australia (Chakraborty and Green, 2014) and the Czech Republic (Frantál and Nováková, 2014), and for immigrants in South Korea (Yoon et al., 2017) and Western European countries (Richardson et al., 2010; Riva et al., 2011; Laurian and Funderburg, 2014; Funderburg and Laurian, 2015; Schwarz et al., 2015; Rüttenauer, 2018) – with the exception of Italy (Germani et al., 2014), although with a very small percentage of foreigners.

Evidence for **occupation** is also largely supportive of the injustice hypothesis: 9 papers found an association between unemployment and EHHIC (De Silva et al., 2016; Dowling et al., 2015; Frantál and Nováková, 2014; Greenberg, 2017; Laurian and Funderburg, 2014; Miller et al., 2011; Schwarz et al., 2015; Glatter-Götz et al., 2019; Smiley, 2020a), and 4 more elicited an association with composite indexes of deprivation which included the occupational status (Chakraborty and Green, 2014; Richardson et al., 2010; Riva et al., 2011; Batisse et al., 2018); conversely, only one from Peru found an inverse association with the unemployment rate (Loayza and Rigolini, 2016), and one from France found none (Funderburg and Laurian, 2015). In a study from Britain (Chaparro et al., 2018) the proportion of unemployed residents was analysed as part of a composite indicator of deprivation (Carstairs index) which had a significant association in the direction of disparity with the measures of proximity and exposure, while the different health outcomes showed significant associations in both

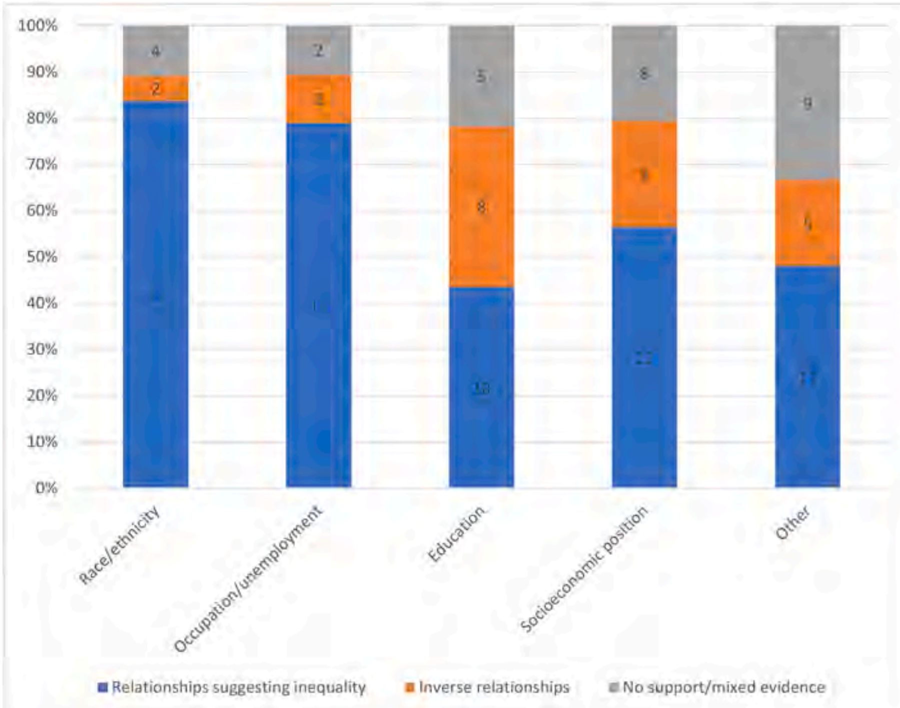

Fig. 3. Absolute number of single associations for each social determinant by type of relationship supported (i.e., whether the association between disadvantage and hazard is positive, negative or uncertain).

directions. Of the 3 studies exploring the occupational dimension in terms of job categories, one found a significant loss of manufacture jobs associated with higher exposure (Smiley, 2020a), another highlighted a disproportionate exposure for Afro-American and Hispanic communities compared to their share of jobs in the polluting industries (Ash and Boyce, 2018), and the last found no significant correlation with job sectors (Mohai and Saha, 2015a).

The relationships with **socioeconomic position** are more convoluted, in part because of different measures among studies and conflicting results both between and within analyses, which complicate an overall appraisal. Most papers reported a significantly greater EHHIC with lower SEP, regardless of the indicators adopted.

Inverse associations with poverty rate were observed in 2 papers (Cannon, 2020; Loayza and Rigolini, 2016), and 5 found a positive association with wealth – including 3 Chinese studies (He et al., 2017; Schoolman and Ma, 2012; Ma, 2010; Loayza and Rigolini, 2016; Ard, 2016). The already mentioned study from Britain reported conflicting associations with the Carstairs index that includes socioeconomic class (Chaparro et al., 2018).

Six more studies (4 from the USA, one from India and one from Italy) hypothesised that the function of EHHIC on wealth could be inverse-U-shaped (environmental Kuznets curve), rather than linear: the hypothesis was confirmed in 5 of them (Ash et al., 2013; De Silva et al., 2016; Zwickl et al., 2014; Kopas et al., 2020; Germani et al., 2014) but not in Ard (2016). Furthermore, one assessment (Grant et al., 2010) highlighted significant associations of low-income communities with both high exposure and low exposure to chemical facilities, while another (Cannon, 2020) showed how the odds of a landfill being located in a county was associated in the expected direction with lower average income, but in the opposite direction with poverty rate.

Lack of a significant or definite relationship emerges in other papers from England (Riva et al., 2011), Germany (Rüttenauer, 2018), South Korea (Yoon et al., 2017), China (He et al., 2019) and the USA (Grineski and Collins, 2018; Smiley, 2019, 2020a, 2020b).

Findings on **education** are even more uncertain. In most cases, when a significant association with EHHIC is seen, it is consistent with the one observed for SEP: towards unfairness in 8 articles (Ard, 2015; Chakraborty and Green, 2014; Frantál and Nováková, 2014; Miller et al., 2011; Glatter-Götz et al., 2019; Batisse et al., 2018; Crowder and Downey, 2010; Pais et al., 2014); against inequality in 3 (He et al., 2017; Schoolman and Ma, 2012; Loayza and Rigolini, 2016). In papers showing a Kuznets curve, education had an association in the expected direction in one (De Silva et al., 2016) and the opposite direction in 2 (Kopas et al., 2020; Germani et al., 2014) – although just marginally significant in the latter.

Gender was not associated with EHHIC when taken as sex ratio of the populace; however, all 3 studies measuring the proportion of *female-headed households* found a significant (Downey et al., 2017; Germani et al., 2014), even strong (Cannon, 2020), relationship towards injustice. No other significant evidence was found for an effect of **family structure** and marital status. As for **age**, the hazard was positively associated with the proportion of elders in one paper from the USA (Miller et al., 2011), of younger people (compared to middle-aged) in another (Huang et al., 2017), and of children in the Italian one (Germani et al., 2014). **Internal migrant status** was associated with greater EHHIC in the study from the Czech Republic (Frantál and Novakova, 2014) and in 2 Chinese studies (Ma, 2010; Schoolman and Ma, 2012), while the remaining 2 showed an inverse relationship (He et al., 2017, 2019). Smiley found significant associations in the USA with a specific **religion** (Protestant Evangelicals) combined with a conservative political leaning (Smiley, 2019), and with **social capital** expressed as the number of "connected" organizations (Smiley, 2020b), while Yoon et al. demonstrated weaker political engagement (another measure of social capital) in exposed jurisdictions in South Korea (Yoon et al., 2017).

3.5. Evaluation of socioeconomic outcomes

Fifteen studies analysed the effects of industry location on social determinants (e.g., gains in wealth and employment), implying a framing of EDJ which includes fairness in said effects for the communities involved (Walker, 2012).

As already mentioned, 6 articles included quadratic and cubic components for the income variable in their regression models (with EHHIC as the dependent variable), to elicit a *Kuznets curve* as the best fitting shape of the association between EHHIC and wealth. Other publications (e.g., Funderburg and Laurian, 2015; Loayza and Rigolini, 2016) analysed the relationship between the environmental and social dimensions in the opposite direction and modelled *social determinants as outcomes* of proximity or exposure to industrial pollution. Several authors (e.g., Smiley, 2020a; Mayfield et al., 2019) assessed *temporal trends* within socioeconomic determinants in hosting communities. Particularly, 4 longitudinal studies evaluated variations in population composition after residents' mobility, under the assumption that disparities may be a consequence, rather than a cause, of industry location – the so-called "*post-siting demographic change*" hypothesis (see below).

4. Discussion and conclusions

4.1. Critical analysis

Most included studies support the notion that, when looking at national or near-national data, communities with increased social deprivation tend to be affected by higher EHHIC. However, the findings are greatly heterogenous – sometimes even within the same paper (e.g., Chaparro et al., 2018). This variability can be attributed to multiple factors (Köckler et al., 2017).

Significant differences between neighbouring communities can be missed, or underestimated, if the territorial unit of analysis is so large that it includes exposed and unexposed areas: a change in scale can even lead to different statistical results, an issue known as the modifiable areal unit problem (Elliott and Wartenberg, 2004). On the other hand, units that are too small, or buffers of arbitrary radius, may not accurately reflect the area of noxious impact from polluting facilities (Liu, 2001). In the papers presented here, most associations based on data at municipal and sub-municipal scale were in support of inequality, while non-significant and inverse relationships prevailed in studies with lower resolution: this seems to confirm that a higher resolution is required to detect inequalities that may otherwise be overlooked (Chakraborty, 2017).

The choice of environmental hazard measure might also affect the results. Most non-significant and inverse relationships are seen in studies based on unit-hazard coincidence, while they are scarce in assessments based on source distance, emission volume and per capita exposure (although the last are once again skewed by the many publications relying on EPA's RSEI, thus mostly reflecting the context in USA). This suggests that distance, emissions and exposure have better sensitivity in capturing inequalities (Chakraborty et al., 2011; Mitchell, 2019). The study by Mohai and Saha clearly shows how unit-hazard coincidence underestimates the associations between SD variables and EHHIC when directly compared with distance-based analysis (Mohai and Saha, 2015a). Furthermore, there is a clear relationship between the choice of spatial unit and the availability of better environmental measures: of the 35 assessments at sub-municipal and municipal scale, only 6 relied on unit-hazard coincidence methods, versus 16 which utilised per capita exposure estimates; conversely, analyses at regional resolution based on unit-hazard coincidence were 6 out of 10.

It is not clear how the chances of finding a significant association are related to the statistical method employed: even if the great majority of studies are based on generalised linear models, there are hardly two papers using the same combination of variables and model type, which complicates any tentative of comparing different works. Some of the included articles utilised spatial statistics (e.g., spatial regression, spatial lag model), a set of models conceived to account for autocorrelation and other spatial effects (Mennis and Heckert, 2017): spatial autocorrelation is the tendency of observed values to be similar to observations from nearby locations, thus violating the assumption of independence (Chakraborty et al., 2011). Interestingly, in most of the analyses adopting spatial statistics a low socioeconomic position is not significantly correlated to more pollution – either in USA (Smiley, 2019, 2020b), South Korea (Yoon et al., 2017), Germany (Rüttenauer, 2018), or China, where contamination is actually associated with higher income (Schoolman and Ma, 2012). The last paper is also the only one providing a comparison with ordinary least squares regression: the coefficient estimates between the two methods are substantially similar.

Mutual relationships between social determinants can also influence statistical findings. Multicollinearity – an important cause of bias on the effect estimates– is expected to be substantial among socioeconomic variables (Liu, 2001): 13 articles included checks for multicollinearity, either through the correlation matrix or by indicators such as variance inflation factor or condition index. However, although isolated significant correlations between two variables are reported in a few papers (e.g., Kopas et al., 2020), measures of multicollinearity were generally non-significant. Thus, the correlations between social determinants do not seem to affect the estimates of association between SD and EHHIC, perhaps due to the aggregated nature of the data. On the other hand, social factors may have synergistic effects on determining environmental inequalities. Grant et al. used fuzzy set qualitative comparative analysis to find combinations of social determinants having the strongest correlation with contamination (Grant et al., 2010): the study found that low income was associated with lower exposure in predominantly white areas but higher exposure in neighbourhoods with a greater Black proportion. Three more studies utilised cross terms in regression equations to explore the combined effect of race/ethnicity with socioeconomic position (Zwickl et al., 2014; Crowder and Downey, 2010) or social capital (Smiley, 2020b) on EHHIC: the interactions were significant in all 3. Therefore, in the USA race appears to differentiate the relationship between SD and contamination; however, this may not hold true in countries where racial segregation is negligible. Nevertheless, this finding indicates more generally that an analysis of interactions between social determinants can potentially uncover inequalities towards communities characterised by disadvantage in multiple dimensions (e.g., high unemployment and low education).

Results do not seem to be affected by the type of facility examined. Specific sectors do not exhibit peculiarities in the SD-EHHIC relationship, with the possible exception of coal mines, analysed in two studies: the presence of coalfields was not significantly associated with deprivation variables, except unemployment, in an English paper (Riva et al., 2011), and was beneficial for host municipalities in another from Peru (Loayza and Rigolini, 2016).

Assessments of health outcomes were scarce, even though the hazards from toxic pollution are health hazards by definition: this causes a gap in knowledge about the actual health disparities due to social inequalities and pollution, which translates into a lack of evidence for policymaking and intervention (Pasetto et al., 2019). Even amongst the three studies which included data on health impacts, only one (Chaparro et al., 2018) provided a formal analysis of the relationship between social disadvantage, objective health biomarkers and the mediating effects of pollution – although the results were quite conflicting; the other two merely conducted a statistical assessment of the association between pollution and alleged health consequences stratified by social determinants (Riva et al., 2011; Mayfield et al., 2019). A fourth paper from Czech Republic (Frantál and Nováková, 2014) included several aggregated health indicators (e.g., infant mortality, admissions for respiratory disease), however, it only measured Pearson's bivariate correlations with industrial contamination without addressing the interactions with social determinants (which were only analysed in their correlations with pollution).

More examples of possible approaches to the appraisal of the three-way association between social disadvantage, environmental contamination and health outcomes can be found in other papers, not eligible for inclusion in this review. A study on the population of Basque autonomous community (Spain) explored the interaction between proximity to air polluting industries and socio-economic deprivation (measured with a composed index) on the rates of mortality from all causes and specific causes (Cambra et al., 2013). This assessment, conducted at a sub-municipal scale, is an example of using health statistics, along with exposure variables and census data, to retrieve an estimate of the intersections between social, environmental and health disparities at a granular level.

A very different publication (Jephcote and Mah, 2019) analysed the distribution of benzene-emitting industries in the EU related to regional affluence and standardised mortality rates (from all causes and neoplasms). Standardised rates are useful measurements in ecological studies to effectively compare health outcomes between communities since they remove any difference attributable to gender and age composition.

4.2. Interpretation of results

Large differences in the results emerge from the comparison among countries.

Publications from the USA are numerous enough (albeit heterogeneous) and show sufficient consistency between various scales of data (even individual level) and different statistical models, to assert that there is convincing evidence of race and class disparities in exposure to industrial hazards (especially air pollution) in said country.

In other high-income nations, ethnic minority prevalence is also the most consistent predictor of EHHIC; however, in publications from Western Europe and South Korea the ethnic component was limited to the proportion of foreign citizens (i.e., migrants), thus excluding second-generation citizens and indigenous cultures (e.g., Roma communities) and potentially leading to an underestimate of minorities having less political weight in siting decisions (Laurent, 2011). The association with class in Western European countries is far less consistent between papers (Köckler et al., 2017); however, the unemployment rate – itself a proxy for a low socioeconomic position – is a solid predictor of EHHIC, which confirms the association with economically deprived zones in Europe (WHO, 2010; WHO Regional Office for Europe, 2019).

The highest proportion of inverse and non-significant associations can be seen in studies from upper- and lower-middle-income countries, regardless of the spatial resolution. Proximity to polluting facilities is quite consistently correlated with better figures in wealth, occupation and education, especially in Peru (Loayza and Rigolini, 2016), likely reflecting the economic benefits of recent industrial development. Indeed, Indian studies show that areas where low caste and discriminated tribes are prevalent have a lower burden of contamination, perhaps because marginalised zones are actively excluded from industrial development – however, where industries are present, their toxic burden is unequally distributed on disadvantaged communities (Kopas et al., 2020).

In Chinese publications, there are different results between regions on some indicators, but associations with wealth and education are consistently against the hypothesis of EDJ. A prominent phenomenon in China is the massive internal migration from rural areas to industrialised districts: all four studies recognise migrant status as a social disadvantage and explore its relationship with EHHIC, albeit with contrasting results. A significant association with ethnic minorities at the national level (He et al., 2017) was not reproduced in assessments on three macro-areas.

Regrettably, very few papers from Africa and Latin America (one each) and none from Western Pacific and Eastern Mediterranean could be found. Despite the abundance of local conflicts reported in these regions (EJAtlas, 2021), EDJ research in developing countries is lacking (Althor and Witt, 2020). The only work from an African country (Ghana) had to rely on limited census data, with an occupation indicator of uncertain value, and a large scale unit of analysis (district) on top of that (Dowling et al., 2015). Researchers conducting national assessments in these countries would likely meet similar difficulties for want of available, granular, complete data.

The contrasting results in the association with wealth outside of USA, including the detection of environmental Kuznets curves, are likely attributable to the economic effects of industrial activities. In many underdeveloped communities, the siting of a large industrial complex can initially lead to an increase in employment and income which can then bring socioeconomic improvements in other dimensions – e.g., higher education, better services and community emancipation. However, it can also force a mono-functional development that sacrifices other economic sectors (e.g., tourism, agriculture) because of pollution: the term "monotown" is often used, especially in Russia, for such communities which are highly dependent on a single facility (Shastitko and Fakhitova, 2015). In these cases, communities are vulnerable to rapid economic decline caused by job dismissals and plant closures, with scant chances for recovery due to lack of alternative opportunities (Pasetto and Iavarone, 2020). Furthermore, the toxic legacy of some plants is bound to persist for generations after their closure, likely outliving any economic benefit they may have brought (Johnston and Cushing, 2020). These phenomena are observed in some of the included studies. When analysing the association with coal impoundments in Appalachia (USA), Greenberg found an increase in poverty rate in communities where the mining activity had stopped or was in decline but its contamination legacy (coal slurry) was still present (Greenberg, 2018). Smiley showed how a decline in the population of manufacture workers is associated with higher air pollution (Smiley, 2020a). A possible explanation is given by the "treadmill of production" theory (Brulle and Pellow, 2006): as capitals accumulate from previous gains, firms can invest in automation to replace workers, thereby causing a contraction in employment without a reduction in polluting output. Furthermore, Ash and Boyce demonstrated how for some marginalised categories (in this case, Afro-American and Hispanic people in USA) the rate of job attainment in a polluting industry is disproportionally lower than their exposure as residents – i.e., a facility could take most of its workforce from different neighbourhoods than the one hosting it (Ash and Boyce, 2018).

The role of residential mobility on observed SD after the location of a contamination source (post-siting demographic change), as opposed to deliberate siting in marginalised communities, is controversial. In the USA, a higher risk for racial minorities of moving towards polluted neighbourhoods was shown in three studies (Pais et al., 2014; Crowder and Downey, 2010; Downey et al., 2017). A fourth study also found similar neighbourhood changes: however, the authors highlighted how the same trends of mobility were already occurring before the sitings (Mohai and Saha, 2015a). As of note, residential history itself is a determinant of health (Namin et al., 2021).

The rationale for the choice of sociodemographic variables is not always explicit (Althor and Witt, 2020) and can only be assumed. Data availability definitely played a role, especially in less developed nations (Dowling et al., 2015). The high prevalence of race and ethnicity measures in research from the USA can be attributed to the tradition of research and grassroot activism on environmental racism in that country (Brulle and Pellow, 2006; Bullard and Johnson, 2000). Some authors do however provide reasons for their selection of socioeconomic indicators. For example, the use of internal migration as a social determinant in studies from China is explained by detailing the characteristics of Chinese society (specifically, the *Hukou* system) which put rural migrants at disadvantage (Ma, 2010).

The proportion of female-headed households as a determinant of environmental disparity was not sufficiently explored in the included studies. However, its relevance was documented previously (Downey and Hawkins, 2008); such phenomenon is part of a more general relationship between gender and environmental injustice (Gaard, 2017). The fact that all three papers which included the prevalence of female-headed households in their analyses reported a significant relationship despite two of them having a regional scale (thus with lower sensitivity), and the fact that one (Germani et al., 2014) was conducted in Europe (therefore showing that the association is not a USA peculiarity), suggest that this indicator could have a strong predictive value within EDJ assessments.

4.3. Limitations

The present work has some important technical limitations. First, restricting the research to studies in English may have excluded some valid works written in other languages. Second, although the search string that was adopted is quite complex and wide, it could still lack some important terms, thereby potentially missing relevant studies. Third, a search for grey literature sources was not performed due to the complexity of the search query, even though it may have provided some relevant reports.

Other limitations are relative to the content of the included articles.

All assessments considered in the review are based on aggregate data: associations existing at group level may be different at the individual level – a distortion known as ecological fallacy (Thomas, 2009). However, such approximation is still adequate for the exploratory scope of these analyses.

Another, more severe, limitation is that these publications only focus on the overall, average results and do not single out the communities having worrisome values. While this stance is valid from a research standpoint, from a political perspective the purpose of such assessments should be to individuate areas with the greatest risk for health, in synergy with environmental and epidemiological monitoring in affected communities (WHO Regional Office for Europe, 2019). Therefore, studies of this kind are ineffective in this regard.

Although race/ethnicity is the strongest predictor of disparity in EHHIC, the inclusion of the ethnic dimension in a counterfactual inferential framework can be troublesome and lead to errors in inference, especially when it is correlated with other determinants of disadvantage (Kaufman and Cooper, 1999; Benmarhnia et al., 2021).

Arguably, the heterogeneity of the findings does not allow for conclusions about the relationships between SD and EHHIC which hold true across all nations, let alone about the strength of such relationships. Besides, quantitative assessments have a fundamental limitation in that they provide a statistical picture of disparities in a country or macro-area but they can hardly capture the social mechanisms behind such disparities (Kaufman and Cooper, 1999): hence, they cannot assert what are the causes of injustice or even if there is "injustice" at all (Mitchell, 2019), although it can be argued that a consistent, significant inequality towards one or more disadvantaged groups is unjust regardless of what causes it (Banzhaf et al., 2019). Also, the numeric correlation between deprivation and facility siting does not explain if, and how, deprivation is a cause or a consequence of siting decisions (Mohai and Saha, 2015b). Thus, quantitative assessments on the unfair distribution of EHHIC (i.e., environmental distributive injustice) should be coupled with qualitative analyses of the social and institutional processes behind such disparities – which could indicate the existence of procedural injustice (Walker, 2012) – in order to fully understand the mechanisms of inequity in a country and act consequently (Liu, 2001).

5. Conclusions

Only a few countries have conducted national or macro-area assessments on EDJ; no nation except the USA has produced a substantial amount of evidence. Publications are especially scarce in developing countries where environmental pressures are rising because of new industrialisation: in these settings, the lack of definitive answers about the actual economic effects on exposed populations may favour the siting of facilities next to communities "in need", with disregard of the health risks.

Most findings in the existing literature support the hypothesis of social inequality in the distribution of pollution sources, especially towards ethnic minorities and economically vulnerable communities. Nonetheless, the association of industrial toxic hazards with social determinants is complex and multifaceted. Dramatic differences in results can be seen not only between territories, but also in separate studies on the same populations: this is likely due to the great heterogeneity in data sources, choice of variables, scale of analysis and statistical models. Results that were comparable within the same population would provide more meaningful evidence for science and policy action. At the same time, a consistent set of methods and indicators shared across scholars and nations could provide a starting base for countries where this kind of research is lacking.

In light of what emerged from this review, the following are key recommendations for high-quality large-scope assessments of environmental distributive justice:

- Indicators of racial/ethnic composition (accounting for the characteristics of each country), socioeconomic position, employment status, and educational attainment should always be included and should be reproducible at national level. Composite indexes may include several measures of social determinants (especially wealth), thus capturing complexity and synergies better than the single variables.
- While rarely measured, the proportion of female-lead households appears to be strongly correlated with contamination and should be included among the determinants of social disadvantage.
- Measures of environmental health hazards should also be consistent and reproducible. Unit-hazard coincidence methods should not be utilised when more sensitive measures are available.
- The scale of analysis should be municipal/sub-municipal, since significant findings are more likely to be missed with larger territorial units. Even with sub-municipal or point-source units, the results should (also) be reported with respect to townships or analogous jurisdictions having authority for localised planning and intervention.
- Statistical models should be consistent, exportable, and structured in a way to highlight interactions between social determinants while controlling for known biases (e.g., collinearity, spatial autocorrelation).
- Health impacts and disparities attributable to the combined impact of environmental and socioeconomic pressures should be evaluated.
- The areas found to be most severely affected should be highlighted and subjected to targeted studies and long-term epidemiologic monitoring.
- Longitudinal assessments, both retrospective and prospective, are needed for comparison between *pre* and *post* scenarios, in order to better understand the sociodemographic effects of facilities on hosting communities through time.
- Quantitative findings should be integrated with qualitative research on procedural justice in contaminated sites.

We declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2022.114834.

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