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Environmental inequality in industrial brownfields: Evidence from French municipalities*

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Abstract

Recent research on environmental inequality has extended its focus from ongoing pollution to legacy pollution by examining the geography of industrial brownfields, defined as non-productive, contaminated land. This article is the first extensive brownfield analysis for a European country from an environmental inequality perspective, exploiting the political momentum in France where brownfield restoration has become a national priority. In doing so, we combine data on over 7,200 industrial brownfields from the 2022 geodatabase 'Cartofriches' with socio-economic variables at the municipality level. We demonstrate communities with higher percentages of foreign-born and unemployed persons are disproportionately more likely to be located near brownfields. The social gradient increases significantly in communities that host many brownfields, the so-called hotspots. There is an inverted U-shaped relationship with income, with a positive correlation until the 75th percentile (€23,700 annually). These findings are robust to different controls, including across urban and rural areas, though with regional differences. Further, we also account for the location of noxious industrial facilities sourced from the E-PRTR database to show the existence of cumulative impacts of environmental risks. Our analysis provides crucial entry points for restorative environmental justice considerations and has important implications for Europe's just transition and cohesion policies.

Keywords: Environmental inequality | Industrial brownfields | Racial and socio-economic disparities | Cumulated impacts
JEL codes: J15 | R11 | Q53 | Q57

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1 Introduction

Evidence from the US (Eckerd and Keeler, 2012; Dorsey, 2009) shows that proximity to brownfields is an important dimension of environmental inequality, yet the geography of industrial brownfields[1] has remained understudied in the European context. Among European countries, France has recently published the first national georeferenced brownfield inventory, data that enable us to carry out the first nationwide environmental inequality analysis of brownfields in Europe.

In this paper, we examine the spatial distribution of industrial brownfields in France, noting clustering dynamics that lead to the creation of so-called 'hotspots'. The geography of legacy pollution is closely linked to historic pathways of changes in production and specialization, often associated with resource depletion, peripheralization, and economic divestment (MacKinnon et al., 2022; Leyshon, 2021).

We map brownfield locations with socio-economic characteristics to provide an account of the social landscape of the country's brownfields. Specifically, we seek to answer the following questions: are the foreign-born and the unemployed disproportionally impacted by living in the vicinity of a brownfield? What is the relationship between brownfields and household income? Are urban areas or larger brownfields more prone to distributional inequalities? Do we find cumulative pollution effects when active industrial facilities are added to the analysis? Our results show substantial social inequalities that could, and in our view should, be taken into account in the formulation of brownfield remediation policies. More broadly, our findings suggest that environmental inequalities should be considered in policy responses to increasing calls for environmental restoration in the nexus of regional planning and the ecological transition.

[1] The understanding of what counts as a brownfield can vary across contexts. In this paper, for the sake of internal coherence, we adopt the definition used by the French Ministry: a brownfield is "any property or right to property, whether built or not, that is unused and whose condition, configuration or total or partial occupation does not allow it to be reused without prior development or work" (see Article L111-26 of the Climate and Resilience Act).

To analyze the socio-demographic characteristics of people living in municipalities that host brownfields, we merge geolocalized brownfield data for metropolitan France from the 2022 Cartofriches inventory (CEREMA, 2022) with socio-demographic data at municipality level from the National Institute of Statistics and Economic Studies (INSEE), covering more than 7,200 brownfields in 31,000 municipalities. We use linear probability regressions to distinguish between municipalities with and without brownfields, municipalities with few or many brownfields, and hotspots. We augment the analysis with spatial data on industrial facilities that still operate, and hence pollute, to account for cumulative disadvantages where industrial brownfields and active facilities coexist.

The analysis provides an important yet missing piece of evidence on environmental inequality in the context of regional planning, a topic of major policy relevance in Europe (Wolch et al., 2014), where brownfield reconversion is increasingly seen as imperative for sustainable urban development and in line with the Just Transition Fund as part of the European Green Deal (Widuto and Jourde, 2021). Brownfield restoration has gained momentum in most industrialized countries (Haninger et al., 2017): it can help to restore the physical, social and economic fabric of neighbourhoods previously impaired and left behind, limit the destruction of natural and agricultural areas, revitalise urban centres, boost land values, and promote local economic spin-offs with positive impacts on health and ecosystems. In addition, restoration agreements often include job guarantees for local residents, investments in social housing, provisions for urban green space, and pilot projects for a circular economy and green urban living (Gouvernement Francais, 2021). Brownfields are often a result of technological innovation and international competition leading to structural economic change, leaving behind industrial contamination and socio-economic decline. Hence, the landscape of brownfields must be understood as a multidimensional phenomenon encompassing social, ecological, and economic aspects (Mazzucato, 2020).

Through industrial policies such as the 2018 initiative *territories of industry*, the 2019 objective of *zero net artificialisation* of soils, and the recently launched *brownfield fund*

(2022), France has created momentum to enhance post-industrial landscape redevelopment. In this way, previously untapped potential for urban regeneration and ecological restoration can be exploited (see Klaus and Kiehl, 2021; Dorsey, 2009). Siting and investment decisions about clean-ups could have a social dimension, however, possibly tending to disadvantage racialized or economically deprived and thus voiceless communities (see "squeaky wheel issue" as in Bullard, 2018; Eckerd and Keeler, 2012). Brownfield restoration and re-use have been discussed in Europe for many years, but the large majority of brownfields are still not remediated. Moreover, most European countries lack georeferenced nationwide brownfield inventories and there is no European community database (firstly noted by Thornton et al., 2007, with no significant changes since then). France's pioneering attempt to tackle both issues provides the basis for this study. In 2020, it made brownfield restoration a key national policy: the *Plan national de relance et de résilience* (PNRR) contains a 'fond friches', a brownfield fund to provide financial incentives for restoration. So far, a total of 1,382 projects have been financed[2] - compared to the 7,200 sites that are on record, this brings up the question of how restorative funds are allocated across potential recipients. The Cartofriches database forms the backbone of the brownfield fund. The project's documents together with the PNRR highlight decontamination, job creation, biodiversity, climate change mitigation and community participation, but do not mention social equity or justice issues. This paper is intended to draw attention to the possible injustices in brownfield distribution and hence also restoration, and provide entry points in the understanding of how to redress past wrongdoings that have resulted in social and racial inequalities.

2 Literature review

In this section, we review recent practices and findings in the environmental inequality literature with a focus on legacy pollution in general, and industrial brownfields in particular.

[2]Please refer to Appendix A from page 34 onwards for more technical details on the French brownfield fund, which also contains a timeline of the different editions with allocated funds and number of projects.

The literature on environmental inequality is largely US-based, mirroring the historical-geographic trajectory of the environmental justice[3] movement, which arose in the 1980s in response to racial stratification of unwanted local land uses (see McGurty, 2009). Inequalities in exposure to industrial pollution and proximity to locally unwanted land uses have been extensively documented (see for instance Ash and Fetter (2004); Bullard et al. (2008); Collins et al. (2016)). This literature shows that siting decisions often follow the path of least resistance (Schelly and Stretesky, 2009), with unwanted sites located near disempowered, racialized and poor communities. Studies of which came first, the pollution or the people, have tried to pinpoint potential causal mechanisms behind observed correlations by using longitudinal analysis to assess the roles of disparate siting decisions by firms and governments and post-siting sorting decisions by households. Most results point to disproportionate siting of facilities near concentrations of poor and people of color as a key driver behind environmental injustices (Mohai and Saha (2015); see also Laurian and Funderburg (2014) on France).

Environmental disparities in Europe have also begun to receive attention (see, for example, Rüttenauer (2018) for Germany, Viel et al. (2011) for the Franche-Comté region in France, Walker et al. (2005) for England, and Bez and Virgillito (forthcoming) for 15 European countries). These contributions find evidence that hazardous facilities are disproportionately located and clustered together in deprived areas and near to poor or racialized populations. A recent survey by Pasetto et al. (2019) reviewes 14 studies on environmental justice and industrial pollution for the European Union. Of these, only two case studies addressed remediation; both focused on procedural justice and concluded that ethnic minorities and/or disadvantaged communities living near contaminated areas often are voiceless and powerless and hence tend to be excluded from the decision-making

[3]Environmental justice is a socio-political category historically including territorial struggles and political movements against the disproportional effects of pollution against communities of colour, but also more recently embracing parts of the regulatory framework undertaken by the Environmental Protection Agency in the US (Kuehn, 2000; Villa, 2020).

process on remediation and future land use.

Data availability for legacy pollution in contaminated sites has been a major obstacle to research, as harmonized registries for brownfields are rare. To date, England and France are the only regions in Europe that provide publicly accessible inventories with geolocalized data. Exploiting England's land use database with approximately 20,000 registered brownfield sites, Longo and Campbell (2017) find "that sites with a history of industrial activities, large sites, and sites that are located in the poorest and bleakest areas [...] of England are more difficult to redevelop" (p.1). The authors hence call for place-sensitive policy tools to increase social cohesion and to correct for the discrimination that socially disadvantaged and economically unattractive geographical locations experience. Recently the focus shifted to brownfields in the context of restoration (Kramar et al., 2018; Haninger et al., 2017). However, the European restoration literature is still very underdeveloped. More attention has been given to the US, especially within the context of Superfund[4] restoration. Hird (1993), who was among the first to analyze the equity implications of the Superfund program, concluded that it was "both inequitable and inefficient", finding for instance that beneficiaries are more likely to live in counties with higher income and education levels (see also Stretesky and Hogan (1998); Eckerd and Keeler (2012); Kramar et al. (2018)). Using official data from the EPA, Burda and Harding (2014) found that sites located in black, urban and lower-educated neighborhoods experience discrimination, proxied through the duration of the cleanup. Brownfields remediation is hence found to have underlying unequal prioritization both in site choice and the pace of cleanup. Other contributions have looked at the local economic benefits attributed to brownfield remediation, finding evidence for increased residential property tax revenue (Sullivan, 2017) and highly localized positive effects on property values (Haninger et al., 2017).

[4]The Superfund is an environmental remediation program within the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) established in 1980 which gives the Environmental Protection Agency (EPA) the economic agency to clean up the nation's most polluted sites (United States Environmental Protection Agency, United States Environmental Protection Agency).

Here we address environmental inequality within the framework of "left-behind" places, an established concept in the regional economics literature (see Wuthnow, 2018; MacKinnon et al., 2022; Rodríguez-Pose, 2018). This lens allows us to explore the uneven development as a political phenomenon with socio-economic underpinnings Long-term polluted regions witness gradual changes not only to human health and the physical environment, but also broader socio-economic decay that in many places has created a landscape of territorial and environmental crisis (Walker et al., 2005). In cases of noxious deindustrialization (a concept developed by Feltrin et al., 2021) employment losses, contamination and toxicity continue to coexist and reconversion is not taken up. Such left-behind places may turn into "sacrifice zones" (see Lerner, 2012) that bear disproportionate costs of unsustainable development strategies. Shrinking cities and hinterlands with post-Fordist and post-mining experiences have in common the experience of economic stagnation or decline, depressed wages, demographic loss, and abandonment (Rodríguez-Pose, 2018). Brownfield analyses can help broaden and deepen the understanding of left-behind places.

3 Data and methodology

3.1 Data

We build a novel dataset containing information on brownfield location, sourced from the Cartofriches inventory (CEREMA, 2022, CEREMA, 2022), with socio-economic data for approximately 31,000 French municipalities, sourced from the National Statistics Bureau of France (INSEE). The data is merged geospatially, i.e., by associating every brownfield polygon to a municipality shapefile.[5]

[5] We perform data validation confirming that polygons uniquely identify municipalities, i.e., do not cross municipality boundaries. This confirms the choice of our unit of analysis as it rules out the issue of fuzzy attribution.

3.1.1 Brownfield Data: Cartofriches

The Cartofriches database was created at the direction of the French Ministry of the Environment and Ecological Transition. The register was launched in 2021 and by July 2022 counts approximately 7,200 industrial brownfields. More specifically, Cartofriches recovers and aggregates various already existing databases, mainly BASIAS, the database of former industrial sites and service activities, and BASOL, a database on potentially polluted sites and soils requiring action by the public authorities, which have been integrated by other various sources and geo-interpretation of satellite photos, supplemented by field visits. The use of satellite images for the collection of spatial environmental data for environmental justice research forms a new promising research method (Weigand et al., 2019). We locate every brownfield in a municipality and then count the number of brownfields at municipality level, the latter being our unit of analysis.

3.1.2 Socio-demographic Data: INSEE

Our main explanatory variables are municipality characteristics in terms of socio-economic status, including migration. All indicators are sourced from INSEE at the municipality level for the last available year (2018). These characteristics are operationalized as the percentage of the foreign-born population (% migrants)[6], the percentage of the unemployed population (% unemployed), and the median income, including its square. The unemployment and income variables capture the social tissue of people left behind by structural change and deindustrialization. We control for industry employment as a proxy for industrial activity, locations of markets, and existing industrial facilities. For our analysis that looks at municipalities by demographic change and urbanity, we procure information on population in the years 2008[7], 2013, 2018, as well as the INSEE density indicator. For

[6]We specify migrants as a status outgroup, translating from the US context of racialization to a European context. US analyses mostly investigate racial and ethnic inequalities by using data on Whites, Blacks, and Hispanics (for instance, Stretesky and Hogan, 1998; Downey et al., 2008; Ash and Fetter, 2004).

[7]We need this variable for the robustness check, as explained in Section 3.2.

various robustness checks, we include population density (people/km^2) and its square for each municipality to control for urban concentration, educational attainment (population out-of-schooling without any diploma, with a high school degree, with two years of higher education), the percentage of foreign-born, and the percentage of old (55-64 years) or male unemployed, again sourced from INSEE at the municipality level. The violin plots (Figure 7) in Appendix B provide descriptives of the socio-demographic variables used in our main analysis.

3.2 Estimation approach

Brownfield location is modeled as a function of the socio-economic characteristics of a municipality according to the following equation:

$$\begin{aligned} BF_i = \beta_0 + \beta_1 Migrants_i + \beta_2 Unemployed_i + \beta_3 Income_i + \beta_4 Income_i^2 \\ + \beta_5 Industry\ Employment + \delta_i + \epsilon_i, \end{aligned} \tag{1}$$

where i represents municipalities. The predicted value BF_i is a probability, modelled as a function of the share of migrants (in %), the share of unemployed (in %), median income and its square (in €1,000). We control for the share of industrial employment (in %). In some specifications we include other covariates X_i potentially associated with the presence of a brownfield. We account for fixed department-specific characteristics by employing department-fixed effects throughout our analysis (n=93, corresponds to NUTS-3 level) which focuses the analysis on the determinants of where, within each department, brownfields are located.

The dependent variable in our analysis is the presence of brownfields by municipality, where we first distinguish between whether a municipality hosts brownfields or not. Among those that host a brownfield, we further distinguish between those that host few and those that host many brownfields, to account for clustering dynamics in so-called ‘hotspots’. We first compare municipalities without brownfields to municipalities with any brownfields (A to B), and then compare municipalities with few brownfields to those with many (B_1 to B_2, where 'few' is defined as one or two brownfields, and 'many' for three and more brownfields). The unit of observation is the municipality with n≈31,000. Much discussion has been dedicated to the role of geographic scale in evaluating environmental justice. Our empirical design addresses the issue of data aggregation.[8] We hence have dichotomous brownfield location outcomes, which we estimate with two linear probability models (LPM). LPM provides ease of interpretation with coefficients read as percentage points of probability associated with unit increases in covariates. As a robustness check and in order to overcome some issues with LPM such as nonlinearity and probabilities below 0 or above 1[9], we also run two binomial logit models, which can be consulted in the Appendix C.2 on page 50. The binomial logit regressions produce results comparable to LPM.

Our results are robust across a variety of specifications, for instance when including population density and population weights, or excluding income (Table 8 on page 47), or when distinguishing by brownfield size (Table 9 on page 49) as carried out as sensitivity analyses. We perform a variety of additional robustness checks (not shown). First, we use alternative socio-economic measures. In particular, on by one, we substitute 1) the share of migrants with the share of foreigners (the latter is a subset of the former, limiting the

[8]The unit of spatial analysis is appropriate for the following reasons. First, our analysis is based on data on the finest level of administrative division in France, namely the municipality level which divides France into over 30 thousand units of analysis. The general consensus on the choice of the appropriate unit of analysis is that neighborhood-wide analyses are more appropriate than larger aggregations, hence in line with our framework. Second, information on brownfield location comes from a geolocalized data set, enabling data set validations prior to aggregating this data at the municipality level. This rules out the existence of brownfields spanning across municipality boundaries, making it difficult to uniquely attribute brownfields to single municipalities. Third, and importantly, our unit of analysis coincides with the level of political decision-making on the local level in general (each is governed by a municipal council and is autonomous in the implementation of national policy) and concerning initiatives to restore brownfields, in particular. Fourth, and contrary to many contributions to the literature, we are not mainly focusing on the health effects of exposure to industrial pollution and contamination from a public health point of view, but conceptualize industrial brownfields as broader signs for the political economy of the environment and (de)industrialization (compare, for instance Ash and Fetter, 2004; Rüttenauer, 2018). Hence, we do not have to calculate potential human health risks to the population in a radius surrounding the source of environmental burden, which often complicates the appropriate choice of socio-economic data.

[9]We deal with heteroskedasticity by using robust standard errors in the LPM.

analysis to those without French citizenship), 2) the share of unemployed with the share of old (55-64 years) or male unemployed and 3) median income with the share of the population up until high school or some college education (two years of higher education). Second, while the dynamics of shrinking and growing municipalities used in the analysis are evaluated in terms of population change over five years, we perform a robustness check using ten years.

4 Results

4.1 Descriptive statistics

Table 1 below presents the descriptive statistics for dependent and independent variables. The count of brownfields by municipality is depicted in Figure 3 in the Appendix. We construct our dichotomous dependent variables based on this count. As shown in the table, approximately 13 per cent of all municipalities host at least one brownfield. One-eighth of municipalities host a brownfield (4,079 out of 31,377), and of these one quarter have more than two brownfields, labelled as 'many'. On average, municipalities have a migrant share of 4.26 per cent (SD=4.35) and an unemployment rate of 10.39 per cent (SD=4.33). The median household income is €21,700 yearly (SD=€3,670). Lastly, an average municipality is 1,563 hectares big with a population of 2,302. Note that variation is high for all of the independent variables.

Dependent variables		Mean	Standard deviation
Number of brownfields:			
Per cent of municipalities with any brownfield	(n=31,377 municipalities)	0,13	0,34
Of municipalities with any brownfields, per cent with more than two	(n=4,079 municipalities)	0,23	0,42

Independent variables	Mean	Standard deviation
Percentage migrants	4,26	4,35
Percentage unemployed	10,39	4,33
Median income (in 1.000)	21,70	3,67
Median income^2 (in 1.000)	484,41	182,56
Percentage industry employment	11,28	15,17
Municipality area (in Ha)	1562,73	1527,56
Municipality population	2302	9871

Table 1: Descriptive statistics

Figure 1 displays the distribution of industrial brownfields in metropolitan France, sourced from the brownfield inventory Cartofriches as of June 2022. As the map shows, brownfields are widely dispersed across French departments. The approximately seven thousand brownfield sites are spread over more than four thousand municipalities, indicating that many municipalities host multiple sites (hotspots).

Figure 1: Map of industrial brownfields in metropolitan France. The grey boundaries depict departments (n=96). Source: Own elaboration based on Cartofriches, June 2022.

Such clusters are visible in particular in the East (region Grand Est), the Southwest (region Nouvelle-Aquitaine) and around cities such as Amiens (department Somme in the North) and Lyon (department Rhône in the central East). Moreover, we see that the affected regions are capturing both the deindustrialized and depopulated types of geography (p.ex., Grand Est) as well as urban conglomerations (p.ex., Ile-de-France). Table 2 below gives a nuanced account of how the number of brownfields varies across regions and municipalities within regions.[10]

[10]Also refer to Figure 4 in Appendix B for a bar diagram showing the number of brownfields by region.

Region (n=12)	Number of municipalities	Number of brownfields	Municipalities with brownfields (%)	Hotspot municipalities among those (%)
Grand Est	4219	792	14	26
Nouvelle-Aquitaine	4034	471	10	20
Auvergne-Rhône-Alpes	3686	571	13	14
Occitanie	3541	433	10	11
Hauts-de-France	3519	375	9	16
Bourgogne-Franche-Comté	3068	228	6	9
Normandie	2504	152	5	13
Centre-Val de Loire	1686	225	12	9
Île-de-France	1251	191	13	15
Pays de la Loire	1222	276	19	12
Bretagne	1201	181	14	7
Provence-Alpes-Côte d'Azur	783	184	20	13
National	30714	4079	12	14

Table 2: Summary statistics of brownfields by region (n=12), ranked by the number of municipalities within each region. Source: Own elaboration based on Cartofriches, June 2022.

The two regions Grand Est and Nouvelle-Aquitaine emerge as clear outliers, together hosting more than three thousand brownfields. We also note that the relative presence of hotspots in the two regions is more than two times higher than the average. For instance, in Grand Est, 26% of all municipalities hosting brownfields are hotspots, i.e., where brownfields are clustered within a municipality. Those two outliers are followed by Auvergne-Rhône-Alpes in southeast-central France (825 brownfields) and by Hauts-de-

France in the North (597 brownfields).

Figure 2 depicts the percentage of migrants and unemployed in municipalities that contain zero, few, or many brownfields. The histogram illustrates how our two main variables of interest vary across values of the dependent variable. Indeed, both percentage shares proportionally increase with the presence (left panel) and number (right panel) of brownfields.

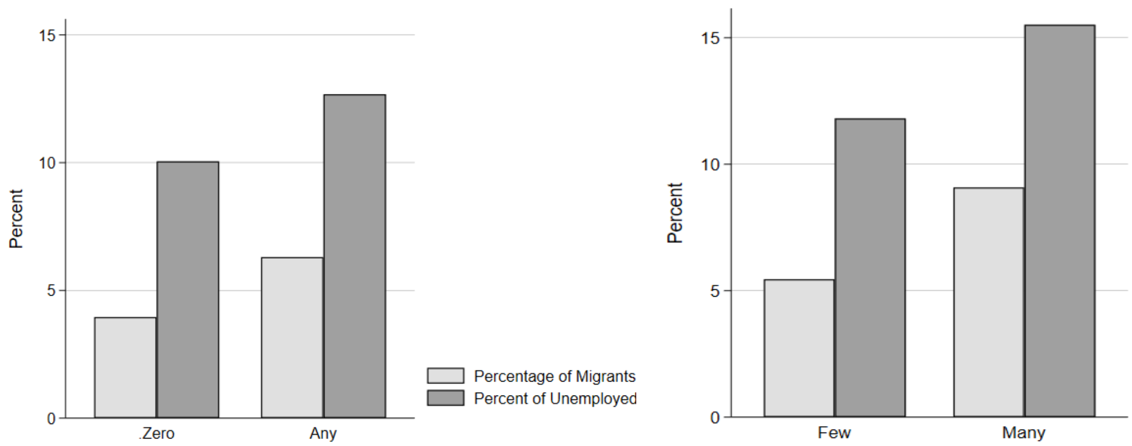

Figure 2: Average percentage of migrants and unemployed by the presence of brownfields in the municipality. The left panel compares municipalities with zero and any brownfields, the right panel compares municipalities with few (1-2) and many (>3) brownfields among municipalities with at least one brownfield.

Complementary to this, Figure 8 in Appendix B shows the kernel densities of the percentage of migrants and unemployed by the number of brownfields. In addition, Figures 9 and 10 show the same densities but separately for the four regions in which most brownfields are located. This enables us to highlight some regional disparities, into which we will look more specifically at the end of Section 4.2.

4.2 Estimation results

Our main results investigate the socio-economic, including racial, correlates of brownfield location in French municipalities. Results of the LPM regression analysis without and with NUTS-3 fixed effects are shown in Table 3. The inclusion of fixed effects, as shown in columns 3 and 4, shows very similar (slightly stronger) coefficients compared to the specification without fixed effects. In the following analyses, we will always include NUTS-3 fixed effects. We find that the shares of migrants and unemployed are statistically and materially important determinants of brownfield location, both when comparing host municipalities to non-host municipalities, and when comparing across host municipalities (few or many).[11]

Sign and statistical significance of effects are crucial, but we also try to put emphasis on the substantive and practical significance of the effects, in order to gauge the magnitude of environmental inequality we encounter. For instance, for the specification including fixed effects, an increase of the share of migrants (unemployed) by 10 per cent on average is expected to increase the probability of hosting a brownfield by 0.126 (0.150) per cent, holding everything else constant (see column 3). We also note that the effect increases when looking at brownfield hotspots, indicating that equity considerations increase in importance where brownfields are clustered. The coefficient for % unemployed for instance nearly doubles, compare 0.0150*** to 0.0246*** (see columns 3 and 4). In Table 8 in Appendix C, we show that our qualitative results are unchanged when excluding income, including population density and its square, and when including population weights. The implications of the latter, i.e., efficiency-based versus equity-based concerns, are also discussed in Appendix C.

[11] The correlation we observe could be the result of causality in one or both directions. Which causal pathways are dominant is not a central question for our purposes.

	Results for all brownfields			
	No FE		NUTS-3 FE	
	(1)	(2)	(3)	(4)
Dep. Var:	NO/ANY	FEW/MANY	NO/ANY	FEW/MANY
% Migrant	0.00884***	0.00948***	0.00983***	0.0137***
	(0.000564)	(0.00137)	(0.000659)	(0.00187)
% Unemployed	0.0101***	0.0169***	0.0120***	0.0185***
	(0.000511)	(0.00170)	(0.000542)	(0.00196)
Median Income	0.0128***	0.0468***	0.0176***	0.0459***
	(0.00314)	(0.0107)	(0.00351)	(0.0114)
Median Income^2	-0.000268***	-0.000958***	-0.000344***	-0.000906***
	(0.00006)	(0.000203)	(0.00007)	(0.000212)
% Industry Empl	0.00169***	0.000451	0.00150***	-0.00008
	(0.000117)	(0.000393)	(0.000115)	(0.000389)
Department FE (n=93)	NO	NO	YES	YES
Population Weights	NO	NO	NO	NO
Obs.	30,714	3,416	30,714	3,416
R2	0.046	0.082	0.095	0.172

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is a probability between 0 and 1, the % variables are bound between 0 and 100. Standard errors are robust. The inflexion point for median income for the specification in column 3 is €25,000.

Table 3: Explaining the probability of brownfield location by share of migrants, share of unemployed, median income, comparing between no/any and few/many. Results without and with NUTS-3 FE are shown.

It is important to stress that our results are valid despite controlling for income. Richer municipalities are more likely to host brownfields, however, the quadratic term indicates a concave relationship.[12] We test such an inverse U-shaped relationship and calculate the Fieller's confidence interval, a confidence interval for the 1st derivative function, to determine the location of the extremum of the quadratic regression specification. Referring to column 3, when comparing zero to any brownfields, the inflexion point for medium incomes is at €25,000 yearly. Note that this value is located within the 85 percentile of the distribution and hence is significantly higher than the average of €21,700 yearly. The corresponding 90% confidence interval ranges from €23,700 (lower bound) to €26,400 (upper bound). This means that the relationship between income and brownfields is positive until income levels of €23,700, not significant around the inflexion point and negative and significant for income levels above €26,400 ($\approx$ 90% percentile of the distribution). Hence, the positive correlation holds up until the 75 percentile - the "noxious dependence" on legacy pollution dissolves for higher income levels. The share of industry employment is, as expected, positively related to the probability of hosting brownfields.

Further, Table 9 in the Appendix C reports results separately for sizes of brownfields, restricting the analysis to brownfields considered as medium and large, i.e., dropping brownfields whose size is below the 25th percentile (columns 1 and 2), and then looking only at large brownfields, i.e., dropping brownfields whose size is below the 50th percentile (columns 3 and 4). Restricting our dataset serves as a robustness check to confirm that equity considerations are still urgent even for small brownfields, implying that brownfield location matters regardless of size. Compared to Table 8 which considers brownfields of all sizes, we see that the coefficients for medium and large brownfields are qualitatively identical. For the results focusing solely on large brownfields, we see a strong increase in the effects of the share of migrants and median income. Moreover, again hotspots are consistently found to have stronger equity issues compared to municipalities with one or

[12]The nonlinear relationship between pollution - broadly conceived - and income is a standard result in the environmental inequality literature, see for instance Ash and Fetter (2004): environmental quality is considered a normal good, hence the rich move to where pollution is low, and keep pollution levels low by exercising their economic and political power. Figure 12 in Appendix B.4 illustrates such a relationship plotting brownfields against income.

two brownfields. Large brownfields can be a huge burden, as they occupy on average 1,4 per cent of their host municipality's surface. In some municipalities, for instance, in Noyant-Villages in the Pays-de-la-Loire region and Livarot-Pays-d'Auge in the Normandy region, more than 10 per cent of the municipality territory is unusable due to vast brownfields, with potentially devastating economic, environmental or public health effects.

To stratify the analysis into urban and rural areas, we split the data set of 31.377 municipalities based on the taxonomy provided by INSEE as explained in Section 3. Urban, hence dense areas are mostly the focus of policy tools aiming at brownfield restoration, or even fail to acknowledge the structural presence of brownfields in more rural, hence sparsely populated areas. We know from Table **??** in Appendix B that approximately 15 per cent of all municipalities are considered as urban (4,105 municipalities) and that together they host approximately 4,100 brownfields, hence brownfields are indeed disproportionally located in urban areas. In Table 4 we present separate regressions for urban and rural municipalities. Comparing the results for urban with rural municipalities, we see that migrant equity plays an important role in urban, and less so in rural areas.

This result arises from the fact that migrants mainly reside in cities. Moreover, we find a consistent unemployment-brownfield gradient across both urban and rural municipalities, with the share of exposed unemployed being higher in dense municipalities. Because of this, we add controls to the analysis of urban areas. We additionally control for the percentage of inhabitants with a high school education or less, and the percentage of social housing among all properties to rent, as well as the percentage of homeowners. The latter has been identified as a possible further contributor to the landscapes of de-industrialization: a document from the Ministry of Ecology points to the existence of thousands of empty apartments in certain cities, particularly those most affected by the loss of industrial activities due to the closure or relocation of large companies or factories (Statistiques

Development Durable, 2022).[13]

Results stratified by Urban and Rural Municipalities						
	Urban		Urban, added controls		Rural	
	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var:	NO/ANY	FEW/MANY	NO/ANY	FEW/MANY	NO/ANY	FEW/MANY
% Migrant	0.0122***	0.00973***	0.00548***	0.00203	0.00156***	0.00404*
	(0.00182)	(0.00302)	(0.00194)	(0.00331)	(0.000566)	(0.00214)
% Unemployed	0.0194***	0.0187***	0.00891***	0.00142	0.00598***	0.00708***
	(0.00291)	(0.00531)	(0.00323)	(0.00588)	(0.000495)	(0.00180)
Median Income	-0.0226*	0.0164	-0.0215	0.00373	0.00917***	0.0251*
	(0.0130)	(0.0222)	(0.0131)	(0.0219)	(0.00276)	(0.0148)
Median Income²	0.000254	-0.000466	0.000276	-0.000233	-0.000176***	-0.000574**
	(0.000218)	(0.000358)	(0.000214)	(0.000342)	(0.00005)	(0.000292)
% Industry Empl	0.00117**	-0.00254**	0.00150***	-0.000333	0.00127***	0.000723*
	(0.000538)	(0.00102)	(0.000531)	(0.00102)	(0.000111)	(0.000405)
Additional controls:						
% HS Education			-0.00273**	-0.00508**		
			(0.00121)	(0.00237)		
% Social Housing			0.00280*	-0.00733***		
			(0.00143)	(0.00247)		
% Homeowners			-0.00554***	-0.0156***		
			(0.00111)	(0.00209)		
Department FE (n=93)	YES	YES	YES	YES	YES	YES
Population Weights	NO	NO	NO	NO	NO	NO
Obs.	4,105	1,201	4,105	1,201	26,609	2,215
R2	0.242	0.254	0.261	0.307	0.063	0.118

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is a probability between 0 and 1, the % variables are bound between 0 and 100. Standard errors are robust.

Table 4: Explaining the probability of brownfield location stratified by urban and rural municipalities by share of migrants, share of unemployed, median income, comparing between no/any and few/many. Additional controls are shown for urban areas are shown.

[13]According to the INSEE data, the average vacancy rate is 3.9% for social housing, less sign of excessive construction than for job losses, which strongly illuminates the need for a territorialized housing policy.

Adding those controls leads to an increase in the R2. The coefficients on migrants and unemployed decline slightly but remain important and statistically significant when we include such strong socio-economic determinants (compare column 3), indicating that anti-migrant injustices, for instance, cannot be explained away. As expected, we find a negative relationship with regard to education, with a stronger coefficient for brownfield hotspots. The relationship with social housing is ambivalent, with a positive, however not significant coefficient in column 3, and a negative coefficient in column 4. Homeowners are negatively associated with brownfield location across the board, and with strong effects, which are especially large when explaining why some areas have many brownfields, while some only have few. Again, the unemployment rate of the local population proves to be a very coherent and strong determinant of brownfield location whenever statistically significant. We also find that median income is a consistent determinant for brownfield location in rural areas, while the relationship is less clear in cities. Indeed, we find a negative, but weak coefficient for the probability of hosting any brownfields (column 1).

Next, we carry out a regional analysis. Figure 4 gives an overview of the number of brownfields by region, sorted from the regions with the most brownfields, to the regions with the fewest. The graph illustrates that regions are very differently affected by brownfields (see also Table 2 above), with the two regions Grand Est and Nouvelle-Aquitaine as clear outliers, together hosting more than three thousand brownfields.

	Results stratified by region			
	Grand Est	Nouvelle-Aquitaine	Auvergne-Rhone-Alpes	Occitanie
	(1)	(2)	(3)	(4)
Dep. Var:	NO/ANY	NO/ANY	NO/ANY	NO/ANY
% Migrant	0.0111***	0.0152***	0.00233*	0.00348**
	(0.00147)	(0.00220)	(0.00123)	(0.00169)
% Unemployed	0.0188***	0.00786***	0.0128***	0.00949***
	(0.00156)	(0.00168)	(0.00143)	(0.00136)
Median Income	0.00666	0.0299***	-0.00131	0.0102
	(0.00746)	(0.00789)	(0.0254)	(0.0136)
Median Income^2	-0.000152	-0.000668***	0.000499	-0.000108
	(0.000128)	(0.000150)	(0.000617)	(0.000305)
Ind. employment control	YES	YES	YES	YES
Department FE (n=93)	YES	YES	YES	YES
Population Weights	NO	NO	NO	NO
Obs.	4,219	3,686	4,034	3,541
R2	0.130	0.112	0.048	0.054

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is a probability between 0 and 1, the % variables are bound between 0 and 100. Standard errors are robust.

Table 5: Explaining the probability of brownfield location stratified by region, comparing between no-any and few-many.

We look at the four regions which host most of France's industrial brownfields, in order to understand if equity considerations are region-specific or a nationally salient issue. Table 5 shows LPM regressions separately for the four regions where most brownfields are located. Together these four regions are associated with approximately 55 per cent of the inventory. There are no substantial differences comparing no to any brownfields or comparing within the universe of brownfields, hence for the sake of brevity, we only show the no/any specification for each region. For the same reason, we omit the coefficients for industry employment, even though this control is present in the analysis.

Our results point to huge regional differences, especially comparing the magnitude of the migrant variable. The latter does not seem to be as important as a determinant for brownfield location in Nouvelle-Aquitaine (column 2) and Occitanie (column 4). Moreover, median income is not significant for some regions, while migrant and unemployment are consistently significant, an interesting finding. For unemployed shares, however, a much more homogeneous picture emerges, with all coefficients being positive and significant at the one per cent level. In Grand Est, unemployment plays a strong role (column 1). This implies that prior job losses due to the closure of industrial activities and the general dynamics of economic stagnation persist and are a consistently good proxy for brownfield clustering. However, migrant histories and legacies are much more heterogeneous, with racial justice considerations being more important in certain regions (for instance in Grand Est and Auvergne).

What can explain such heterogeneity? In Grand Est, for instance, the dismantling of basic industries led to population outflow. It contains Lorraine, known to be one of the most heavily industrialized areas of France, specialising in coal (see the mining town Forbach) and iron ore. The steel industry that depends on iron ore, however, has declined due to increased competition that led to mass closures of steel factories. The Vosges department, also part of Grand Est, has a rich history in textile industries, which are equally in decline. Nouvelle-Aquitaine, too, is home to many towns that have lost their industries, for instance, Mauléon, known for its shoe and tannery industry until the 70s, and Poitiers (Vienne department) where many the closure of automotive foundries led to an increase in industry unemployment. Auvergne-Rhône-Alpes is France's second largest region with many large urban centres (Lyon, Grenoble, etc.) with an economic landscape of industrial specialization: basic chemical industry, textiles, and machinery and equipment manufacturing. At the same time, inter-regional heterogeneities play an equally important role. A INSEE report (Regions and territories, 2017) states that for instance Nouvelle-Aquitaine and Bourgogne-Franche-Comté belong to the regions with higher homogeneity, while Occitanie, Auvergne-Rhône-Alpes and Grand Est appear to be more unequal. These territorial discontinuities, of course, suggest strong implications for our study of unequal brownfield distribution.

4.3 Additional results on cumulative disadvantages

Environmental policies often fail to acknowledge cumulative impacts coming from multiple stressors. It is of crucial importance to foster a more robust understanding of the drivers of cumulativeness in order to address disproportionate pollution impacts on low-income or minority communities (Environment Agency, 2007; Brulle and Pellow, 2006), an endeavour that partially stems from US EPA's conceptual framework for cumulative risk assessment (compare Callahan and Sexton, 2007; Linder and Sexton, 2011). One critical aspect of cumulated harm that has been mostly overlooked arises from the interplay between ongoing and legacy pollution, i.e., where ongoing industrial pollution from facilities operating in emission-intense sectors are in proximity of brownfields, thus jointly burdening communities.

Additionally, cumulative impact research lacks robust empirical underpinnings, and data scarcity still remains one of the key barriers. Furthermore, definitions and quantification strategies remain inconclusive. One way to advance the understanding of cumulative impacts in order to improve the status quo is the use of point-source data on contamination and pollution. This part of the analysis suggests a way to quantify cumulative exposure to better understand multiple environmental stressors. In the following, we analyze how legacy and ongoing pollution overlap within and across municipalities to create a geography of cumulative disadvantage. It allows us to add the environmental equity dimensions of ongoing noxious industries. To do so, we merge our data set of industrial brownfields with geolocalised facility-level data from the European Pollutant Release and Transfer Register (E-PRTR) (European Commission, 2006). Appendix D provides technical information on the dataset and on the construction of the indicator for facility location. Mainly, we are interested in understanding which municipalities host E-PRTR facilities, and which ones host both, brownfields and facilities, as shown in the summary statistic in Figure 11, Appendix C. We also show an exemplary map of brownfields (polygons) and toxic facilities (points), see Figure 14 on page 53.

Table 6: Explaining the probability of brownfield and E-PRTR facility location, illustrating cumulative disadvantages.

	Results for cumulative disadvantages			
	(1)	(2)	(3)	(4)
Dep. Var:	ZERO/ANY E-PRTR FACILITIES	ZERO/ANY BROWNFIELDS	FEW/MANY BROWNFIELDS	ONLY BROWNFIELDS/ ALSO E-PRTR FACILITIES
% Migrants	0.00638***	0.00983***	0.0137***	0.0145***
	-0.000454	-0.000659	-0.00187	-0.00184
% Unemployed	0.00506***	0.0120***	0.0185***	0.0161***
	-0.000316	-0.000542	-0.00196	-0.0018
Median Income	0.00901***	0.0176***	0.0459***	0.0396***
	-0.0019	-0.00351	-0.0114	-0.011
Median Income^2	-0.000210***	-0.000344***	-0.000906***	-0.000754***
	-0.00003	-0.00006	-0.000212	-0.000208
% Industry Employment	0.00163***	0.00150***	-0.00008	0.00326***
	-0.00009	-0.000115	-0.000389	-0.000414
Department FE (n=93)	YES	YES	YES	YES
Population Weights	NO	NO	NO	NO
Obs.	30,714	30,714	3,416	3,416
R2	0.073	0.095	0.172	0.171

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is a probability between 0 and 1, the % variables are bound between 0 and 100. Standard errors are robust.

We run four LPM models to understand qualitative differences between municipalities that host only E-PRTR facilities to those that host brownfields, or host both. Columns 1 and 2 can be set in relation to each other, both comparing zero to any. Columns 3 and 4 show results for hotspot and cumulative risk municipalities, once in terms of having many brownfields, and once in hosting both facilities and brownfields.

Table 6 shows LPM regressions comparing municipalities that illustrate cumulative disadvantages. The results clearly show a proportional increase in exposure of migrants and unemployed with the intensity of exposure to ongoing and legacy pollution. This points to strong cumulative disadvantages that combine legacy with ongoing pollution. Moreover, we see that equity issues exist across the board, but, are relatively less pronounced for industrial facilities compared to brownfields. For instance, unemployment plays a relatively more important role in brownfield location (compare 0.00506*** to 0.0120*** and 0.0185***) Here, further research is needed to assess the cumulative risk and the potential synergistic effects of various contamination sources, disaggregated by pollution sources and pollutants. The French government should hence make cumulative risk assessment a scientific and socioeconomic research priority and include ongoing toxic pollution from industrial facilities into its broader framework of green industrial and cohesion policy, not lastly to begin taking regulatory actions to reduce industrial pollution. Furthermore, the relationship between income and E-PRTR facilities is concave, and analogue to all other specifications.

5 Discussion and conclusion

Recent interest in environmental inequality has shifted its focus from ongoing pollution to legacy pollution by looking at the geography of brownfields, defined as non-productive, contaminated land. This paper is the first of its kind to analyse the environmental inequality implications in the distribution of legacy pollution in Europe. We make use of the recently published database 'Cartofriches' to test the hypothesis that French municipalities are not equally affected by the presence of brownfields. This hypothesis is guided by the environmental inequities well documented in the US literature. Our results show that communities that are burdened with industrial brownfields have higher shares of foreign-born and unemployed. Hence, present and future policy tools for industrial brownfield regeneration must be designed explicitly to redress past wrongdoings. This has strong implications for France's brownfield fund as part of the PNRR.

Moreover, we focus on urban municipalities, which represent a smaller yet important fraction of the overall geography due to the strong environmental equity implications in such places, and propose the percentage of social housing and of homeowners to be two potentially important determinants worthwhile to be further explored. Further, we find that equity considerations are region-specific, hence policy tools to restore brownfields need to take local specificities of the social and economic tissue, such as post-fordist and post-mining experiences, geographies of production, migration histories and urban shrinkage, into consideration. By extending our analysis to integrate ongoing industrial pollution, we find evidence for a step-wise increase in cumulative disadvantages considering the frequency and combination of industrial brownfields and noxious facilities.

This analysis pinpoints the stratification of socio-economic and environmental risks and opens up another channel of inequalities and asymmetries characterizing modern capitalism, namely environmental inequality which exacerbates economic deprivation. From a policy perspective, addressing the economic consequences of wasteland is crucial for the design of place-specific industrial policies able to reconvert sacrifice zones by reducing contamination and non-productive sites, thus fostering the transition to a more socially and environmentally just society. Moreover, our results will provide political economy entry points crucial for restorative justice considerations.

In fact, our analysis provides the basis for adopting the concept of restorative environmental justice, a term first used by Dorsey (2009), applied to brownfield revitalization initiatives for community-driven economic development in Florida, US. Re-distributive components of brownfield redevelopment are targeted at rectifying or ameliorating situations that disenfranchised or harmed communities in the past (reparation for previous systemic inequities).

Toxic industries and mining activities, for instance, leave behind contaminated properties and sites that remain idle or underused. Hence, the geography of industrial brownfields is closely linked to historic pathways of shrinking cities and left-behind places with post-fordist and post-mining experiences, often characterised by a change in the geography of production, resource-depletion, and peripheralization. Our analysis focuses on the need to redress such inequalities by enforcing specifically designed environmental restoration policies. The scientific community and policymakers should acknowledge the importance of the restoration of previously left-behind places, often as a consequence of deindustrialization, more wholeheartedly. However, to date, most European countries have engaged relatively little with the social and environmental potential of contaminated sites. The recent release of rich French data will hopefully attract more scholarly attention in the future and will be a guiding principle for other countries.

Industrial policy evaluation must look at the net effect of restoring legacy sites. In fact, resources are often redistributed regressively from taxpayers to better-off municipalities, as they participate more in public policy design (higher political influence), have a higher ability in mobilizing remedial efforts (Hird, 1993), and are more likely to satisfy the selection criteria concerning the reuse choice (reconversion towards high-tech, green sectors). Brownfield restoration is then paid for directly in form of taxes, and indirectly by affected communities, for instance through channels such as depressed wages, fewer jobs and reduced output.

We propose the following research agenda to further explore the political economy of brownfields. The most imminent extension of the present paper is the analysis of the determinants and socio-economic tissue associated with brownfield *restoration* within the concept of restorative environmental justice. Data on applicants and winners of the brownfield fund (round 1-3)[14] provided by the French Ministry of the Environment and the Ecological Transition should form the backbone to understand whether the fund indeed succeeds in redressing some of the distributive inequalities uncovered here. Further research will be needed to better grasp the political economy around the application and selection process. The rest of the research agenda departs from the narrow framework of the French setting: first, and most compellingly, endeavours should include further justice considerations, for instance, to understand (1) where the contaminated soil gets

[14] More information on the different application rounds is provided in Appendix C.

transported to - do the toxins get dumped in even poorer communities or countries? and (2) who benefited from improved environmental quality upon successful restoration to test for potential patterns of gentrification (i.e., policy evaluation focus, see for instance Essoka (2010); Maantay and Maroko (2018) for the US context). Second, in terms of causal research, the availability of longitudinal data will extend the present analysis of "who lives near brownfields today", enabling to trace material dependencies on toxic economic growth, patterns of industrial development and specialization, and associated labour market growth and deprivation. Third, further lines of research include corporate responsibility frameworks to understand who is responsible for the left-behind wasteland and its underlying mechanisms such as weak regulation, monitoring, spills, and illegal activities. In that regard, a study of who benefited from the legacy activities versus who pays for the clean-up, e.g., possible lawsuits related to the right of nature. Lastly, research could delve into understanding whether the existence of brownfields affects the siting of operating industrial facilities, together reinforcing the shown dynamics of cumulative disadvantage.

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Appendix

A Details on the French brownfield inventory and fund

A.1 Details on the French case

The number of industrial jobs has been halved in fifty years, making France the most deindustrialized economy in the G7 (France Stratégie, 2020). The remaining vast landscape of industrial brownfields has detrimental effects on the local economy, public health and the environment, and hence must be urgently tacked by industrial policy, which for many years "was no longer considered a priority in France" (France Stratégie, 2020). The growing ecological crises then justify the rise of green industrial policy that has environmental and societal sustainability at its core. In fact, the Ministry of Ecological Transition in France has made industrial brownfields a policy priority, as part of the action plan toward a more sustainable and green economy. This is an important effort of disclosure and inventorization, in a European setting where the collection of geolocalized brownfield data is rare. In the following, all relevant policies are presented and discussed.

A.2 Details on the policy 'Zero Net Artificialisation'

The context of land scarcity, real estate pressure and soil protection requires a reflection on the future of brownfields in the context of the implementation of the Zero Net Artificialisation (ZAN) trajectory, included in France's 2021 Climate and Resilience bill and Biodiversity Plan (France Stratégie, 2019). The reconversion of already artificial land contributes to this policy target. Every year, 20,000 to 30,000 hectares of natural or agricultural areas disappear in France, comparable to the surface area of the city of Marseille. The Ministry for Ecological Transition's goal is to halve the rate of net land artificialisation by the end of the decade. The key policy towards achieving this goal is the national resilience and recovery plan, which is mobilising €300 million to facilitate and accelerate the rehabilitation of brownfields. This sum should make it possible to reconvert approximately 900 hectares on 230 sites within the framework of urban development operations and revitalisation of town centres or urban peripheries. This is a pioneering land use regulation which includes a requirement for land sobriety brought about by the 2021 Climate and Resilience Act. In concrete terms, this translates into an objective of halving the rate of artificialisation and consumption of natural, agricultural and forest areas by 2030, leading to a policy of zero net artificialisation from 2050. In order to achieve these objectives, the conversion of brownfield sites is a powerful lever available to local authorities, as brownfield sites are, by definition, already developed.

A.3 Details on the brownfield inventory

Very recently, France published its first georeferenced national brownfield inventory called 'Cartofriches' listing approx. 7,200 sites, produced by the Ministry of the Environment and Ecological Transition with the help of the CEREMA[15]. The inventory of brownfield sites is generally the first step in the conversion process. This work allows a strategic vision of the territory to be obtained, in order to prioritise and stagger the various operations required. The national inventory of brownfields went online in September 2021 and lists commercial, industrial and residential brownfields throughout the country and is intended at helping local authorities and project developers. Prior to the Cartofriches registry, there was no national standard and platform for data on brownfields.

A.4 Details on the brownfield fund

The main objective of the recent brownfield recycling fund, open to public authorities and private companies, is to unblock situations which fail to progress without public support, in particular, due to soil contamination (Gouv., 2022). The overall idea of restoring a brownfield is to develop spaces that have lost their use, are under-exploited or abandoned, with the Climate and Resilience Act insisting on the principle of development or work prior to the reuse of these areas. Below, we list the timeline of stages I-III which gives an overview of the number of applicants versus winners per round and the funds allocated (Gouv., 2022).

- 1st edition launched in January 2021; 544 winners for €290 m

[15]The CEREMA is the French public agency for developing public expertise in the fields of urban planning, regional cohesion and ecological and energy transition.

- 2nd edition launched on 15 July 2021; 1,130 applications for €431 m in subsidies; 503 winners for €280 m
- 3rd edition launched on 15 February 2022; 1,210 applications for €431 m in subsidies; 264 winners for €121 m for the recycling of 675 ha of brownfields

The latest edition is said to be generating around 1 million m² of housing - of which nearly 50% will be social housing -, 179,000 m² of public facilities and 750,000 m² of economic space, including nearly 200,000 m² of industrial space. Taking the three editions together, a total of 1,382 projects have been financed, enabling the recycling of 3,375 hectares of wasteland. They should generate 6.7 million square metres of housing, 4.85 million square metres of economic space, and 4.07 million square metres of public facilities, according to the Ministry of Ecological Transition (actu-environnement, 2022).

A.5 Details on the concept of citizen participation

In the French case, the public sector provides incentives as well as national support that the market cannot, especially when a brownfield has a corporate owner that prefers to leave it idle rather than redevelop it, often associated with high cleanup costs. This is a crucial step, making it easier to build new homes from the regeneration of vacant and redundant buildings on brownfield land. Here, shifting from corporate liability to community assets is crucial from a social point of view and can overcome nimbyism. Local involvement is key but has often lacked in the past, sometimes making top-down reuse choices controversial. The French case is hence a good example of the opportunity of citizen participation, turning nimby protesters into those eligible for application. In this regard, France has a clear pioneering role, being a role model for other industrialized countries: the success of the brownfields fund shows the extent to which elected officials are willing to play the game, as long as the state provides financial backing for the projects. Although there are obstacles, particularly in terms of decontamination, the recycling of brownfields is becoming one of the most-used pathways of using the available land.

B Additional summary statistics

B.1 Details on distribution of brownfields

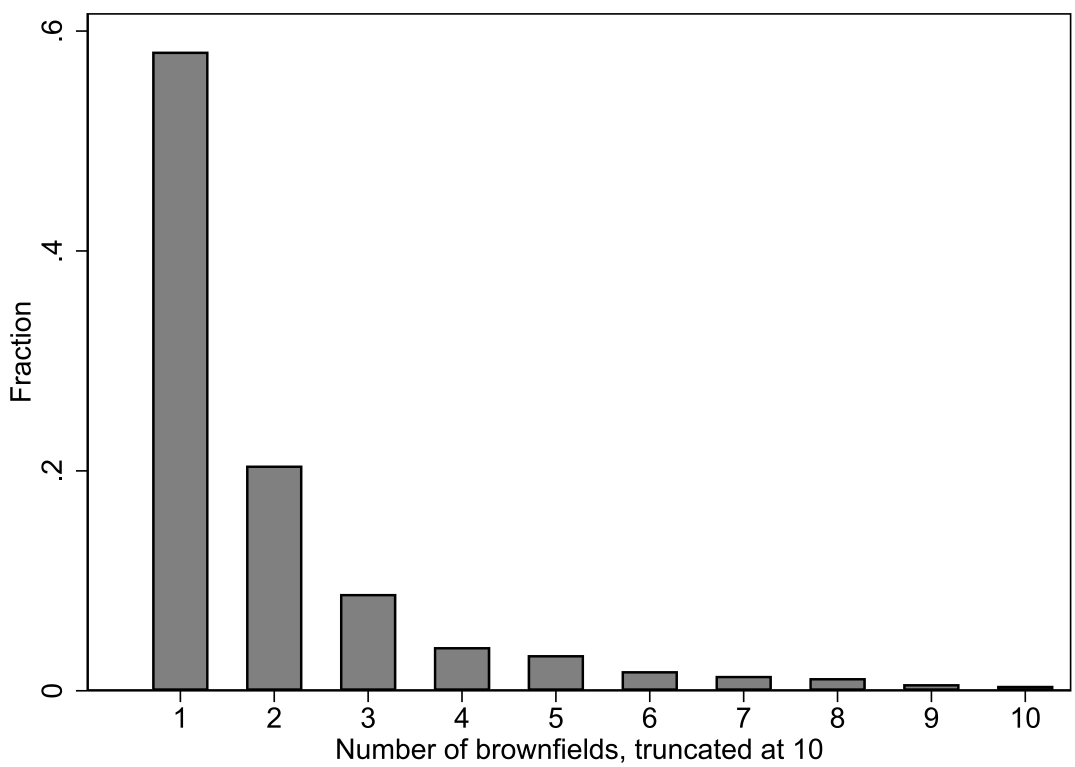


Figure 3: Histogram of the number of brownfields by municipality, excluding municipalities without brownfields, and truncated at 10, depicted as fraction. Sourced from Cartofriches, version June 2022.

B.2 Details on French municipalities

Region (n=12)	**Growing municipalities (%)**	**Shrinking municipalities (%)**	**Urban municipalities (%)**	**Rural municipalities (%)**
Grand Est	41	59	13	87
Nouvelle-Aquitaine	39	61	7	93
Auvergne-Rhône-Alpes	52	48	17	83
Occitanie	45	55	10	90
Hauts-de-France	44	56	18	82
Bourgogne-Franche-Comté	43	57	7	93
Normandie	48	52	9	91
Centre-Val de Loire	37	63	8	92
Île-de-France	56	44	48	52
Pays de la Loire	56	44	10	90
Bretagne	54	46	11	89
Provence-Alpes-Côte d'Azur	47	53	28	72
National	47	53	16	85

Table 7: Summary statistics of population dynamics and urbanity by region (n=12), partitioning the municipalities of each region into growing versus shrinking and urban versus rural (expressed in %).

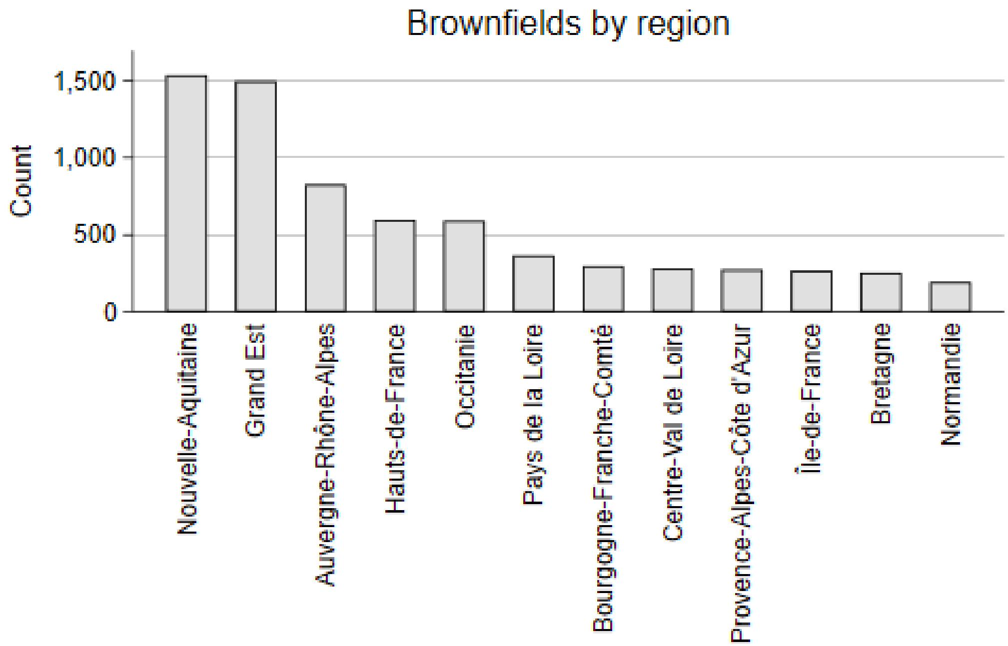


Figure 4: Number of brownfields by region (n=12), sorted.

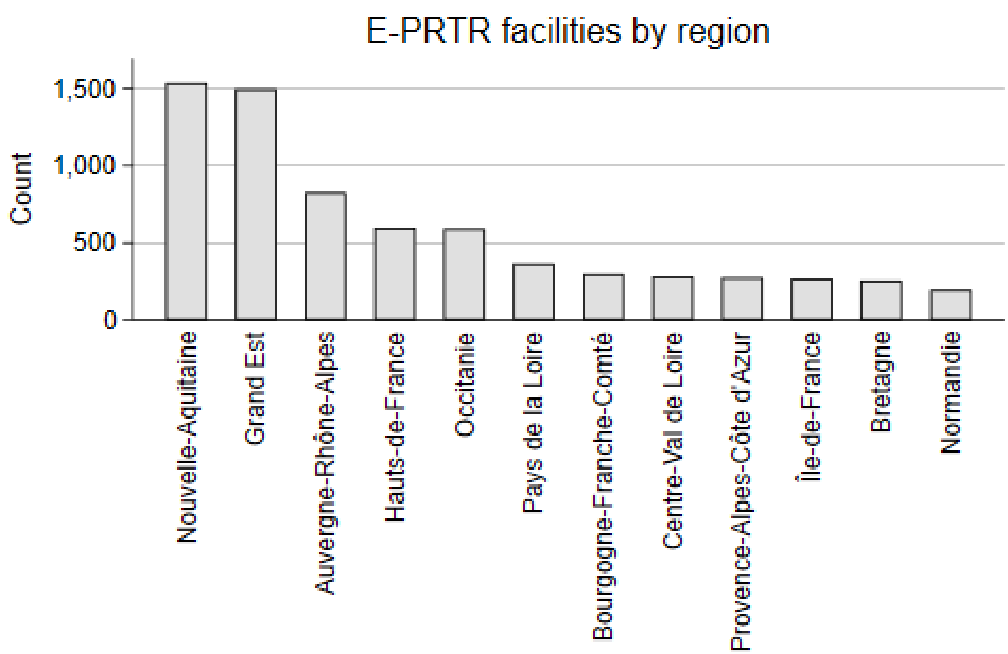


Figure 5: Number of E-PRTR facilities by region (n=12), sorted.

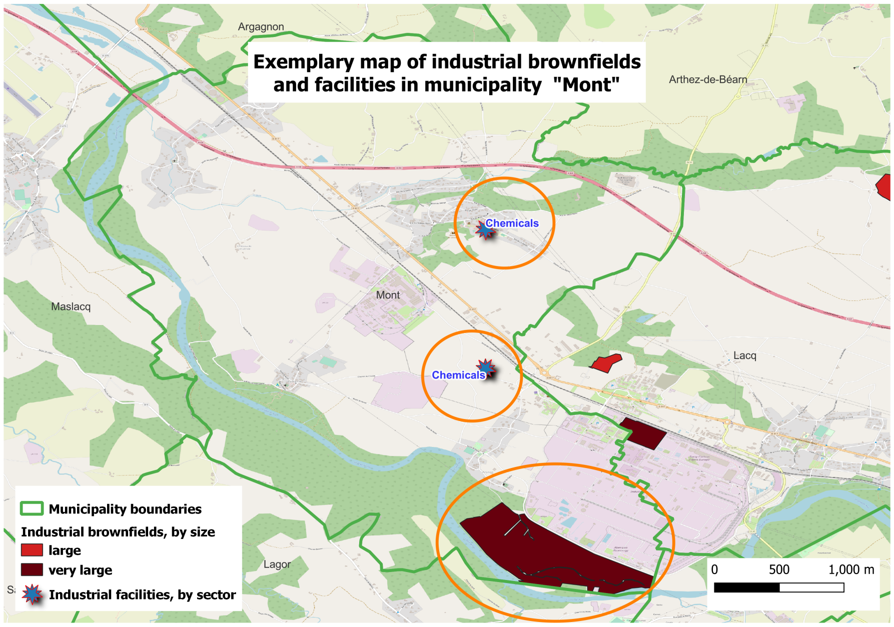
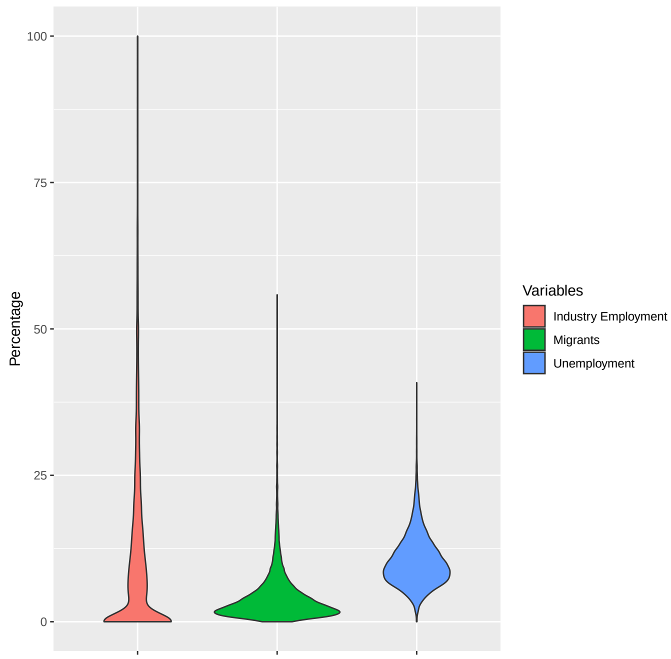
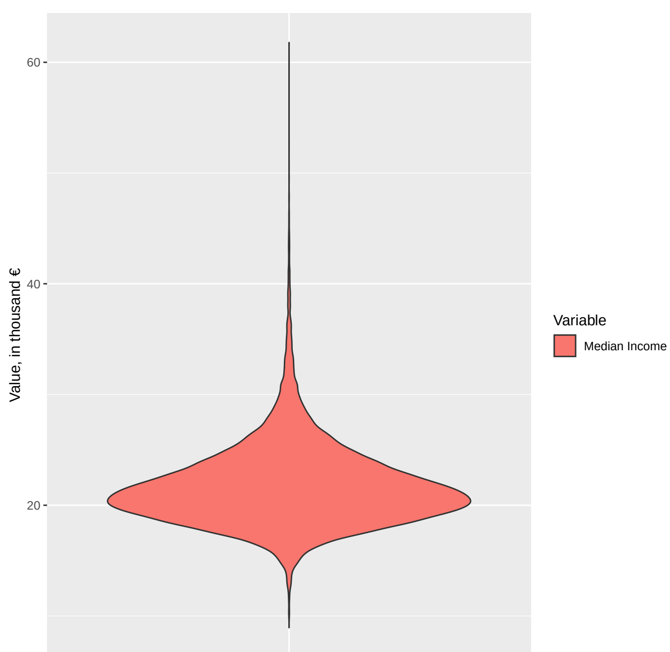


Figure 6: Mapping of the municipality Mont as example of how industrial brownfields (polygons) and facilities (points) are located across municipalities.

B.3 Details on socio-economic variables

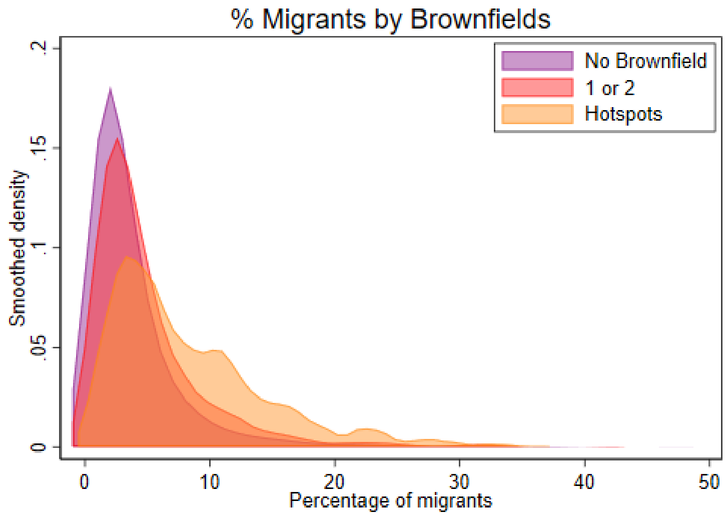


(a) Variables expressed in per cent

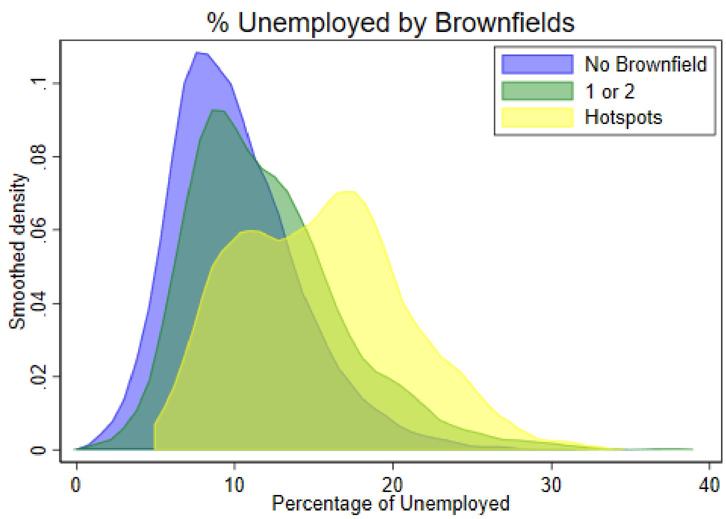


(b) Variable expressed in €1,000

Figure 7: Violin plots for (a) socio-economic variables as used in the analysis: industry employment, migrants and unemployed (all in %). The former is used as proxy for industrialization level; and (b) median income. The data refers to the year 2018 sourced from INSEE.

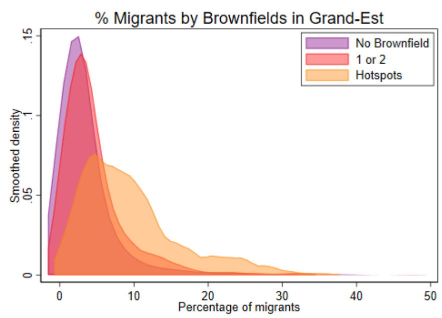


(a) Percentage of migrants by brownfields

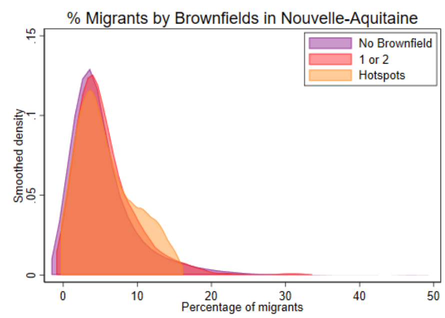


(b) Percentage of unemployed by brownfields

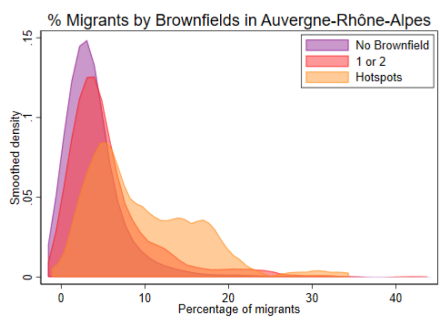
Figure 8: Kernel densities of (a) % migrants and (b) % unemployment, by the number of brownfields as classified by the dependent variable.



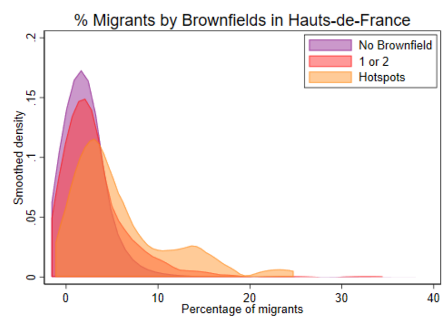
(a)



(b)



(c)



(d)

Figure 9: Percentage of migrants by brownfields in (a) Grand-Est (b) Nouvelle-Aquitaine (c) Auvergne-Rhône-Alpes (d) Hauts-de-France, the four regions where most brownfields are located, see Table 2.

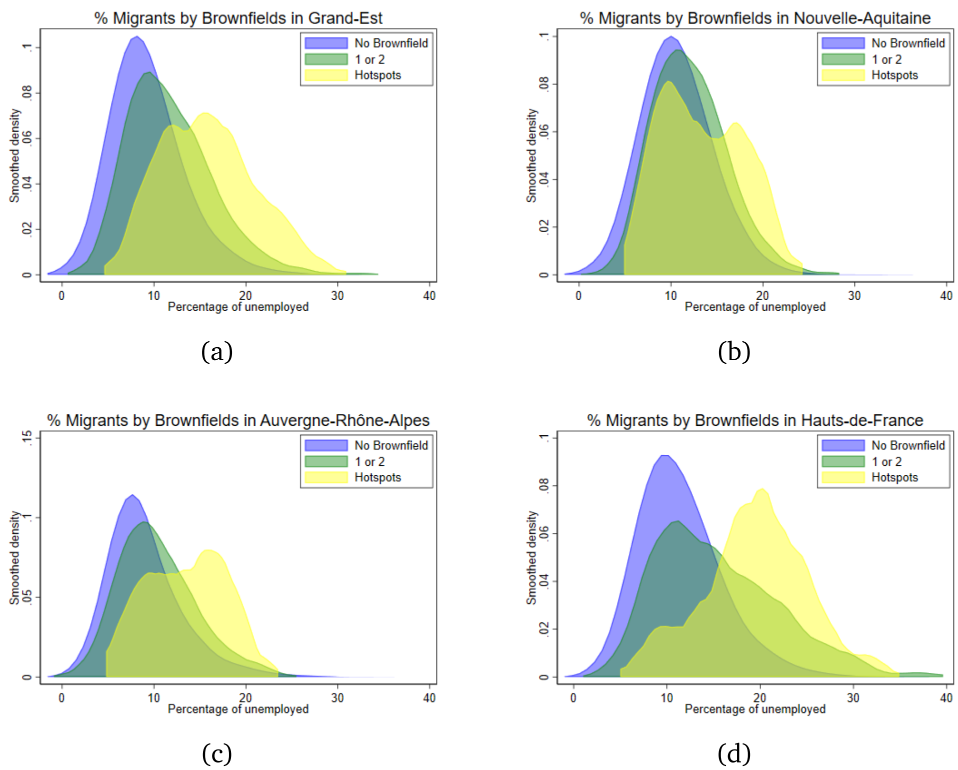


Figure 10: Percentage of unemployed by brownfields in (a) Grand-Est (b) Nouvelle-Aquitaine (c) Auvergne-Rhône-Alpes (d) Hauts-de-France, the four regions where most brownfields are located, see Table 2.

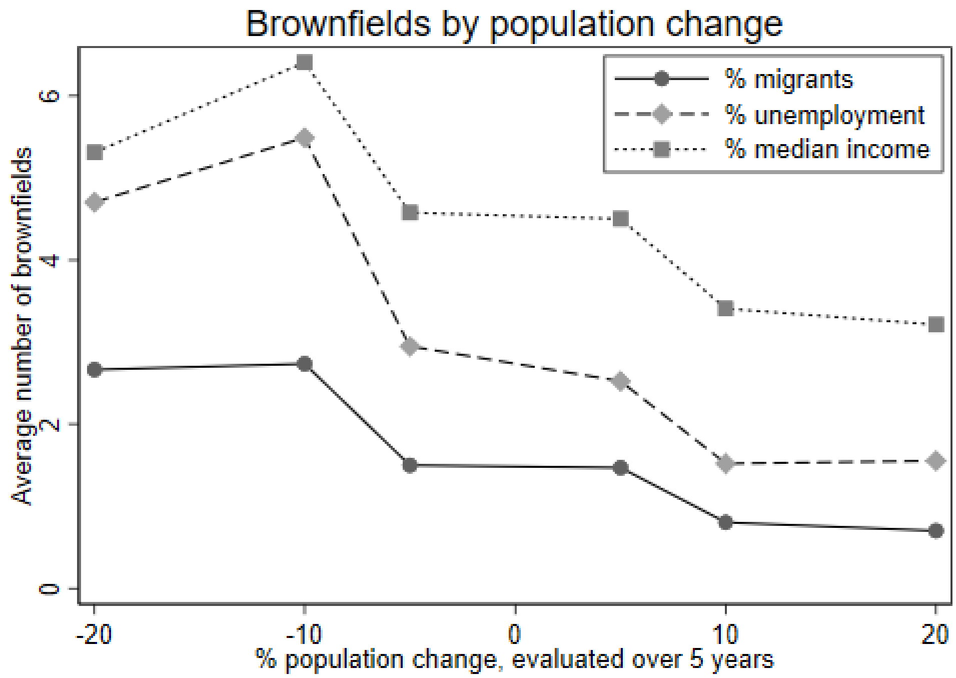


Figure 11: Brownfields by population change. Average number of brownfields by population change and socio-economic indicators: migrants, unemployed, median income, in per cent.

B.4 Details on the relationship with income

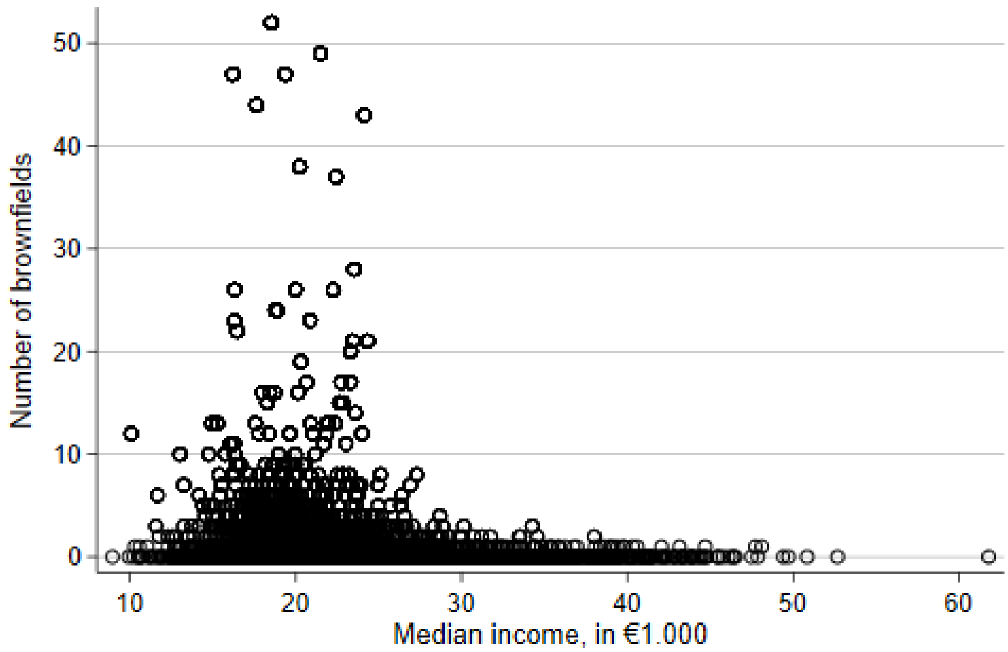


Figure 12: Scatterplot of number of brownfields per municipality and median income (in €1,000).

C Additional regression results

C.1 LPM models

	Supplementary Material for Baseline LPM Results					
	NUTS-3 Fe, excl. income		NUTS-3 FE, incl. pop density		NUTS-3 FE, incl. pop weights	
	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var:	NO/ANY	FEW/MANY	NO/ANY	FEW/MANY	NO/ANY	FEW/MANY
% Migrant	0.00926***	0.0126***	0.00463***	0.00564***	0.0249***	0.0262***
	(0.000639)	(0.00184)	(0.000622)	(0.00186)	(0.00205)	(0.00414)
% Unemployed	0.0112***	0.0158***	0.00931***	0.0141***	0.0399***	0.0346***
	(0.000514)	(0.00167)	(0.000526)	(0.00186)	(0.00260)	(0.00641)
Median Income			0.00846**	0.0248**	0.0705***	0.120***
			(0.00335)	(0.0105)	(0.0131)	(0.0326)
Median Income²			-0.000173***	-0.000495**	-0.00124***	-0.00224***
			(0.00006)	(0.000192)	(0.000233)	(0.000580)
% Industry Empl	0.00152***	-0.00002	0.0163***	0.0131***	0.000935**	-0.00587***
	(0.000115)	(0.000388)	(0.000910)	(0.00136)	(0.000453)	(0.00121)
Pop Density			-0.00006***	-0.00005***		
			(0.00007)	(0.00006)		
Pop Density²			0.00145***	0.000324		
			(0.000113)	(0.000381)		
Department FE (n=93)	YES	YES	YES	YES	YES	YES
Population Weights	NO	NO	NO	NO	YES	YES
Obs.	30,714	3,416	30,714	3,416	30,713	3,416
R2	0.094	0.168	0.123	0.209	0.314	0.349

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is a probability between 0 and 1, the % variables are bound between 0 and 100. Standard errors are robust.

Table 8: Explaining the probability of brownfield location by share of migrants, share of unemployed, median income, comparing between no/any and few/many. Results excluding income, including population density and including population weights are shown.

Discussing population weights

Table 8 presents regression results without (columns 1 - 4) and with population weights (columns 5 and 6). While qualitative results are similar, we observe that the use of weights leads to larger coefficients. Using population weights is a sensitive issue in the literature on environmental inequalities. Different weights change the amount of weight placed on differences at various points in the distribution, making it possible to explicitly and quantitatively express preferences.The decision to not use weights implies that all populations should be considered identically, hence carrying explicit value judgments. Weighting for population favors people that reside in highly populated municipalities over those in sparsely populated ones, and therefore is biased towards urban conglomerations, contributing to the dynamics of overlooking or sacrificing inhabitants of more rural areas.[16] Applying population weights means efficiency-based concerns prevail (cost-benefit analysis to benefit the largest amount of people possible, and hence implying distinct rights to environmental quality) while its absence implies equity-based concerns. For instance, such weights would imply that in rural areas the presence (and lack of restoration) of industrial brownfields is efficient. Deciding which option to choose can create tensions in environmental policy decision-making as they imply distinct normative and ethical criteria. Our results imply that the population weights are not the driver behind the results on environmental justice. Given that both specifications yield the same qualitative results, in the remainder of the analysis we will refrain from using weights, in an effort to have social equity as a guiding principle.

[16]In the US context, for instance, the Environmental Protection Agency (EPA) publishes facility-level data on environmental pollution. The widely used RSEI score aggregates toxicity- and population-weighted impacts in proximity to a given industrial facility (compare, for instance, Ash and Fetter, 2004). In particular, tons of pollutant emissions are multiplied by the number of people residing within a designated buffer zone. This tool is then used for environmental enforcement actions.

	Results for brownfields by size			
	Medium and large brownfields		Large brownfields	
	(1)	(2)	(3)	(4)
Dep. Var:	NO/ANY	FEW/MANY	NO/ANY	FEW/MANY
% Migrant	0.00553***	0.0175***	0.00189***	0.0198***
	(0.000532)	(0.00274)	(0.000279)	(0.00612)
% Unemployed	0.00858***	0.0212***	0.00245***	0.0253***
	(0.000469)	(0.00251)	(0.000264)	(0.00557)
Median Income	0.0129***	0.0795***	0.00158	0.131**
	(0.00260)	(0.0171)	(0.00123)	(0.0519)
Median Income^2	-0.000260***	-0.00157***	-0.00004**	-0.00260**
	(0.00004)	(0.000335)	(0.00002)	(0.00111)
% Industry Empl	0.00108***	-0.000614	0.000284***	-0.00204
	(0.00009)	(0.000499)	(0.00005)	(0.00126)
Department FE (n=93)	YES	YES	YES	YES
Population Weights	NO	NO	NO	NO
Obs.	30,714	2,436	30,714	755
R2	0.070	0.197	0.042	0.266

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable is a probability between 0 and 1, the % variables are bound between 0 and 100. Standard errors are robust.

Table 9: Explaining the probability of brownfield location by share of migrants, share of unemployed, median income, comparing between no/any and few/many. Results for brownfields by size are shown, looking at medium and large brownfields (columns 1 and 2) and large brownfields (columns 3 and 4).

C.2 Binomial Logit models

	All brownfields using binomial Logit			
	No FE		NUTS-3 FE	
	(1)	(2)	(3)	(4)
Dep. Var:	NO/ANY	FEW/MANY	NO/ANY	FEW/MANY
% Migrant	0.0659***	0.0649***	0.0711***	0.103***
	(0.00370)	(0.00764)	(0.00481)	(0.0142)
% Unemployed	0.0978***	0.147***	0.125***	0.177***
	(0.00467)	(0.0136)	(0.00542)	(0.0175)
Median Income	0.189***	0.946***	0.237***	1.082***
	(0.0431)	(0.174)	(0.0460)	(0.215)
Median Income^2	-0.00382***	-0.0208***	-0.00457***	-0.0236***
	(0.000911)	(0.00406)	(0.000957)	(0.00502)
% Industry Empl	0.0157***	0.00396	0.0151***	-0.000163
	(0.000927)	(0.00342)	(0.000992)	(0.00376)
Department FE (n=93)	NO	NO	YES	YES
Population Weights	NO	NO	NO	NO
Obs.	30714	3416	30714	3317
Log Likelihood	-10100	-1340	-9404	-1184
LR Statistic	1260	244.5	2429	414.4
Pseudo R2	0.0579	0.0948	0.123	0.191

Notes: *** p<0.01, ** p<0.05, * p<0.1, LR Statistic refers to Likelihood Ratio Chi-Square Tests. The percentage variables are bound between 0 and 100. Standard errors are robust.

Table 10: Explaining the probability of brownfield location by share of migrants, share of unemployed, median income, comparing between no/any and few/many. Binomial Logit analysis.

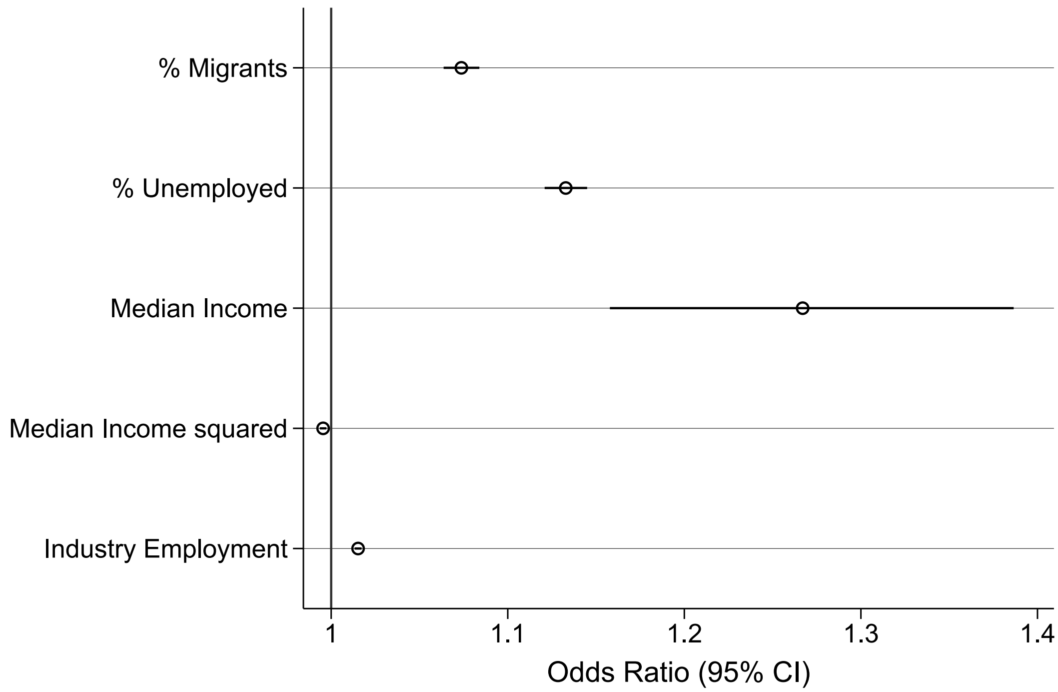


Figure 13: Odds ratio Logit, based on the specification with NUTS-3 FE comparing no to any brownfields (column 3 in Table 10).

D Details on E-PRTR facilities

In order to address the question of cumulative disadvantage, we combine our data set of industrial brownfields with geolocalised facility-level data from the European Pollutant Release and Transfer Register (E-PRTR) (European Commission, 2006). Starting from 2007, the register has been updated every year with annual data reported by some 30,000 industrial facilities covering 65 economic activities.[17] We select facilities that are (geo)localized within the boundaries of metropolitan France and operate in the most toxic, pollution-intense sectors - i.e., energy, metals, minerals, and chemicals - which coincide with the sectors largely associated with industrial brownfields. This leaves us with 1,426 toxic facilities nested in 839 municipalities. To analyse cumulative effects, we extend the dependent variables to integrate the location of toxic industrial facilities and their clustering, or co-existence, with brownfields. For doing so, we construct two new categories, one for municipalities that host at least one E-PRTR facility, and one for municipalities where both brownfields and facilities exist.

Figure 14 below illustrates how brownfields (polygons) and E-PRTR facilities (points) are spread across and within municipalities, here exemplary for the region of Bordeaux in the South-West. We note that citizens affected by toxic pollution coming from operating facilities mostly live in municipalities that also host brownfields. In other words, municipalities that host a facility also often host a brownfield. Some municipalities host a brownfield but not a facility, and large or multiple brownfields tend to coincide with ongoing industrial pollution, see for example Blanquefort or Bordeaux.

[17] Each active industrial facility is required to provide annual information on the deliberate and accidental quantities of pollutants released into air, water and land. The data covers 91 key pollutants including heavy metals, pesticides, greenhouse gases and dioxins. The E-PRTR defines a pollutant as “a substance or a group of substances that may be harmful to the environment or to human health on account of its properties and of its effects on the environment” (European Commission, 2006, Annex I, Article 2, p.74). Hence the E-PRTR gives insights into the releases and transfers of regulated substances of the largest industrial complexes in Europe.

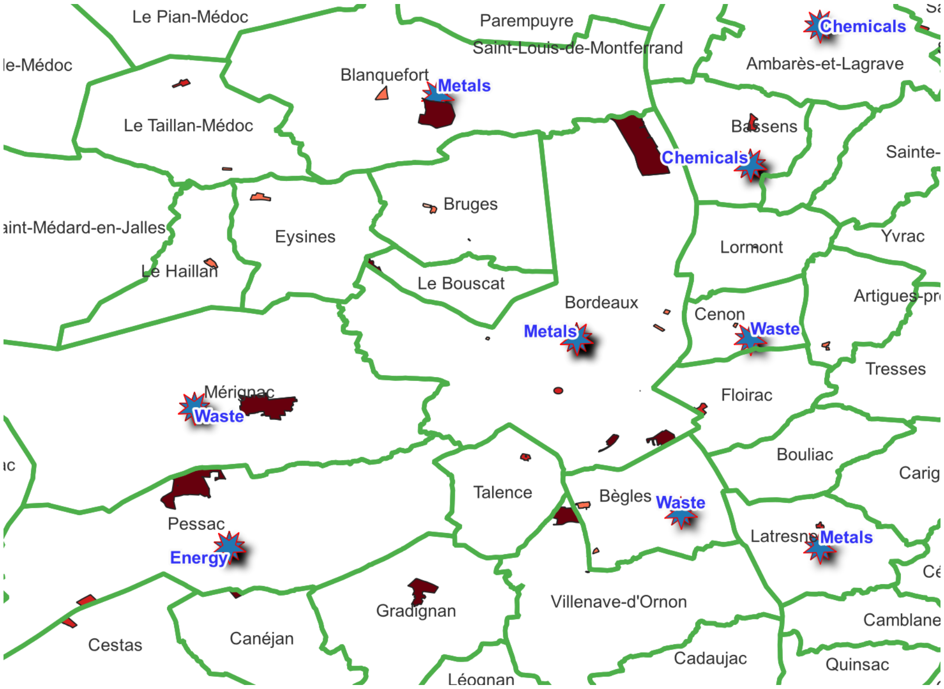


Figure 14: Mapping of the broad area around Bordeaux as an example of how industrial brownfields (polygons) and facilities (points) are located across municipalities.

Region (n=12)	Number of municipalities	Municipalities with facilities	Municipalities with facilities (%)
Grand Est	4219	147	3
Nouvelle-Aquitaine	4034	91	2
Auvergne-Rhône-Alpes	3686	144	4
Occitanie	3541	58	2
Hauts-de-France	3519	145	4
Bourgogne-Franche-Comté	3068	66	2
Normandie	2504	64	3
Centre-Val de Loire	1686	57	3
Île-de-France	1251	89	7
Pays de la Loire	1222	49	4
Bretagne	1201	28	2
Provence-Alpes-Côte d'Azur	783	48	6
National	30714	986	4

Table 11: Summary statistics of E-PRTR facilities by region (n=12), ranked by the number of municipalities within each region.