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Toxic pollution and labour markets: uncovering Europe's left-behind places

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Toxic pollution and labour markets: uncovering Europe's left-behind places[*]

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Abstract

This paper looks at the nexus between toxic industrial pollution and the spillovers from the plant's production activities, leading to regional lock-ins. Geolocalised facility-level data from the European Pollutant Release and Transfer Register (E-PRTR) are used to calculate annual chemical-specific pollution, weighted by its toxicity. We combine the latter with regional data on employment, wages and demographics sourced from Cambridge Econometrics, covering more than 1.200 NUTS-3 regions in 15 countries, over the period 2007-2018. We employ quantile regressions to detect the heterogeneity across regions and understand the specificities of the 10th and 25th percentiles, the so-called left-behind places. Our first contribution consists in giving a novel and comprehensive account of the geography of toxic pollution in Europe, both at facility and regional level, disaggregated by sectors. Second, we regress toxic pollution (intensity effect) and pollutant concentration (composition effect) on labour market dimensions of left-behind places. Our results point to the existence of economic dependence on noxious industrialization in left-behind places. In addition, whenever environmental efficiency-enhancing production technologies are adopted this leads to labour-saving effects in industrial employment, but positive spatial spillovers at the regional level. Through the lens of evolutionary economic geography our results call for a new political economy of left-behind places.

Keywords: Environmental inequality | Left-behind places | Toxic pollution | Labour markets
JEL codes: Q52 | P18 | R11 | O3

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1 Introduction

The dark sides of pollution are still relatively understudied by the economic literature. Although more attention has been devoted to health-related effects, fewer investigations have been conducted in terms of the negative effects propagating from pollution to socio-economic deprivation, particularly in terms of labour market outcomes, by looking at point-source pollution from industrial facilities. Indeed, the presence of a highly polluting facility in a given area might adversely affect regional economic development, both in terms of employment segregation in such facility and sector, inducing dependence on noxious industrialization, but also in terms of the poor economic trajectory and bad specialization in which the entire place might end up, reducing employment opportunities over time and depressing local labour markets (see relatedly Boschma et al., 2017). Such negative spillovers are tangible in places such as ILVA in Italy, INEOS Chemicals Grangemouth in UK, and Lausitz Energie Kraftwerke in Germany, the so-called left-behind places in Europe. So far, only a few case studies have been conducted on such places (Greco and Bagnardi, 2018; Feltrin et al., 2021). In addition, the literature lacks both a quantitative way to identify such places and a comprehensive mapping of their actual status and evolution.

The analysis of the productive specialization patterns of a given region and trajectories of related or unrelated diversification are core themes of Evolutionary Economic Geography (EEG). However, such stream of literature has tended to largely focus on performance attributes of firms, clusters, and regions (MacKinnon et al., 2022). Less room has been devoted to studying both negative-quality indicators, such as environmental pollution as by-product of industrialization, and more generally the dark side of economic activity that varies significantly at the facility level (see, e.g., Biggi et al., 2022). In addition, inequality, and more specifically environmental inequality, are not under the spotlight of such stream of literature.

Recent calls in such directions are in Pinheiro et al. (2022) that highlight the need to include social and environmental dark sides of innovation, resulting from concentration of highly complex production activities in a series of few already advanced areas, accelerating therefore regional disparities. Geographic disparities emerge because of *Matthew effects* leading to path-dependent processes which stratify along different dimensions: advanced production and complex industrial diversification go hand in hand with high-innovative activities, with good jobs (Rodrik and Stantcheva, 2021), raising employment opportunities and urbanization for the "winning" areas. On the other side, deindustrialization, deterioration of productive capacity and locked-in productive activities with low complexity characterize left-behind places, with bad jobs and reduced employment chances.

Beyond the economic characterization of social inequality, what happens in terms of environmental inequality? Far from random order, the distribution of highly toxic pollution across areas tends to be concentrated as well, and it does so exactly in those places experiencing socio-economic degradation. In this respect, environmental and social inequality tend to stratify. More specifically, does toxic pollution produce socio-economic inequalities at the regional level and industrial decay? In order to address such question, we use geolocalised facility-level data from the European Pollutant Release and Transfer Register (E-PRTR) (European Commission, 2006) to calculate annual chemical-specific pollution, weighted by CAS-number toxicity using the USEtox 2.12 model. The E-PRTR contains environmental data from over 30,000 georeferenced industrial facilities in Europe, with information on quantities of 91 key pollutants released to air, water and land. Our first contribution is therefore to produce a *geography of toxic pollution*. Accordingly, still nowadays many left-behind places are still heavily dependent on fossil and other toxic industries, mainly producing metals, minerals, coal and other raw materials.

Given the geography of toxic pollution, our second contribution is to investigate the nexus between toxic industrial pollution and the socio-economic spillovers on industrial labour markets. For doing so, we combine facility-level pollution, aggregated by sector at the regional level. Our analysis covers more than 1.200 NUTS-3 regions for 15 European countries, over the period 2007-2018, and includes high-polluting traditional industries. This allows to detect eventual lock-in effects in bad specialization strategies. In this way, our contribution lies in identifying the particularities of left-behind places. Third, after mapping toxic pollution to left-behind places we study channels and sources of spillovers from industrial activities to the whole regional economy. Next, we build two indices of pollution: a toxic pollution index, weighting the quantity of pollutants emitted by their toxicity (via CAS number), and a concentration index, capturing the pollutant portfolio at the facility level. The intensity of pollution, i.e., its overall toxicity, and the pollutant concentration are contrasted, by means of quantile regression, against the dynamics of left-behind places in terms of direct sectoral level effects on industrial employment and wages, and indirect regional level effects (NUTS-3). By the latter, we study the eventual spatial spillovers in the regions left-behind, in terms of employment, wages and demographic losses.

We lay out two effects of toxic pollution: a first-order effect according to which intensity of toxic pollution is positively associated with employment and wages at the industrial level. Not surprisingly, this result mainly holds for the lower quantiles of wages and employment distributions, therefore in favour of the *noxious dependence* that left-behind places have developed with industrial decay. A second-order effect according to which the reduction of the pollutant mix at the facility level, a proxy for technical change regarding environmental efficiency, is negatively associated with industrial employment and wages, again with higher magnitudes for the lower quantiles of the distributions. The increasing concentration of pollutant portfolios over time represents a proxy for clean technology adoption processes ensuing labour-saving effects in the facility/industry of adoption inasmuch it reduces the number of toxic compounds. Therefore, environmental-efficiency technologies, proxied by higher pollutant concentration, are associated with labour-saving effects at the industrial level. In this respect, the abatement of toxic pollution via improved environmental efficiency and clean technical adoption might spur employment reallocation toward other, less noxious sectors of activity, rather than noxious industrialization. We finally document the existence of spatial inequality feedback loops at the regional level, according to which toxic pollution is robustly negatively associated with migration outflows from left-behind places. Vice versa, environmental technology adoption, proxied by higher pollutant concentration, reduces the probability of leaving the place. Therefore, direct effects toward the industrial labour market propagate into the regional economy as whole, inducing indirect, negative spillover effects.

Putting together our results, this makes the case for understanding the materialistic histories of left-behind places. While the literature stresses the multidimensionality of such a concept (MacKinnon et al., 2022), so far it has contented itself with investigating the socio-economic and in particular cultural-political consequences (see, e.g., Rodríguez-Pose, 2018; Dijkstra et al., 2020; MacKinnon et al., 2022). At the same time, it remains silent on the environmental dimension. We suggest to include the latter in the notion of left-behind places by proposing exposure to toxic pollution as a structural socio-economic driver of degradation to be taken into account. Indeed, deindustrialization might easily end-up in industrial decay, without record of employment reallocation in other sectors but rather lock-in in bad jobs. Recent history is indeed plenty of cases of *noxious deindustrialization* (Feltrin et al., 2021) wherein employment losses and toxicity continue to coexist and reconversion is not taken up. Such consideration opens the issue of the political economy (Hassink et al., 2014) of left-behind places insofar they might turn into “sacrifice zones” (see Lerner, 2012) which can - and somewhat have to - bear the cost of unsustainable development strategies. Overall, the 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 toxic pollution is crucial for the design of place-specific industrial policies able to reconvert sacrifice zones by reducing toxic pollution, thus fostering the transition to a more socially and environmentally just society.

The rest of the article is structured as follows. The following section 2 embeds the environmental dimension of left-behind places into an evolutionary economic geography perspective, which proves to be well equipped for tracing toxic pollution to socio-economic deprivation through different theoretical channels. Section 3 describes our data and methods, including how we construct our explanatory variables. We then show some descriptive evidence to give a nuanced account of the geography of toxic pollution in Europe, both at facility and regional level, and disaggregated by sector (Section 4). Section 5 explains our estimation strategy and shows the estimation results, for both the direct effect focused on industry, as well as the indirect effect on the regional economy as a whole. Section 6 concludes and lays out several policy considerations.

2 EEG and Left-behind places

The geography of discontent and left-behind places are closely related concepts. With the recent surge of populist and anti-system tendencies around Europe (Rodríguez-Pose, 2018), for instance the Brexit referendum (Goodwin and Heath, 2016; Antonucci et al., 2017), left-behind places conceptually have received increasing attention. While the term "left-behind" has been around in regional inequalities studies since 2006, less attention has been given to its link with the environmental dimension. Such places have in common the experience of economic stagnation or even decline, depressed wages, demographic loss and a general pattern of abandonment. This marginalisation was then compound by the policy tendency to target urban agglomerations, "smart cities", and innovative hub-clusters as main engine of economic growth (MacKinnon et al., 2022). The ballot box backlash brought to the forefront socio-economic issues that have grown out of long-term tendencies, but have often been neglected by the economics literature. Hence, while deindustrialized, marginalized and declining areas have moved out of policy focus, their urgent political relevance has sparked general renewed policy attention.

The EEG has not yet devoted specific attention to the geography of left-behind places and neither to the geography of toxic pollution. However, left-behind places are conceptually not so far from uneven development theory (Prebisch, 1950), which builds upon dependence, power structure and persistent positional asymmetries (Pavlínek, 2018; Leyshon, 2021). Uncovering left-behind places involves expanding the more traditional evolutionary economic literature on North-South gaps and unequal development (Cimoli and Dosi, 1995) with a territorial and geographical focus (Boschma et al., 2017) in order to advance the identification of the so-called triple crisis of contemporary capitalism (Mazzucato, 2020). Only since very recently, EEG is seeking to accommodate the notion of crisis within its framework in order to explore the resurgence of uneven development as a political problem with socio-economic underpinnings.

We contribute to this new endeavour by viewing EEG through the lens of the crisis and, in particular, the environmental crisis. We therefore advance with respect to the geography of discontent focusing on the political consequences of left-behind places. Based on facility-level data stratified by industry and mapped on the geographical area, our approach provides a micro-level evidence of the coexistence of a labour market and an environmental crisis. By adding the environmental crisis to the social and economic crises, we also contribute to the pressing need of linking the literature on economic geography with climate and ecological challenges. While this literature rightly acknowledges that the economy is a complex system embedded in societal and natural environments, evolutionary understanding applied to the goal of increasing social and environmental justice[1] must be heightened (Adkisson, 2009).

EEG proves to be equipped with the appropriate toolbox to trace the materialist histories of such left-behind places. Long-term polluted regions witness gradual changes not only to

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[1] 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 U.S. (Kuehn, 2000; Villa, 2020).

human health and the physical environment, but also lead to broader socio-economic decay through channels laid out in the following subsections. In fact, the evolutionary economics literature can contribute to understanding the industrial lock-ins of high-polluting facilities that, in many places, have created a landscape of territorial and environmental crisis. We provide an explicit connection between unsustainable industrial economic system risking social equity and growing environmental problems, and its implications for regions and regional development.

The following subsections explain the intersection between a new conceptualization of left-behind places under the lens of EEG. We mobilize three concepts of the EEG toolbox namely path dependence and regional lock-ins, environmental technologies and their effects on labour markets, and the political economy of left-behind places, including spatiality of power.

Path dependence and regional lock-ins

The first tools from EEG we confront are path dependence and regional lock-ins. Indeed, path dependence and regional lock-ins are among the main channels explaining the materialistic dimension of left-behind places. The two latter processes can go in both ways, good and bad "equilibria". EEG gives much attention to the drivers of regional diversification, in order to understand how regions develop into existing technologies and growth paths. In fact, a high degree of diversification is associated with a higher probability to innovate. The phenomenon, also known as Jacobs externalities (Jacobs, 1969), predicts diversification as a driver of growth, because spillovers propagate from one industry to another. In addition, diversification, and even more, coherent diversification has been proven to be a quite successful recipe for growth and shock resilience (Frenken and Boschma, 2007).

However, spillovers might also be negative, turning into paths of lock-in. Given the high clustering of innovative and complex industrial activities, agglomerations create spatial inequality feedback loops (Pinheiro et al., 2022). On the contrary, specialisation, and especially specialisation in the production of less dynamic products, pushes toward low growth trajectories and high vulnerability to crises (Dosi et al., 2022). Lock-ins entail place and history-dependent paths occurring by means of the continuous reproduction of localized knowledge and socio-technological regimes. Indeed, the properties of sectoral systems of innovations have been long ago identified as crucial for economic development (Malerba and Orsenigo, 1996).

The flip sides of industrial diversification and concentration are environmental consequences deriving from the productive composition of the region. Traditionally, heavy industries are expected to differ in their technological regimes of innovation and competition compared to others (Breschi and Malerba, 1997). In fact, they are not susceptible to neither high levels of innovation nor intense competition (Tödtling and Trippl, 2005). Therefore, ex-ante, heterogeneity of between-sectoral pollution patterns are expected to be more relevant than within-sectoral ones, therefore assuming that industrial facilities are equally responsible for toxic pollution. However, research on disproportionality (Freudenburg, 2005; Collins et al., 2016) and co-pollutant elasticities (Dedoussi et al., 2019; Zwickl et al., 2021), looking at pollution at the facility-level, finds little evidence for technological imperatives to pollute. In fact, in general it seems that major polluters are often within-sector outliers characterised by a low rate of efficiency, indicating that environmental damage is often neither economically nor technologically required by the variety of production techniques available. In this respect, pollution, and particularly high-scale toxic pollution, is a proxy for low-technological dynamism and absence of investment in efficient techniques of production, rather than a necessary externality.

Consider for instance the well-known case of the ILVA steel plant in Taranto, Italy (Greco and Bagnardi, 2018). The latter represents a clear combination of lack of technological upgrading, absence of investment in enhancing techniques of production and purported employment-health trade-off, revealed by an ownership-managerial orientation historically resistant to promote technical progress in the plant. However, the mono-industrialization pattern of the area has created a strong economic dependence in terms of job opportunities. Another example is the once-notorious Ruhr region in West Germany, and especially the cities of Duisburg and Bochum. Nowadays, this region is marked by a high incidence of toxic pollution and structural weakness, indicating the importance of equity considerations (Arora and Schroeder, 2022). Grabher (1993) gives an in-depth explanation of the lock-in of regional development in the Ruhr area, once a complex industrial growth pole, deeply specialized in coal, iron and steel. As we shall show, many industrial complexes, especially in the energy and steel industry, are still operating in this area, however the social contract unraveled and employment worsened or disappeared. The author puts forward the “weakness of strong ties” as the main cause of such lock-in trajectories. Hence, the understanding of left-behind places, especially with respect to deindustrialization, is still often about political and economic factors, but it should also be extended to include the strong exposure to still ongoing toxic pollution (Feltrin et al., 2021).

The Ruhr area is one of multiple examples in Europe for regional traps of rigid specialization, whereby a highly specialized infrastructure, interfirm clustering, and strong political support by regional institutions let to a multidimensional lock-in that prevented the reorganization of such areas (see also Tödtling and Trippl, 2005). This leads to polluting-industry lock-in being a multi-level, stratified process. Lock-in creates economic dependence and impedes opportunities of transition toward decarbonization paths (Lamperti et al., 2018).

Environmental technology in toxic industries and labour market effects

The empirical literature points to mixed results on whether new technologies are labour-saving or labour-friendly. As summarized by Calvino and Virgillito (2018); Vivarelli (2022), a positive relationship tends to be found in high-tech sectors and with regards to product innovation. Labour-saving effects are associated with process innovation in more traditional, low-tech sectors such as the chemical industry, which counts to the highly toxic industries.

On the one hand, regarding efficiency-enhancing technologies in toxic industries, several empirical contributions confirm that environmental technologies in process innovation tend to destroy jobs. For instance, Sheriff et al. (2019) find that new air quality standards negatively affect employment in US power plants, as they have contributed to labour-saving technical change. In a similar vein, Raff and Earnhart (2020) conclude that environmental enforcement targeted at chemical manufacturing facilities negatively affects labour directly dedicated to production.

On the other hand, Biggi et al. (2022) show that R&D investments and therefore also patent activities are continuing for toxic chemical compounds, a finding that sheds light on the dark side of innovation. Furthermore, they find evidence for inventing around banned components, such as Persistent Organic Pollutants (POPs), which are also covered in our data set. Those chemicals are highly toxic and persistent and hence are subject to constant observation, while 28 POPs are completely banned from production.

Our analysis covers high-polluting industries (energy, metals, minerals, chemicals, etc.), largely characterized by low-tech, scale-intensive facilities. Hence, we investigate whether efficiency-enhancing technologies are actually labour-saving, leading to employment losses in facilities and sectors of adoption. Lacking a direct measure of adoption, we proxy environmental technology as the facility-level reduction of the mix of toxic pollutants emitted. Therefore, we intend the ex-post reduction of pollutant mixes as a proxy for recombination of materials, parts, components, and energy processes able to reduce the end pollutant mix. For this purpose, our analysis makes use of a newly created pollution concentration index that accounts for pollution reduction at the source, i.e., it is an indicator for cleaner production. Departing from facility-level data, we are interested in understanding the potential employment effects of pollutant-mix reduction technologies and processes. In this way, we test for a potential labour-saving effect of environmental technology.

The political economy of left-behind places

Are left-behind places a necessary cost to pay for economic development? In the presence of toxic pollution, left-behind places can be considered industrial sacrifice zones (Lerner, 2012) with socio-economic erosion as key agent necessary for the reproduction of spatialities of power marking the difference between cores and peripheries. Exposure to toxic harm coupled with the slow decay of chemical change maintains and reinforces the regional divergences. The concept of sacrifice allows to conceptualize toxic pollution as an intended imposition of power over a region and its inhabitants, creating an uneven toxic geography, and implies the "right to pollute" enabled by a naturalized economic power (Freudenburg, 2005).

Industries that are dirtier, more dangerous and more threatening to human health present a special case for the spatiality of power, as conceptualized by Massey (2009). Around those industries, social and labour struggles are actually shaped by their objective relation with capital directed to polluting activities. Given that such places have material interests embedded into the production process, place and path dependence mutually reinforce each other, and lead to a lock-in of pollution-dependent growth. Indeed, the geography of toxic pollution might also help to understand the direction in which the political economy of left-behind places might manifest by means of the spatial reproduction of power.

3 Data and Methods

Our aim is to give an account of the geography of toxic pollution in Europe, to then study the effect of toxic pollution on economic deprivation, in particular with respect to employment, wages, and net migration flows. This allows us to investigate the environmental dimension of left-behind regions. We combine two data sets in a novel way: facility-pollution data and regional economic data at sectoral level, covering more than

1.200 regions in Europe, over the period 2007 - 2018. Subsection 3.1 describes the data set of facility-specific industrial pollution sourced from the E-PRTR, which we use to calculate two measures at the sector-region-year level. The first index is the facility-level pollution augmented by its toxicity which informs about an intensity effect (Subsection 3.2), while the second is a pollutant concentration index which informs about the mix of the facility pollutant portfolio (Subsection 3.3). Subsection 3.4 presents the industry level distribution of the constructed indices. Subsection 3.5 describes the set of outcome variables sourced from Cambridge Econometrics (employment and wages) and Eurostat (migration) which illustrate the different dimensions of left-behind places.

3.1 Industrial Facilities, sourced from E-PRTR

We get facility-level pollution data from the European Pollutant Release and Transfer Register (E-PRTR) that provides environmental data from industrial facilities in European Union Member States, Iceland, Liechtenstein, Norway, Switzerland, Serbia and the UK (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. Each active industrial facility is required to provide annual information on the deliberate and accidental quantities of pollutants released to air, water and land. This 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 introduction into 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.

Annex I of the E-PRTR Regulation lists 65 activities, which we group into 7 activity sectors: agriculture and leather industry, chemical industry, energy, production and processing of metals, mineral industry, paper and wood production and processing, waste and waste water management. The information to which sector a facility belongs allows for an industry-specific analysis.[2]

To build our original data set, we select emissions released by air, taking into consideration both deliberate and accidental emissions, and drop facilities with data entries for four or less consecutive years, as we want to focus on polluters that have shown some degree of continuity with regard to their presence in and hence possible impact on the territory.[3] Facilities that did not exceed a threshold of emissions as established by the Commission (2006, pp. 83–86) do not have to report in the E-PRTR in that specific year (even though these facilities were still operating), which leads to missing data within the facility-specific time series. If pollution records are missing in one or more years, but are present before and after, we perform linear interpolation in order to control for those falsely missing values.[4]

To sharpen our analysis, we drop the countries that belong to the lowest five percent in terms of the number of polluting facilities. This leaves us with the following 15 countries: Austria, Belgium, Czech Republic, Germany, Spain, Finland, France, UK, Greece, Italy, Netherlands, Poland, Portugal, Romania, and Sweden.

The top-ten polluting facilities of the four most toxic sectors (energy, metals, minerals, chemicals), are presented in Table 1. It lists the name of the facilities as well as the countries and cities that host such facilities, which provides a first glimpse of the detailed information provided by the E-PRTR dataset.

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[2] An extensive overview of the E-PRTR classification including a detailed description of all activities covered by out data can be found in the Appendix, Table 8.

[3] The minimum presence in the data set is one year, the maximum 13. On average, a facility has pollution entries for ten years. Eleven per cent of facilities are present in the data base for five years or less. Those are the facilities that we exclude from the analysis.

[4] This is motivated by the assumption that missing values, i.e., gaps, arise from the threshold issue. Missing years at the beginning or the end of the time period instead indicate the seized activity of a facility, and therefore are not interpolated.

Name of Facility	*Country*	*City*	*Log Poll.*
Energy			
PGE Górnictwo i Energetyka Konwencjonalna	PL	Rogowiec	12,61875
PPC S.A. SES AGIOY DHMHTRIOY	GR	Agios Dimitrios	12,58762
Drax Power Station EPR/VP3530LS	GB	Selby	12,24817
ENEA Wytwarzanie Polsce energii	PL	Swierzach Górnych	12,01695
LEAG Lausitz Energie Kraftwerk Lippendorf	DE	Neukieritzsch	11,81845
LEAG, Kraftwerk Jänschwalde	DE	Teichland	11,77331
RWE Power AG Kraftwerk Niederaußem	DE	Bergheim	11,66642
RAFFINERIA DI GELA SPA	IT	Gela	11,48725
Elektrownia ZE PAK S.A. Patnów	PL	Konin	11,45654
Elektrowni Adamów	PL	Turek	11,44843
Metals			
ArcelorMittal Italia (ILVA)	IT	Taranto	14,15508
Outokumpu Chrome&Stainless Oy, Tornion	FI	Tornio	13,63423
ACCIAI SPECIALI TERNI - stabilimento di TERNI	IT	Terni	12,89282
Tata Steel IJmuiden BV	NL	Velsen-Noord	12,60091
ArcelorMittal Fos Sur Mer	FR	Fos Sur Mer	12,14459
ArcelorMittal Dabrowa Górnicza steel plant	PL	Dabrowie Górniczej	12,01051
thyssenkrupp Steel Europe Werk Schwelgern	DE	Duisburg	12,00896
ARCELORMITTAL FRANCE	FR	Dunkerque	11,77123
Port Talbot Steelworks Tata Steel	GB	Port Talbot	11,73189
ARCELORMITTAL LIEGE sa (Coke-Fonte)	BE	Ougree	11,62174

Name of Facility	*Country*	*City*	*Log Poll.*
Minerals			
CBR sa - Site de Lixhe	BE	Lixhe	10,49804
HOLCIM Belgique sa - Usine d'OBOURG	BE	Obourg	10,31415
CEMEX Polska Cementownia Chelm	PL	Chelm	9,582096
CCB sa - Site de Gaurain-Ramecroix	BE	Gaurain-Ramecroix	9,302887
TITAN CEMENT S.A. - KAMARI PLANT	GR	Kamari	9,148636
Whitwell Works	GB	Worksop	9,146606
HERACLES G.C.Co, VOLOS PLANT	GR	Portaria	9,055297
Górazdze Cement S.A. - Cementownia	PL	Chorula	9,026553
VERALLIA FRANCE	FR	Chalon sur Saone	9,007586
Grupa Ozarów S.A.	PL	Karsy	8,876104
Chemicals			
Runcorn Halochemicals EPR/BS5428IP	GB	Runcorn	12,17456
INOVYN FRANCE	FR	Tavaux	11,20224
KEM ONE LAVERA	FR	Martigues	10,86025
NAPHTACHIMIE	FR	Martigues	10,74064
SC CHIM COMPLEX S.A. Borzesti	RO	Ramnicu Valcea	10,52307
BASF SE	DE	Ludwigshafen a.R.	10,0455
VYNOVA BELGIUM	BE	Tessenderlo	9,865824
Spolana Neratovice	CZ	Neratovice	9,709022
ORLEN Unipetrol RPA	CZ	Litvínov	9,68126
ThermPhos International BV	NL	Ritthem	9,323645

Table 1: Top-10 polluting facilities that operate in the energy, metals, minerals, and chemicals industries. The column "*Log Poll.*" refers to facility pollution summed over all years, in logs. Source: Own calculation based on E-PRTR.

3.2 Measuring toxic pollution

The E-PRTR allows to disentangle pollutants and their underlying toxicity. Indeed, it is well known that pollutants from industrial facilities are dangerous to human health and the environment. The amount of pollution and its pollutant mix is a result of the existent technologies and production processes of the industrial system. Although progress has been made in terms of reduction of the environmental impacts of toxic pollution from industry through regulations and bans, the evidence tells us that there are still innovative search efforts around toxic chemical components (Biggi et al., 2022). Moreover, as we shall see, even banned compounds are still present in the E-PRTR, as for example hexachlorobenzene and polychlorinated biphenyls, which are banned globally and universally. They belong to the ten most toxic pollutants present in the data.

In terms of toxicity, the chemical with the highest toxicity in absolute is mercury and its compounds (HG), which clearly emerges as an outlier being twelve times more toxic than the average compound in the data set, and is a highly potent neurotoxin that is closely linked to energy production. Given that evidence, it is worrying to see that environmental protection agencies fail to acknowledge and account for the direct ecological and health benefits from the reduction of air toxins. For instance, in 2020 the EPA proposed to roll back its Mercury and Air Toxics Standards (MATS) as regulatory limits on hazardous air pollution from coal-burning power plants (EPA, 2019).[5] It is hence crucial to account for pollutant's toxicity which differs widely across pollutant groups and single compounds. Given the heterogeneous toxicity of the different pollutants we weigh pollutants by their toxicity.

We focus on long-term exposure to all pollutants that are known to be dangerous for human health. Out of the original 91 key pollutants we retain 41 distinct pollutants, whose toxicity varies by several magnitudes.[6] The chemical group of heavy metals are the most toxic; at the same time they are frequent due to wide industrial application. As said, the data set also shows the presence of several pollutants that are banned worldwide since the Stockholm convention from 2001.

We account for the variation of toxicity by weighting the quantity (mass in kilogram) of each pollutant by a toxicity weight that we source from the USEtox 2.12 data base, as shown in Equation 1. We match pollutants with their respective toxicity via information on Chemical Abstracts Service numbers (short CAS), which are numerical designations for chemicals of the American Chemical Society. The same methodology has been applied,

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[5] This decision is based on cost-benefit analyses, trying to economically justify industrial contamination and disregarding the significant health and environmental benefits by reducing a broad range of hazardous air pollutants, especially mercury, as argued by Aldy et al. (2020), see also Ofrias (2017).

[6] The full list of toxic pollutants retained for this analysis can be found in the Appendix, Table 7.

for instance, by Rüttenauer and Best (2021).[7] USEtox is a scientific consensus model endorsed by UN's Environment Programme "Life Cycle Initiative" for characterizing human and ecotoxicological impacts of chemicals. By matching each pollutant to a toxicity weight, we enable the comparative assessment of chemicals, i.e., the toxic significance of releases of different pollutants.

Therefore, at facility level, pollution quantity weighted by toxicity, called *Tox Poll* hereinafter, can be defined as:

$$Tox\ Poll_{it} = \sum_{p=1}^{P} Tox\ Weight_{p} * Quantity_{ipt} \tag{1}$$

for each pollutant p and facility i in year t. In 2007, total weighted toxic pollution amounted to 1.62 billion tons. In comparison, in 2017, facilities released a total of 1.29 billion tons. The facility-level measure $Tox\ Poll_{it}$ will then be aggregated by sector and region later on, which will be our main explanatory variable throughout the analysis.

The summary Table 2 illustrates the scope of the E-PRTR data set in terms of countries, facilities, and distribution of distinct pollutants and toxic pollution in Europe. Countries are ranked by their number of facilities. While the four larger economies rank in the top positions, the evidence reveals the presence of eastern countries as Poland and Czech Republic among highly toxic polluted countries, while Sweden, the Netherlands and Finland rank in the bottom. Therefore, the index informs about different polluting strategies and ensuing impacts across facilities by countries.[8]

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[7] The E-PRTR provides the CAS numbers for large majority of the present components. We have attributed the missing CAS numbers manually if applicable, collaborating with an organometallic synthetic chemist to ensure accuracy in the matching. In the case of heavy metals the CAS registry number for the most stable metal cation was assigned, which matches the form typically encountered and most revelant in the environment.

[8] Note that the data set does not provide any information about the productive output or the profit rates of such facilities.

Country code	Number of facilities	Number of distinct pollutants	Toxic pollution emitted	Percentage total toxic pollution
FR	513	33	24874	13.97
ES	382	32	23666	13.30
DE	397	31	23494	13.20
GB	603	38	20385	11.45
PL	273	30	19242	10.81
IT	267	31	13963	7.84
CZ	93	27	11361	6.38
BE	169	37	9957	5.59
GR	37	27	6552	3.68
PT	79	22	6050	3.40
SE	77	25	4786	2.69
NL	137	29	4775	2.68
FI	81	20	4712	2.65
RO	39	17	2265	1.27
AT	32	20	1920	1.08

Table 2: Summary table of industrial facilities in E-PRTR sample, by country. Toxic pollution is expressed in million of tons and weighted by toxicity. The last column "Percentage total toxic pollution" refers to a country's share of toxic pollution to all pollution in the data set, and sums to 100. The first row in the summary table shows the country with the highest level of aggregate toxic pollution.

3.3 Concentration index of pollutants

Other than the level of toxic pollution, we are interested in the pollution portfolio, i.e., in the composition of toxins. In fact, we observe a great deal of heterogeneity with respect to the number of distinct pollutants emitted at facility level. Figure 1 shows the histogram of distinct pollutants by facility, ranging between one and 21, with an average of six pollutants by facility and year.

The literature on co-pollutants with respect to CO_2 confirms this finding (Dedoussi et al., 2019; Zwickl et al., 2021; Boyce, 2020), acknowledging very heterogeneous levels

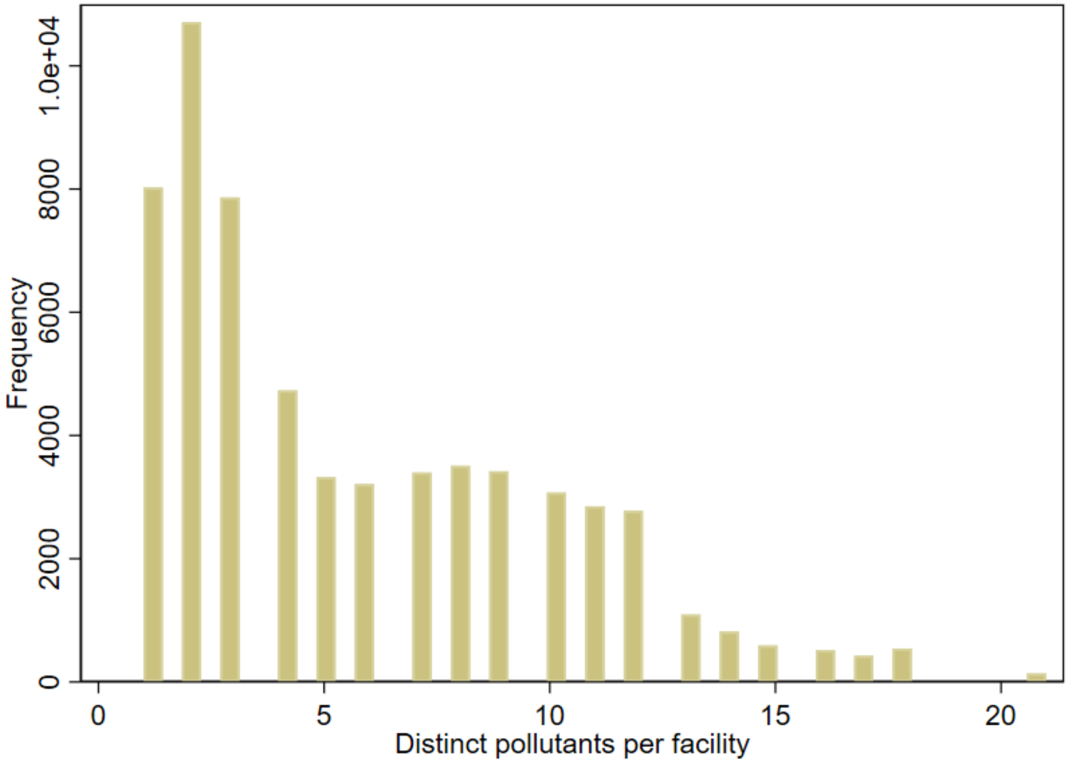

Figure 1: Histogram of distinct pollutants by facility. Source: Own calculation based on E-PRTR.

of so-called co-pollutant efficiency for fixed amounts of CO_2.[9][10] To capture the heterogeneity of the pollutant portfolio, we construct a Herfindahl-Hirschman Index (HHI) of the concentration of number of distinct pollutants at facility-year level, calculated as:

$$HHI_{it} = \sum_{p=1}^{N} p_{it}^2, \tag{2}$$

where p is the number of distinct pollutants. The mean of this facility-level HHI is 0.46, i.e., on average we have a portfolio of three distinct pollutants.[11]

The index accounts for the composition effect, and in that proxies for the degree of innovativeness (backwardness) of the production process in use. In line with this, Freudenburg (2005) finds that major polluters are often inefficient producers of low-value commodities. Hence, this measure goes beyond so-called end-of-pipe technologies, which are mostly driven by incremental innovations as they are aimed at mitigating already existing environmental problems. What we aim to capture, instead, is the implementation of technological and production processes that reduce the amount of dangerous, polluting substances introduced into water, land, air, therefore reducing the danger for society and environment. Such transition and conversion processes then lead to changes in the technological-organizational structure of the firm, and can be considered as a form of eco-innovation as described in Cecere et al. (2014). From the point of view of the firm, adopting new production processes for pollution prevention can be motivated by cost reduction, productivity gains, safety issues, waste reduction, and the adaption to technological change.

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[9] Co-pollutant efficiency measures the ratio of co-pollutant damages to carbon dioxide emissions. From a policy point of view, such co-benefits arise when compliance with a regulation leads to reductions in other pollutants that were not the regulation's intended target.

[10] The E-PRTR does not provide data on industrial output or production, hence those contributions to the literature use CO_2 as a proxy for size.

[11] The minimum of the index is 0.05, i.e., 21 distinct pollutants, indicating that a facility emits a very large quantity of different pollutants (half of all possible pollutants in the data set). Energy and metals are the two main industries with a multi-pollutant portfolio. The maximum of the index is 1, which are mono-polluters.

3.4 Why industries matter

We move toward aggregating facilities at the industry level. In fact, we are interested in the industry composition with respect to toxic pollution and composition of pollutant groups. Given that our data set is industry and pollutant specific, we are able to disaggregate and visualize toxicity-weighted emissions by industry by pollutant groups.[12] Figure 2 below shows the disaggregation of such pollutant groups by industry. Heavy metals account for the largest share of toxic pollution across all industries, except for the chemical, agriculture and leather industry, however their pollutant portfolios vary significantly. The energy and metal industry are the heaviest polluters, and their sectoral characteristics show high percentages of heavy metals compared to other pollutant groups: approximately 50 per cent of toxic pollution coming from energy is associated to the release of heavy metals, while this share increases to approximately 70 per cent for the metal industry (see blue segment of bars).

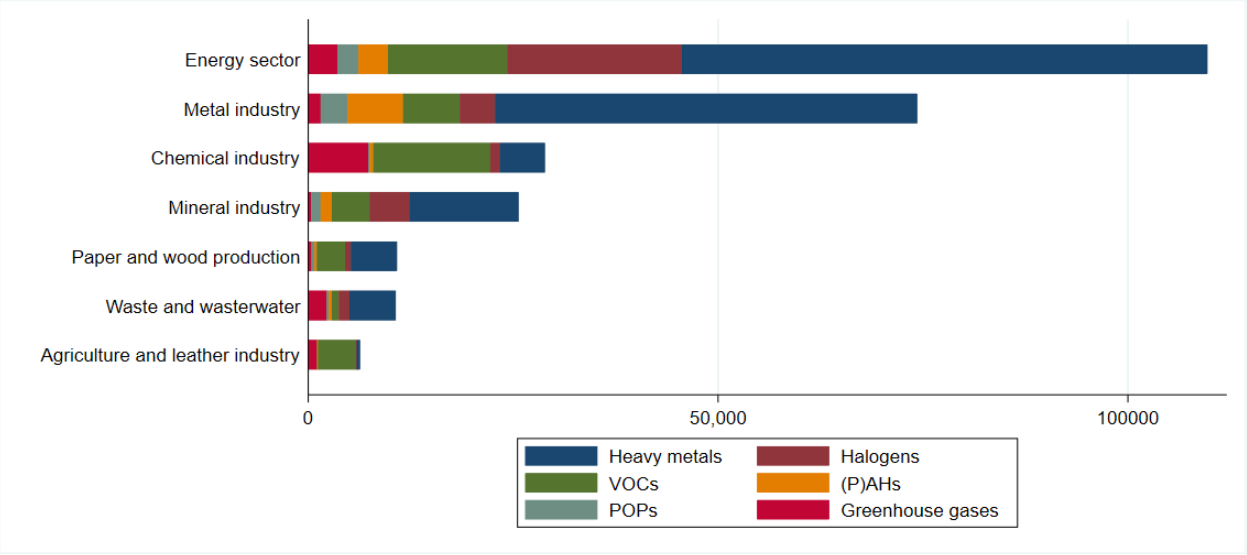

Figure 2: Total toxic pollution by industry, disaggregated by pollutant groups, and ranked from industry with highest toxic pollution to lowest, over 2007–2018. Source: Own calculation based on E-PRTR.

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[12] We distinguish between the following pollutant groups: Greenhouse gases, halogens, heavy metals, (polycyclic) aromatic hydrocarbons ((P)AHs), persistent organic pollutants (POPs), and volatile organic compounds (VOCs). Note that even though the E-PRTR collects information on CO_2, it has no toxicity information for local exposure and hence is not part of our data sample, which focuses on industrial pollutants known to be dangerous for human health.

Within the energy sector, the release of mercury and other highly noxious heavy metals is mostly associated to coal combustion but also oil-fired power plants (EPA, 2019). This makes the alarming case for the biggest industrial emitters of globally-harming CO_2, often situated in proximity to urban zones, being also a highly dangerous local polluter.

Next, we explore the inter-industry variability of our measures of toxic pollution and how they evolve over time. For doing so, we depict mean toxic pollution, in logs, and mean pollutant concentration, as by the index HHI, by industry over time (see Figure 3). The overall trend of toxic pollution is slightly decreasing, meaning that most industries were able to moderately curb their toxic emissions down. The metal, waste and wastewater, and paper and wood production industries, however, show a stagnating trend over the period 2007-2018.

The pollutant concentration index is a proxy for technological efficiency at the sectoral level, e.g., the end effect of the adoption of pollution-abatement technologies, potentially induced by environmental regulations, that reduce the number of co-pollutants emitted. As shown below, the index increases over time, i.e., the average number of pollutants by region and sector decreases as facilities on average reduce their number of pollutants by approximately 20%: from 0.41 in 2007 to 0.49 in 2018. The HHI measures the production of co-pollutants especially for the energy sector, where CO_2 is the main pollutant. However for the remaining industries, it is mainly a proxy for environmental and technological efficiency.

Across-industry variability of both measures is very high. The energy and the metal industry clearly emerge as the two most pollution-intense and toxic industries (see blue and dark red line in upper panel), while other sectors contribute very little to overall levels of toxic pollution, for instance waste and wastewater (orange line), and agriculture and leather industry (green line). Average pollution concentration is more clustered than toxic pollution. With regard to the former, the agriculture and leather industry emerges as an outlier, with an index close to one which indicates mono pollution.

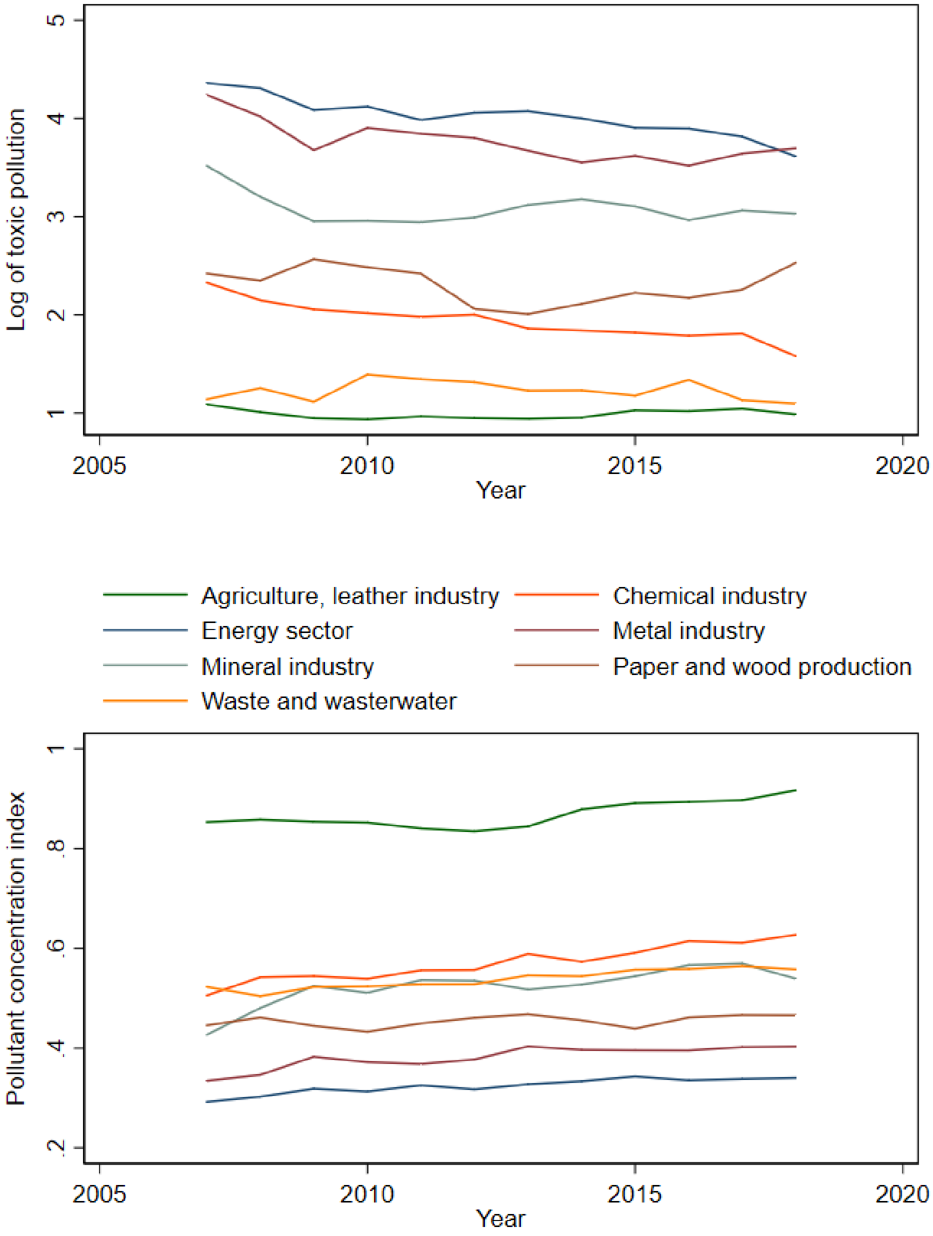

Figure 3: Mean toxic pollution by industry from 2007 to 2018 (upper panel) and mean concentration index of pollutants by industry from 2007 to 2018 (bottom panel). Source: Own calculation based on E-PRTR.

The energy industry has the lowest pollutant concentration index, i.e., on average is the industry that emits the highest number of different toxic pollutants (blue line in bottom panel), followed by the metal industry (red line in bottom panel).

Higher levels of toxic pollution are on average associated with lower levels of pollutant concentration, i.e., tend to have multi-pollutant portfolios as they emit a great variety of different chemicals. A scatterplot confirms this notion of inverse relationship. Figure 4 plots unweighted pollutant concentration against toxic pollution. Every dot of the same color represents one country in our sample. The clear negative relationship indicates that on average facilities with a multi-pollutant portfolio also are bigger emitters.

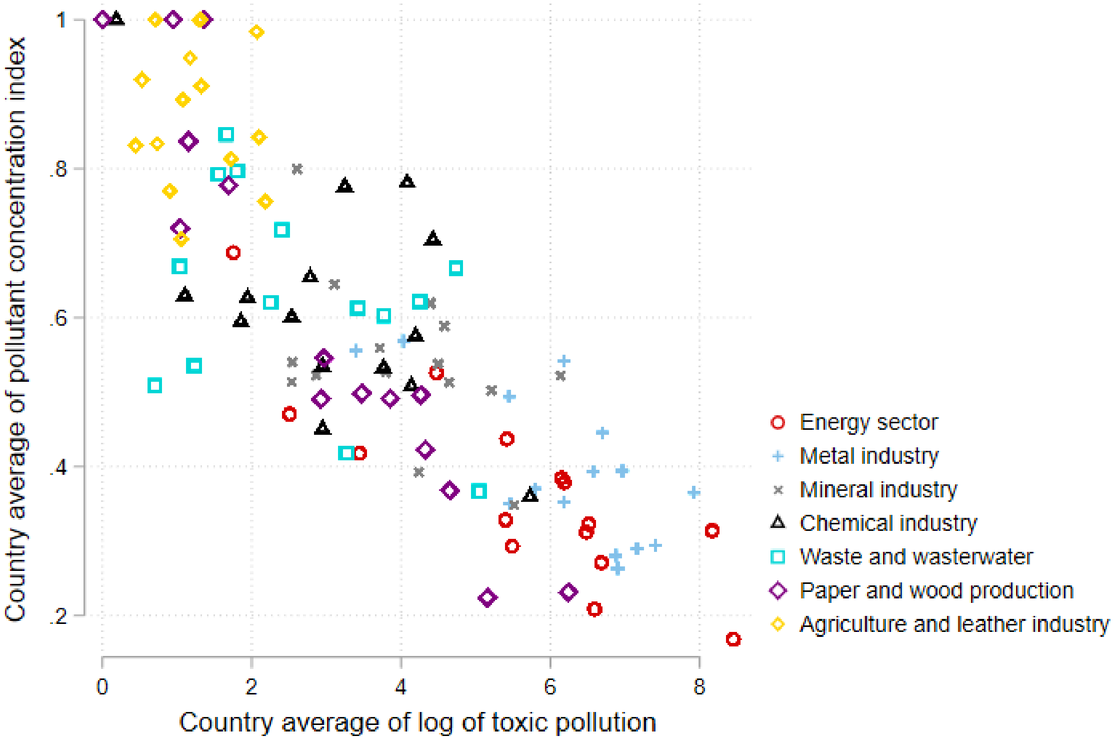

Figure 4: Scatterplot of country averages of pollutant concentration (y-axis) and toxic pollution (x-axis) across 2007-2018. Source: Own calculation based on E-PRTR.

The within-industry clustering, especially strong for industries such as minerals (see grey cross symbols) or metals (see blue cross symbols), reflects industry-specific pollution patterns and production processes. However, we highlight significant within-industry variation across countries. For instance, there are countries in the chemical industry that have comparable levels of toxic pollution but different levels of environmental technology, i.e., pollutant concentration indices (see for instance the vertical variations of the black triangle symbols).

3.5 Regional Economic Variables: Cambridge Econometrics

Next, we turn to the regional economic variables. With those variables, we aim to depict the local labour market in left-behind regions, often characterized by precarious employment, underemployment and demographic changes. The labour market data come from Cambridge Econometrics, which combines regional and sectoral data from both Eurostat's REGIO database and AMECO, which is provided by the European Commission's Directorate General Economic and Financial Affairs. The disaggregated data is available for 27 EU countries (all EU member states except Malta) at NUTS-3 level and six sectors from 1990 to 2018.[13] From this data base, we use employment (both industry and total) which "covers all persons engaged in some productive activity" and wages (both industry and total) for the countries and years as in the E-PRTR data. All variables are expressed in logs.

In addition, we source population changes from Eurostat's "demographic balance and crude rates at regional level". In specific, we look at crudes rate of net migration, which represents total population changes cleaned for natural changes (births and deaths). It is expressed as the change of the population in region r over the past four years.[14]

4 Geography of Toxic Pollution

Our first contribution consists in giving a novel account of the geography of toxic pollution in Europe. Below is shown the spatial distribution of the industrial facilities in our data set. Emission quantity is expressed in kilograms, weighted by human toxicity of each pollutant and summed by facility and across all years in the sample, 2007-2018. The size of the dots is proportional to the amount of toxic pollution released per facility, aggregated

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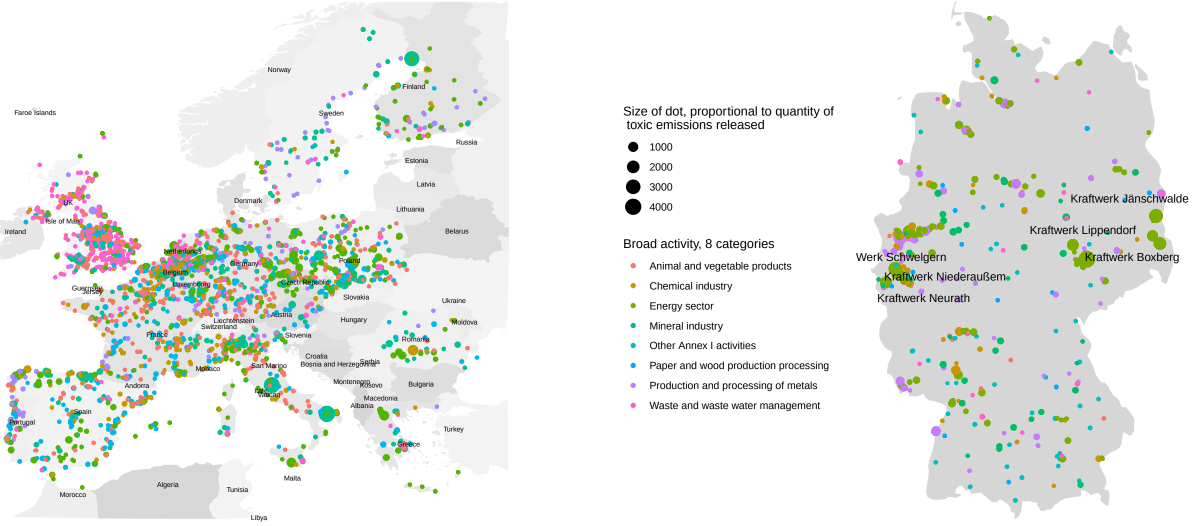
[13] These are: A (agriculture, forestry and fishing), B-E (industry), F (construction), G-J (wholesale, retail, transport, accommodation and food services, information and communication), K-N (financial and business services) and O-U (non-market services).

[14] Section 2 of the Appendix shows a map of employment at NUTS-3 level in Europe and the descriptive statistics of the regional economic variables using violin plots, see Figures 7 and 8, respectively.

into four clusters. The color indicates to which broad activity the facility is associated, as described in the legend of Figure 5.



(a) Europe

(b) Germany

Figure 5: Spatial distribution of industrial facilities in 15 European countries (a) and of Germany (b) over 2007 - 2018. Color of the dots indicates industry, size of the dot indicates quantity of toxic pollution. Source: Own calculation based on E-PRTR.

Most industrial facilities are located in France, Spain, Germany and the UK, and less so in smaller countries and Scandinavia. Furthermore, industries are clustered within countries and regions. We thus carry out our analysis at the sectoral level, not least because sectors are very heterogeneous with respect to toxicity levels and emission quantities.

Zooming in, the example of Germany (Figure 5.b) shows that the facilities that emit the largest amount of toxic pollution are from the energy sector (green large dots). They mostly belong to coal-fired power stations, located in the Rhine area (state of North Rhine-Westphalia, Western Germany) and in Lusatia (state of Saxony, Eastern Germany). However, also other industries are home to major polluting facilities, as for example “Werk Schwelgern”, one of Europe’s biggest steelworks, also located in the Rhine area (city of Duisburg). Indeed, a recent study on structurally weak regions in Germany points to the cities of Duisburg and Dortmund - both in the Rhine area heavily impacted by deindustrialization -, as well as several areas in Eastern Germany (Bitterfeld-Wolfen and Vorpommern-Greifswald) (Das Progressive Zentrum, 2021). This anecdotal evidence points to a potential link between the presence of highly toxic industrial complexes and regional economic deprivation.

The E-PRTR provides geospatial information, i.e., longitude and latitude, for every facility. We use the latest Administrative Level data from Eurostat (2021), and use the same NUTS-3 borders for all years. We attribute a NUTS-3 level code to every point, i.e., a facility's geolocation, that falls within a polygon from the shapefile.[15] This matching strategy results in a data set of approximately 69.000 industry-region-year pairs nested within 1.215 NUTS-3 regions (this methodology is explained, for instance, in Mohai and Saha, 2006). Next, departing from Equation 1, we aggregate toxic pollution at industry-region-year level according to the following specification:

$$Tox\ Poll_{srt} = \sum_{i=1}^{N} Tox\ Poll_{isrt}, \tag{3}$$

where i refers to facilities, s to sectors, r to NUTS-3 regions, and t to years.

Figure 6 displays the distribution of toxic pollution in logs and averaged over the years 2007–2018 across European NUTS-3 regions in the data set. This map shows patterns of clusterisation of toxic pollution: a highly polluted region is likely to be in geographical proximity to another polluted region. Such clusters are visible in particular in Spain, the UK, Germany, Poland, Czech Republic, and Romania. Moreover, we see that the polluted regions are capturing both the deindustrialized (p.ex., Ruhr Valley) as well as rural types of geography (p.ex., North Finland).

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[15] In this way, offshore facilities get dropped from the data set, as for instance oil and gas platforms.

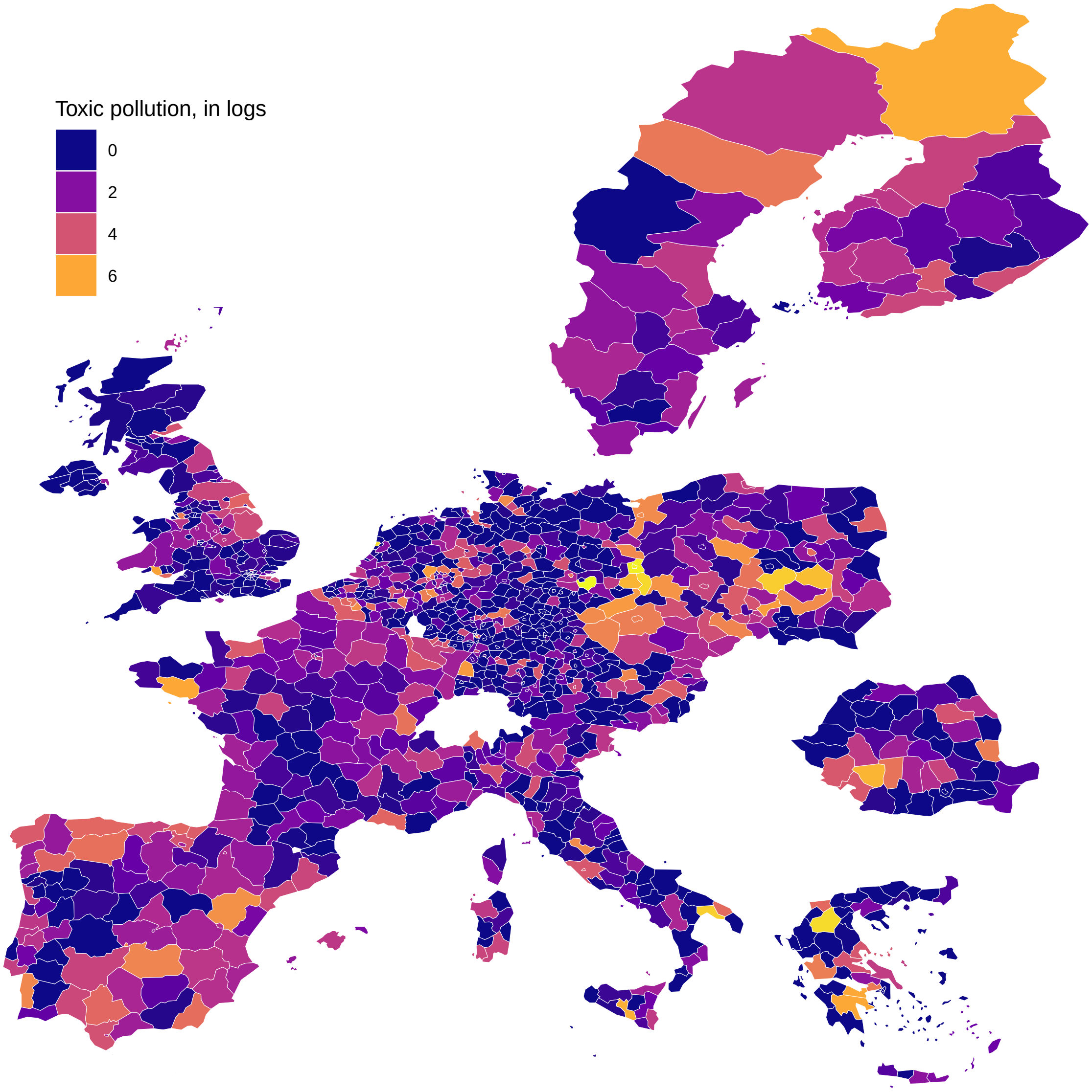

Figure 6: Regional map of toxic pollution in Europe, in logs, averaged over 2007–2018. Source: Own calculation based on E-PRTR.

We proceed in a similar way to regionally aggregate the concentration index of pollutants (HHI). We aggregate the HHI at sector-region-year level, and weight it by the contribution of each sector to the overall regional toxic pollution, expressed as percentage (see right part of equation). The weighted sectoral HHI is then written as:

$$HHI_{srt} = \frac{\sum_{i=1}^{N} HHI_{it}}{N_{srt}} * \frac{Tox\ Poll_{srt}}{Tox\ Poll_{rt}}. \tag{4}$$

This regional concentration index has a mean of 0.22 and a standard deviation of 0.25. Once aggregated, the heterogeneity of the HHI becomes especially visible across industries, with facilities belonging to the energy, metals and paper industry having the highest number of distinct pollutants (so-called multi-polluters), and therefore lower values of the concentration index.

5 Toxic pollution and labour markets in left-behind places

In the following we present our econometric specification distinct in direct effects, estimated for the industrial labour market, and indirect effects, estimated at the regional level, including therefore also non-industrial labour markets. In both cases, we are interested in detecting the effects of toxic pollution on employment, wages and migration (in the regional estimation), in order to characterize the labour market dynamics in left-behind places.

5.1 Econometric Specification

We use quantile regressions as in Koenker and Hallock (2001) to estimate our dependent variables. Quantile regressions are advantageous because they allow us to analyze the different role of toxic pollution for left-behind places vis-à-vis the rest. In this way, we take into account and stress the heterogeneity across regions regarding employment and wages levels, as well as demographic changes. Furthermore, this estimation method is more robust to outliers than OLS models and we do not have to make assumptions about the parametric distribution of the error term (see Koenker and Hallock, 2001). We estimate percentile equations for the 10th, 25th, 50th, 75th, and 90th percentiles. Quantile Regression methods allow flexibility in the estimation of the coefficients enabling to obtain a range of conditional quantile functions (CQF), which in our case will be given by the employment, wages and migration CQF.

Furthermore, we take into account that there are regions in the dataset for which toxic pollution is zero due to the absence of a large industrial facility in that area.[16] Hence, our predictor is left-censored, meaning that we can observe toxic pollution only above a certain threshold, as established by the E-PRTR regulation (European Commission, 2006) and our own methodology that drops non-continuous polluters. We also find that the average employment and wage difference between polluted and censored regions is positive. To correct for the censoring, we introduce a binary indicator variable at region-year level, $Indicator_{rt}$, as specified in Equation 5.[17] Following this approach, we estimate baseline specifications of the following general form:

$$LB_{rt} = \alpha_c + \alpha_t + \beta_1 log(Tox\ Poll)_{srt} + Indicator_{rt} + \gamma \mathbf{X}_{rt} + \varepsilon_{rt}, \tag{5}$$

where the dependent variable LB, “Left-Behind”, is a vector that takes into consideration three different dimensions of being left-behind of a given NUTS-3 region r in year t: log of employment, log of wages and net migration. This is regressed on sectoral toxic pollution, in logs, computed at the regional level. Sectoral toxic pollution is the amount of pollution weighted by toxicity and emitted at the regional level in sector s at time t. $Indicator_{rt}$ is the dummy for the censored regions, for which we do not observe any toxic pollution. α_c and α_t are country and year fixed effects, respectively. $\mathbf{X}_{rt}$ represents the set of control variables, which are lagged gross value added (gva) per capita and lagged employment, both lagged by

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[16] For 23.7 per cent of the data set, we observe the economic variables, but do not observe the level of toxic pollution.

[17] Note that the indicator takes the value 1 for a censored region, i.e., when there is no observed pollution, and 0 otherwise.

four years.[18] Both controls for regional economic activity and lagged employment account for feedback effects from past levels of employment.[19] Standard errors are bootstrapped.

While toxic pollution is a measure of intensity and dangerousness, the concentration index adds the notion of pollutant mix, or negative quality, to the analysis. On average, sectors with multi-pollutant profiles also have higher levels of toxic pollution as shown in Figures 3 and 4. We hence augment the baseline specification by introducing the pollutant concentration index HHI_{srt} at sector-region-year level:[20]

$$LB_{rt} = \alpha_c + \alpha_t + \beta_1 log(Tox\ Poll)_{srt} + \beta_2 HHI_{srt} + Indicator_{rt} + \gamma \mathbf{X}_{rt} + \varepsilon_{rt}. \tag{6}$$

5.2 Direct Effects: Industrial labour market

We consider as direct the first-order effects at the industry level. We look at the effect of toxic pollution and pollutant concentration on industrial labour markets in terms of employment and wages. Table 3 departs from the baseline specification as written in equation (5). The estimation of different percentiles makes emerge a nuanced picture of left-behind places (defined as the 10th and 25th percentiles) vis-à-vis the rest. For industry employment, we find a positive and significant relationship particularly for the lower end of the distribution, i.e., the 10th and 25th percentile (columns 1 and 2). The effect decreases along the quantiles, becoming even negative in the 90th percentile, even though not significant.

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[18] We carry out a robustness check on the control variables by using different lags, from two to five years. However, this does not change the qualitative results of the analysis.

[19] The inclusion of the lagged employment variable is standard in estimation of labour demand equations.

[20] A Wald test between the baseline and the augmented specification confirms the statistical significance between those models.

Table 3: Direct Effects on Industrial labour market, baseline

	Direct Effects on Employment and Wages									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dep. Var:	Industry Employment					Industry Wages				
Quantile (%):	10	25	50	75	90	10	25	50	75	90
Log(Sectoral toxic pollution)	0.014***	0.008***	0.004**	0.001	-0.001	0.008***	0.005***	-0.009***	-0.007***	-0.007***
	[0.002]	[0.001]	[0.001]	[0.001]	[0.001]	[0.003]	[0.002]	[0.002]	[0.002]	[0.002]
Indicator censored regions	-0.474***	-0.344***	-0.267***	-0.186***	-0.099***	-0.301***	-0.135***	-0.096***	-0.026*	0.008
	[0.013]	[0.014]	[0.012]	[0.009]	[0.009]	[0.036]	[0.018]	[0.014]	[0.015]	[0.035]
Log(gva per capita) lagged	-0.335***	-0.160***	-0.013	0.173***	0.340***	0.126***	0.239***	0.409***	0.368***	0.398***
	[0.027]	[0.021]	[0.014]	[0.024]	[0.013]	[0.041]	[0.023]	[0.013]	[0.015]	[0.020]
Log(employment) lagged	0.974***	0.918***	0.909***	0.881***	0.852***	0.253***	0.290***	0.232***	0.218***	0.205***
	[0.007]	[0.005]	[0.006]	[0.004]	[0.003]	[0.016]	[0.007]	[0.007]	[0.005]	[0.014]
Country Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	30,074	30,074	30,074	30,074	30,074	28,314	28,314	28,314	28,314	28,314
Pseudo R2	0.5931	0.5902	0.601	0.615	0.6387	0.3133	0.2996	0.2832	0.3218	0.3725

Notes: Standard errors are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1

Hence, we find the effect to be mostly limited to what we identify as left-behind places, which are characterized by weak labour markets. For instance, for the 10th percentile, a 1 per cent increase in toxic pollution is associated with a 0.014 per cent increase in industry employment. The result highlights the economic dependence, above outlined, that left-behind places manifest with noxious industrialization. In addition it points to poor economic trajectories and bad specialization those places find themselves in, whereby industry employment (even though potentially of poor quality) is directly linked to the presence of noxious facilities. For the regions characterised instead by higher levels of employment, the lack of significance points to a decoupling between industry employment and toxic pollution. Indeed, the higher the employment level of a given region, the higher the economic performance therein, and the lower will be the burden exerted by bad specialization, here proxied by pollution at the sectoral level. Therefore, employment dependence on toxic pollution overall decreases along the conditional distribution of employment.

For industry wages, a comparable picture emerges. While the coefficient of industry wages is positive for left-behind places (column 6 and 7), the effect becomes negative for the higher quantiles. Hence, within regions with low industry wages, toxic pollution is positively associated with wages, again signalling dependence on the sector, while in regions with already high industry wages, the association gets negative. The effect for the 10th percentile is comparable in magnitude with the median, however of opposite sign. The opposing effects for left-behind places vis-à-vis the rest is in line with the notion of spatial inequality feedback loops as pointed out by Pinheiro et al. (2022). The declining effect of toxic pollution along the wage distribution, similar to the employment dynamics, suggests that in high-wage regions, take the example of Bavaria, highly toxic facilities have a penalizing effect on wages. These results therefore highlight the relationship being heterogeneous along the conditional distribution of both industry employment and wages. At the same time, they suggest that OLS estimation clouds such heterogeneity, undermining the speciality of left-behind places. Such heterogeneity therefore strengthens the case for our choice of applying quantile regression to the data.

Furthermore, the indicator for the censored regions is always negative and significant, and increases monotonically along the employment and wage quantiles. Hence, in left-behind regions (first two quantiles), the difference between polluted and non-polluted areas is greater. The negative relationship is mainly due to the degree of industrialization and industrial activity, which has a direct effect in terms of both economic activities and higher pollution levels, when compared with e.g., rural areas non presenting industrial activities. Overall, we document that toxic pollution impacts especially the left-behind places. Lagged gva per capita is negative in the lower quantiles, indicating a regional employment reconversion towards sectors other than industry. Lagged employment is always positive, with high persistent magnitudes which decrease along the distribution.

Table 4: Direct Effects on Industrial labour market, augmented

	Direct Effects on Employment and Wages									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dep. Var:	Industry Employment					Industry Wages				
Quantile (%):	10	25	50	75	90	10	25	50	75	90
Log(Sectoral toxic pollution)	0.010***	0.009***	0.005***	0.001	-0.001	0.008**	0.005***	-0.009***	-0.007***	-0.006***
	[0.002]	[0.002]	[0.001]	[0.001]	[0.001]	[0.003]	[0.002]	[0.002]	[0.002]	[0.002]
Sectoral pollutant concentr.	-0.255***	-0.149***	-0.098***	-0.051***	-0.022**	-0.103***	-0.072***	0.025**	-0.024*	-0.022
	[0.013]	[0.013]	[0.013]	[0.009]	[0.009]	[0.027]	[0.015]	[0.012]	[0.012]	[0.016]
Indicator censored regions	-0.567***	-0.420***	-0.309***	-0.213***	-0.108***	-0.345***	-0.162***	-0.087***	-0.036**	-0.006
	[0.016]	[0.016]	[0.010]	[0.011]	[0.014]	[0.043]	[0.020]	[0.021]	[0.014]	[0.027]
Log(gva per capita) lagged	-0.312***	-0.161***	-0.005	0.172***	0.330***	0.137***	0.240***	0.409***	0.363***	0.399***
	[0.017]	[0.013]	[0.012]	[0.013]	[0.013]	[0.043]	[0.018]	[0.023]	[0.019]	[0.030]
Log(employment) lagged	0.951***	0.910***	0.896***	0.877***	0.853***	0.257***	0.290***	0.234***	0.218***	0.208***
	[0.007]	[0.004]	[0.007]	[0.005]	[0.005]	[0.017]	[0.005]	[0.010]	[0.007]	[0.014]
Energy sector	-0.304***	-0.209***	-0.161***	-0.128***	-0.102***	-0.290***	-0.209***	-0.097***	-0.002	0.023
	[0.015]	[0.011]	[0.010]	[0.010]	[0.009]	[0.031]	[0.019]	[0.016]	[0.012]	[0.014]
Metal Industry	-0.020	-0.029**	-0.034***	-0.036***	-0.008	-0.110***	-0.058***	-0.039**	0.033**	-0.001
	[0.017]	[0.014]	[0.012]	[0.010]	[0.010]	[0.025]	[0.012]	[0.017]	[0.016]	[0.018]
Mineral industry	-0.148***	-0.083***	-0.015	0.006	-0.003	-0.121***	-0.054***	-0.036***	0.015	0.040**
	[0.033]	[0.014]	[0.011]	[0.010]	[0.010]	[0.027]	[0.014]	[0.013]	[0.019]	[0.016]
Chemical industry	-0.093***	-0.097***	-0.063***	-0.064***	-0.053***	-0.014	-0.023	-0.008	0.043***	0.016
	[0.014]	[0.014]	[0.010]	[0.011]	[0.009]	[0.019]	[0.015]	[0.015]	[0.011]	[0.010]
Waste and wastewater	-0.171***	-0.123***	-0.123***	-0.080***	-0.036***	-0.206***	-0.112***	-0.041**	0.005	0.001
	[0.018]	[0.011]	[0.013]	[0.009]	[0.011]	[0.035]	[0.021]	[0.018]	[0.012]	[0.015]
Paper and wood production	0.071***	0.015	-0.042***	-0.065***	-0.040***	-0.097**	-0.024	-0.030	-0.033**	-0.025
	[0.016]	[0.011]	[0.011]	[0.010]	[0.010]	[0.038]	[0.018]	[0.024]	[0.016]	[0.022]
Country Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	30,116	30,116	30,116	30,116	30,116	28,339	28,339	28,339	28,339	28,339
Pseudo R2	0.5984	0.5928	0.6022	0.6154	0.6388	0.3138	0.3001	0.2832	0.3219	0.3726

Notes: Standard errors are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1

Next, we include the pollutant concentration index, as per Equation 6. Table 4 shows the augmented specification. The introduction of the additional explanatory variable does not change the qualitative results with respect to the baseline specification. Again, we find a positive effect of sectoral toxic pollution on industry employment especially for left-behind regions. Looking at the newly introduced variable, sectoral pollutant concentration, we see that the coefficients are negative along all quantiles. For instance, looking at the 10th percentile, a 1 per cent increase in pollutant concentration is associated with a 0.255 per cent decrease in industry employment. This confirms that the concentration index is a proxy for efficiency-enhancing processes inasmuch its increase over time signals the elimination of some specific pollutants.

Therefore, technological efficiency gains have a labour-saving effect: if environmental technology increases, that is process innovations to reduce and abate pollutant emissions, employment in industry decreases. As expected, such effects steadily reduce in magnitude along the quantiles, meaning that left-behind places, being more dependent on noxious industrialization, are also exposed to higher labour expelling effects whenever process innovation is undertaken. The negative employment effect might be the consequence of a reorganization of productive systems, processes, input recomposition, and new techniques of production employing a higher capital/labour ratio. Therefore, the type of technical change we measure, given the neat negative effects on employment, goes well beyond the effect that the introduction of an end-of-pipe technology could have, and hence validates our assumptions. The effects on wages are coherent, with negative and statistically significant coefficients in left-behind places.

Given the importance of industry heterogeneity, we now want to focus on industry-specific pollution to pin down whether the origin of pollution plays a role in affecting industrial labour markets. Therefore we show in the bottom part of Table 4 a series of dummy variables capturing the sectoral origin of pollution. Considering that our dependent variables are industrial employment and wages, the effects are negative, whenever significant, as expected, signalling substitution effects in terms of industrial specialization and composition across industries. Granted the overall positive effects of toxic pollution, seen as a sign of economic dependence on noxious industrial specialization, higher negative signs as in energy and in waste and wastewater mean that if the area is specialized in those industries, overall industrial employment eventually declines for transition to non-industrial employment. In fact, both industries have facilities normally more embedded into and closely located to urban areas. Their proximity to urban territories prompts indeed higher possibility of tertiarization of the region.

5.3 Indirect Effects: regional spillovers

We now move on to present the analysis in terms of indirect effects, i.e., the potential propagation effects of industrial pollution beyond the industrial labor market to the regional labor market as a whole. In this set-up we also add as dependent variable the regional net migration, a proxy for labour force outflows/inflows. In doing so, we look at the entire bulk of employment and wages in other sectors of the economy, beyond the industrial one. Effects are therefore expected to be of lower magnitude, when compared to the previous specification, considering that our measure of pollution is only related to the industrial activities and does not take into consideration pollution from, e.g., logistics, among the most responsible for greenhouse gas emissions in the service sector. Therefore, the question we want to address is the extent to which propagation effects from the industrial-polluter complex exist, and affect other places in the region, beyond left-behind ones.

This time, we directly show in Table 5 the augmented specification including toxic pollution and the concentration index. The regression table of the baseline configuration can be found in the Appendix (Table 9). The coefficients for sectoral toxic pollution are identical for both specifications (employment and wages), negative and significant across the board, but with a very low magnitude. In contrast to the industrial labour market, in the regional specification the negative coefficients become relevant for the upper part of the conditional employment and, particularly, wage distributions, in line also with the effect of the indicator variable for censored regions. This means that, across more advanced regions in terms of economic performance, the presence of toxic pollution from the industrial sector is negatively associated with employment and wages when compared to similar high-productive regions non-exposed (or less exposed considering the E-PRTR construction) to toxic pollution. In this respect, toxic pollution does represent a clear signal of low-innovative strategies, rather than a necessary burden that a community must bear.

Table 5: Indirect effects of toxic pollution on regional labour market, augmented

	Indirect Effects on Employment and Wages									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dep. Var:	**Total Employment**					**Total Wages**				
Quantile (%):	10	25	50	75	90	10	25	50	75	90
Log(Sectoral toxic pollution)	-0.000	-0.000***	-0.001***	-0.001***	-0.001***	-0.001	-0.005*	-0.008***	-0.010***	-0.008***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.004]	[0.003]	[0.002]	[0.003]	[0.002]
Sectoral pollutant concentr.	0.001	0.002*	0.001	0.001	0.003	0.059*	0.034**	0.060***	0.037**	-0.006
	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]	[0.035]	[0.016]	[0.015]	[0.015]	[0.009]
Indicator censored regions	-0.002	-0.002*	0.000	0.003***	0.006**	0.155***	0.042**	0.135***	0.118***	0.092***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]	[0.022]	[0.020]	[0.014]	[0.015]	[0.013]
Log(gva per capita) lagged	0.009***	0.011***	0.015***	0.018***	0.019***	0.143***	0.236***	0.378***	0.447***	0.512***
	[0.002]	[0.002]	[0.001]	[0.002]	[0.003]	[0.022]	[0.020]	[0.022]	[0.020]	[0.033]
Log(employment) lagged	1.010***	1.008***	1.007***	1.003***	0.999***	0.417***	0.384***	0.301***	0.260***	0.134***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.016]	[0.011]	[0.012]	[0.009]	[0.012]
Energy sector	-0.001	0.000	0.002***	0.004**	0.006***	-0.025	-0.026	0.021	0.047***	0.094***
	[0.002]	[0.002]	[0.001]	[0.001]	[0.003]	[0.044]	[0.025]	[0.019]	[0.017]	[0.016]
Metal Industry	-0.002	-0.001	-0.002*	0.000	0.001	0.010	0.017	0.019	0.034**	0.034**
	[0.002]	[0.001]	[0.001]	[0.001]	[0.002]	[0.027]	[0.020]	[0.014]	[0.017]	[0.015]
Mineral industry	-0.002	-0.003**	-0.002**	-0.000	0.000	0.067**	0.030	0.058***	0.062***	0.064***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]	[0.032]	[0.020]	[0.019]	[0.016]	[0.014]
Chemical industry	0.000	-0.001	-0.001**	-0.001	-0.001	0.121***	0.033	0.063***	0.066***	0.074***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]	[0.029]	[0.026]	[0.018]	[0.018]	[0.017]
Waste and wastewater	-0.004*	-0.002	-0.000	0.001	-0.000	0.021	0.019	0.075***	0.086***	0.090***
	[0.002]	[0.001]	[0.001]	[0.001]	[0.002]	[0.035]	[0.024]	[0.017]	[0.019]	[0.017]
Paper and wood production	-0.000	-0.001	-0.001	-0.001	0.000	0.047	-0.009	-0.026	-0.009	0.032
	[0.002]	[0.002]	[0.001]	[0.001]	[0.002]	[0.037]	[0.022]	[0.032]	[0.024]	[0.025]
Country Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	23,087	23,087	23,087	23,087	23,087	21,718	21,718	21,718	21,718	21,718
Pseudo R2	0.9473	0.949	0.9484	0.9489	0.95	0.4022	0.3738	0.3328	0.3227	0.3578

Notes: Standard errors are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1

As expected, the HHI shows positive but weakly significant effects on employment and wages. The result confirms that the HHI index is essentially a proxy for industry-level technological improvements, therefore regions experiencing technological advancement, hereby in terms of abatement of some toxic pollutants, also benefit from positive, although quite weak, effects on the labour market.

Table 6 shows the results for demographic change, again employing the augmented specification. The results for the baseline specification can be found in the Appendix (Table 10). Demographic changes are measured as the changes in net migration, hence overall changes in the population cleaned for its natural changes, births and deaths, measured across one year. The quantile approach allows to distinguish between regions of inflows (above median quantiles) versus regions of outflows (below median quantiles).

Interestingly enough and in line with results on employment, the coefficient for sectoral toxic pollution is negative and significant at the 1 per cent level for all quantiles. The magnitude of the effect however increases along the quantiles. Higher quantiles are associated to regions that have experienced an influx of inhabitants, i.e., a positive change. Therefore, the higher the influx of migrants (higher quantiles) the higher the negative effects of pollution. The flip side is that toxic pollution discourages migration toward a given region. Lower quantiles, experiencing instead below-median changes and therefore being regions of abandonment, also record a negative and significant effect of toxic pollution, after controlling for the lagged employment and the value added of the region, as in the other specifications.

The concentration index is instead positive whenever significant, meaning that higher levels of concentration, i.e., less distinct pollutants, are associated with less people leaving the region (below the median) or positively affect migration inflows (above the median). This result is again inline with high levels of HHI as a proxy for a less polluting, dangerous mix when compared to low levels of HHI representing a more dangerous mix.

In line with our previous results and interpretation on the industry mix of pollution, especially the concentration of pollution from the energy sector is negatively associated with migration outflow (below the median) or alternatively is positively associated with migration inflow (above the median), as shown by the sector dummy variable.

Table 6: Indirect effects of toxic pollution on regional demographic change, augmented

	Indirect Effects on Demography				
	(1)	(2)	(3)	(4)	(5)
Dep. Var:	**Net Migration, Changes**				
Quantile (%):	10	25	50	75	90
Log(Sectoral toxic pollution)	-0.056***	-0.076***	-0.100***	-0.098***	-0.118***
	[0.020]	[0.015]	[0.012]	[0.011]	[0.026]
Sectoral pollutant concentr.	-0.141	0.310***	0.754***	0.767***	1.085***
	[0.125]	[0.078]	[0.079]	[0.111]	[0.207]
Indicator censored regions	-1.150***	-0.449***	0.519***	1.002***	1.640***
	[0.180]	[0.113]	[0.122]	[0.118]	[0.214]
Log(gva per capita) lagged	1.506***	2.609***	3.456***	3.617***	4.114***
	[0.264]	[0.171]	[0.138]	[0.063]	[0.251]
Log(employment) lagged	0.451***	0.255***	0.164**	0.082*	-0.170**
	[0.092]	[0.048]	[0.064]	[0.048]	[0.084]
Energy sector	-0.367**	0.025	0.218*	0.265*	0.633***
	[0.144]	[0.106]	[0.111]	[0.139]	[0.230]
Metal Industry	-0.491***	-0.301***	-0.317**	-0.173	0.022
	[0.165]	[0.090]	[0.137]	[0.144]	[0.194]
Mineral industry	-0.354**	-0.131	-0.139	-0.191	-0.183
	[0.157]	[0.101]	[0.109]	[0.135]	[0.186]
Chemical industry	-0.228	0.050	-0.046	-0.147*	0.060
	[0.179]	[0.081]	[0.084]	[0.077]	[0.200]
Waste and wastewater	-0.523***	-0.165	-0.214*	-0.057	0.078
	[0.136]	[0.104]	[0.126]	[0.147]	[0.182]
Paper and wood production	0.164	-0.045	0.017	-0.020	0.005
	[0.119]	[0.076]	[0.118]	[0.122]	[0.202]
Country Effects	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes
Obs.	23,087	23,087	23,087	23,087	23,087
Pseudo R2	0.1383	0.1609	0.17	0.1507	0.1321

Notes: Standard errors are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1

The result indicates that the energy sector, being the most proximate to urban, diversified and dynamic areas, is a signal of labour market attraction. The opposite holds for traditionally low-innovative sectors as the metal and mineral industries, whose toxic emission encourages abandonment of the region, with effects particularly strong in the lowest quantile of the conditional demographic change distribution. Therefore, bad specialization in low-innovative, high-toxic industries favours economic deprivation of an area.

Overall, the study of the indirect effects of toxic pollution has confirmed the presence of spatial spillovers ranging from the site of the industrial facilities toward the entire region. Indeed, our place-based analysis helps to overcome the productivist false dichotomy between labour market dependence and exposure to toxic pollution.

6 Conclusions and policy implications

Arguably, the contemporary crises overlapping across social, economic and ecological spheres are creating systemic inequalities across space. We conceptualize left-behind regions through economic deprivation, and explore their environmental dimension. We explore the effects propagating from toxic industrial pollution to socio-economic deprivation through channels of path dependence, regional lock-ins and the labour-saving effects of technology, therefore adopting the lens of evolutionary economic geography and its scope of interpretation as a useful toolbox to address environmental inequality. Using data for 15 European countries at NUTS-3 level, after providing one of the first comprehensive attempts to map toxic pollution in Europe, we employ quantile regression to study how toxic pollution and pollutant concentration impact disproportionally the left-behind regions.

All in all, our findings trace histories of industrial decay, providing evidence that persistent exposure to pollution works as a compounding factor aggravating already-existent socio-economic deprivation. We find opposing effects for left-behind places vis-à-vis the rest, pointing to spatial inequality feedback loops. Due to path dependence in industry, such left-behind places, often materially dependent on toxic industries and with a heavily impaired environment, find themselves locked in their poor economic trajectories and bad specialization path they have evolved into. Therefore, for such left-behind places the trade-off between health and employment kept being perpetuated. In fact, Lerner (2012) uses the term “sacrifice zones” which jointly conceive environmental toxicity and economic disinvestment. This concept has recently been developed further by Feltrin et al. (2021) to coin the term “noxious deindustrialization” as left-behind places where ongoing pollution and underemployment coexist.

Hence, while the sustained release of industrial toxic pollutants disrupts human, environmental and economic health, it maintains the status quo of reproductive and social disparities. The political economy of left-behind places would suggest that a transition of technological systems towards a zero-toxic world requires the co-evolution not only of productive forces and technological domains, but also of political structures currently too much favouring inertia. Taken at large, the relationship between labour, capital and the environment laid bare in the analysis raises questions about the environmental and societal sustainability of capitalism (Faber, 2008).

Exiting the noxious job blackmail of left-behind places can and must be achieved in primis by banning the emission of toxic pollutants, considering the wide range of technical solutions that are available. In addition, the empirical analysis strongly supports the need for a place-sensitive regional policy, with an urgent focus on left-behind places, which can guide the new Just Transition Fund (2021-2027) and EU cohesion policy. In order for environmental and climate policies to even out territorial inequalities, policy-makers have to take into account local contexts in terms of industrial specialization, technological lock-ins, employment segregation as well as the materialist and economic dependence on highly toxic industries. Moreover, the results of our place-based analysis help to partially overcome the productivist opposition between labour and environment, as we show that whenever processes of environment technological upgrading are undertaken, they tend to crowd out workers from the industrial labour market but are associated with positive regional spillover effects, improving labour market variables overall. Thus, regions where fewer toxic pollutants are emitted are regions with in-migration flows, while the opposite is true for regions characterised by a highly diversified, highly polluting mix of pollutants.

Furthermore, it is crucial to understand the policy implications of a labour-saving effect of environmental technology in polluting industries. A very recent publication by the International Monetary Fund (IMF) lays out the high geographical concentration of high-polluting jobs (Bluedorn et al., 2022). However, the report stresses the issue of labour reallocation, given that individual workers are less likely to successfully reallocate to greener jobs, hence compounding the disadvantages of already left-behind people and places. Behind the impediment of a labour transition away from toxic and fossil-dependent occupations towards greener ones is the lack of an industrial policy able to create coordinated policy actions to govern the twin (technological and ecological) transition (Bianchini et al., 2022). Although growing, "green jobs" do not represent a sector per se but are rather occupations related to the production of potentially "greener goods". However, they hardly might represent the solution for entire sectors and related supply chains under deep organizational and productive restructuring, such as automotive. In this respect, place-based policy initiatives require to coexist with coordinated European industrial policies (Cimoli et al., 2009) aiming to build productive but sustainable capacity in the near future. Left-behind, peripheral regions ought to be the starting point for this type of policy action, with guided reconversion and socio-economic upgrading.

Finally, our paper also connects to the broader concept of the geography of discontent. If toxic pollution contributes to a place being left-behind, then the environmental dimension might matter for politics, i.e., populist stances, which however are mostly anti-environmentalist. Instead, left-behind places would have reason to become subjects in environmental struggles in general and the Green New Deal in particular, due to their materialist dependencies on toxic economic growth. In this regard, economists are advised to apply environmental justice approaches to contemporary environmental challenges. This points to the general need to bring deindustrialized and marginalized places back into policy focus, apart from their political relevance.

Future lines of research include, firstly, the use of spatial econometric techniques to detect spatial correlation processes across left-behind places. Second, a study of growth patterns at the facility level could be useful to distinguish between "growth by pollution" and "growth by decontamination" strategies. Thirdly, research could delve into the materialist histories of left-behind places by looking at micro-level data on workers, examining labour market outcomes, and intersecting class and gender dimensions of environmental justice (Faber et al., 2021).

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Appendix

1 Details on E-PRTR data sample: pollutants and sectors

pollutant name	**pollutant cas**	**pollutant group name**	**toxicity score (USEtox 2.12)**
Tetrachloromethane	56-23-5	Greenhouse gases	0.0000974
Hydrochlorofluorocarbons	593-70-4	Greenhouse gases	0.0000301
Halons	1897-45-6	Greenhouse gases	4.71E-03
Chlorofluorocarbons	75-69-4	Greenhouse gases	1.75E-04
Hydro-fluorocarbons	811-97-2	Greenhouse gases	1.52E-04
Fluorine and inorganic compounds (as HF)	75-02-5	Halogens	0.0000756
Chlorine and inorganic compounds (as HCl)	136-40-3	Halogens	0.0000281
1,1,2,2-tetrachloroethane	79-34-5	Halogens	0.0000205
Mercury and compounds (as Hg)	14302-87-5	Heavy metals	3.49
Cadmium and compounds (as Cd)	22537-48-0	Heavy metals	0.195
Arsenic and compounds (as As)	17428-41-0	Heavy metals	0.0538
Chromium and compounds (as Cr)	18540-29-9	Heavy metals	0.0465
Lead and compounds (as Pb)	14280-50-3	Heavy metals	0.0428
Zinc and compounds (as Zn)	23713-49-7	Heavy metals	0.0155
Nickel and compounds (as Ni)	14701-22-5	Heavy metals	0.00136
Copper and compounds (as Cu)	15158-11-9	Heavy metals	0.0000892
Benzo(g,h,i)perylene	191-24-2	(Polycyclic) Aromatic Hydrocarbons	0.000412
Anthracene	120-12-7	(Polycyclic) Aromatic Hydrocarbons	0.000288
Di-(2-ethyl hexyl) phthalate	117-81-7	(Polycyclic) Aromatic Hydrocarbons	0.0000228
Xylenes	1330-20-7	(Polycyclic) Aromatic Hydrocarbons	6.66E-04
Toluene	108-88-3	(Polycyclic) Aromatic Hydrocarbons	2.55E-04
Phenols (as total C)	108-95-2	(Polycyclic) Aromatic Hydrocarbons	2.35E-04
Nonylphenol and Nonylphenol ethoxylates	25154-52-3	(Polycyclic) Aromatic Hydrocarbons	2.33E-04
Hexachlorobenzene	118-74-1	Persistent Organic Pollutants	0.000934
Polychlorinated biphenyls	1336-36-3	Persistent Organic Pollutants	0.000519
Pentachlorophenol	87-86-5	Persistent Organic Pollutants	0.000128
Pentachlorobenzene	608-93-5	Persistent Organic Pollutants	0.0000732
Ethyl benzene	100-41-4	Persistent Organic Pollutants	6.98E-03
Polycyclic aromatic hydrocarbons	2243-62-1	Persistent Organic Pollutants	5.03E-03
Vinyl chloride	75-01-4	Volatile Organic Compounds	0.0000617
Naphthalene	91-20-3	Volatile Organic Compounds	0.0000243
Ethylene oxide	75-21-8	Volatile Organic Compounds	0.0000119
Tetrachloroethylene	127-18-4	Volatile Organic Compounds	8.34E-03
Trichloromethane	67-66-3	Volatile Organic Compounds	7.13E-03
Non-methane volatile organic compounds	100-41-4	Volatile Organic Compounds	6.98E-03
1,2-dichloroethane	107-06-2	Volatile Organic Compounds	5.91E-03
Benzene	71-43-2	Volatile Organic Compounds	5.34E-03
Dichloromethane	75-09-2	Volatile Organic Compounds	3.38E-03
Trichloroethylene	79-01-6	Volatile Organic Compounds	5.54E-04
1,1,1-trichloroethane	71-55-6	Volatile Organic Compounds	4.73E-05

Table 7: Summary table of 41 distinct toxic pollutants and CAS numbers as in our E-PRTR sample, listed by pollutant groups and ranked according to their USEtox 2.12 toxicity score.

sector	detailed description of activity as in Annex I of the E-PRTR
Energy sector	Coal rolling mills with a capacity of 1 tonne per hour
Energy sector	Installations for gasification and liquefaction
Energy sector	Thermal power stations and other combustion installations
Energy sector	Installations for the manufacture of coal products and solid smokeless fuel
Energy sector	Mineral oil and gas refineries
Energy sector	Coke ovens
Metal industry	Metal ore (including sulphide ore) roasting or sintering installations
Metal industry	Installations for the processing of ferrous metals, Application of protective fused metal coats
Metal industry	Installation for the production of non-ferrous crude metals from ore, concentrates or secondary raw materials by metallurgical, chemical or electrolytic processes
Metal industry	Ferrous metal foundries with a production capacity of 20 tonnes per day
Metal industry	Installations for the production of pig iron or steel (primary or secondary melting) including continuous casting
Metal industry	Installation for the smelting, including the alloying, of non-ferrous metals, including recovered products (refining, foundry casting, etc.)
Metal industry	Installations for the processing of ferrous metals.
Metal industry	Installations for the production and/or smelting of non-ferrous metals.
Metal industry	Installations for the processing of ferrous metals, Hot-rolling mills
Metal industry	Installations for surface treatment of metals and plastic materials using an electrolytic or chemical process
Mineral industry	Installations for the production of cement clinker in rotary kilns, lime in rotary kilns, cement or lime in other furnaces
Mineral industry	Opencast mining and quarrying
Mineral industry	Installations for the production of lime in rotary kilns
Mineral industry	Installations for the production of cement clinker or lime in other furnaces
Mineral industry	Installations for the production of cement clinker in rotary kilns
Mineral industry	Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain
Mineral industry	Installations for the manufacture of glass, including glass fibre
Mineral industry	Underground mining and related operations
Mineral industry	Installations for melting mineral substances, including the production of mineral fibres
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Nitrogenous hydrocarbon.
Chemical industry	Chemical installations for the production on an industrial scale of basic inorganic chemicals: Acids.
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Synthetic rubbers
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Sulphurous hydrocarbons
Chemical industry	Chemical installations for the production on an industrial scale of basic inorganic chemicals.
Chemical industry	Chemical installations for the production on an industrial scale of basic inorganic chemicals: Bases.
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Surface-active agents and surfactants
Chemical industry	Chemical installations for the production on an industrial scale of basic plant health products and of biocides
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Dyes and pigments
Chemical industry	Chemical installations for the production on an industrial scale of basic inorganic chemicals: Salts
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Organometallic compounds
Chemical industry	Installations for the production on an industrial scale of explosives and pyrotechnic products
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Simple hydrocarbons
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Phosphorus-containing hydrocarbons
Chemical industry	Chemical installations for the production on an industrial scale of basic inorganic chemicals: Non-metals, metal oxides or other inorganic compounds
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Basic plastic materials
Chemical industry	Chemical installations for the production on an industrial scale of phosphorous, nitrogen or potassium based fertilisers (simple or compound fertilisers)
Chemical industry	Chemical installations for the production on an industrial scale of basic inorganic chemicals: Gases
Chemical industry	Installations using a chemical or biological process for the production on an industrial scale of basic pharmaceutical products
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Halogenic hydrocarbons
Chemical industry	Chemical installations for the production on an industrial scale of basic organic chemicals: Oxygen-containing hydrocarbons
Waste and wasterwater	Installations for the disposal or recycling of animal carcasses and animal waste
Waste and wasterwater	Urban waste-water treatment plants
Waste and wasterwater	Installations for the recovery or disposal of hazardous waste
Waste and wasterwater	Independently operated industrial waste-water treatment plants
Waste and wasterwater	Installations for the incineration of non-hazardous waste
Waste and wasterwater	Installations for the disposal of non-hazardous waste
Waste and wasterwater	Landfills
Paper and wood production	Industrial plants for the preservation of wood and wood products with chemicals
Paper and wood production	Industrial plants for the production of pulp from timber or similar fibrous materials
Paper and wood production	Industrial plants for the production of paper and board and other primary wood products
Agriculture and leather industry	Installations for the building of, and painting or removal of paint from ships with a capacity for ships 100 m long
Agriculture and leather industry	Treatment and processing intended for the production of food and beverage products from vegetable raw materials
Agriculture and leather industry	Treatment and processing intended for the production of food and beverage products from animal raw materials (other than milk)
Agriculture and leather industry	Treatment and processing of milk
Agriculture and leather industry	Installations for the production of carbon (hard-burnt coal) or electro-graphite by means of incineration or graphitisation
Agriculture and leather industry	Slaughterhouses
Agriculture and leather industry	Plants for the tanning of hides and skins
Agriculture and leather industry	Intensive aquaculture
Agriculture and leather industry	Treatment and processing intended for the production of food and beverage products
Agriculture and leather industry	Plants for the pre-treatment or dyeing of fibres or textiles
Agriculture and leather industry	Installations for the surface treatment of substances, objects or products using organic solvents

Table 8: Summary table of sectors and description of activity as in Annex I of the E-PRTR.

2 Details on regional economic variables

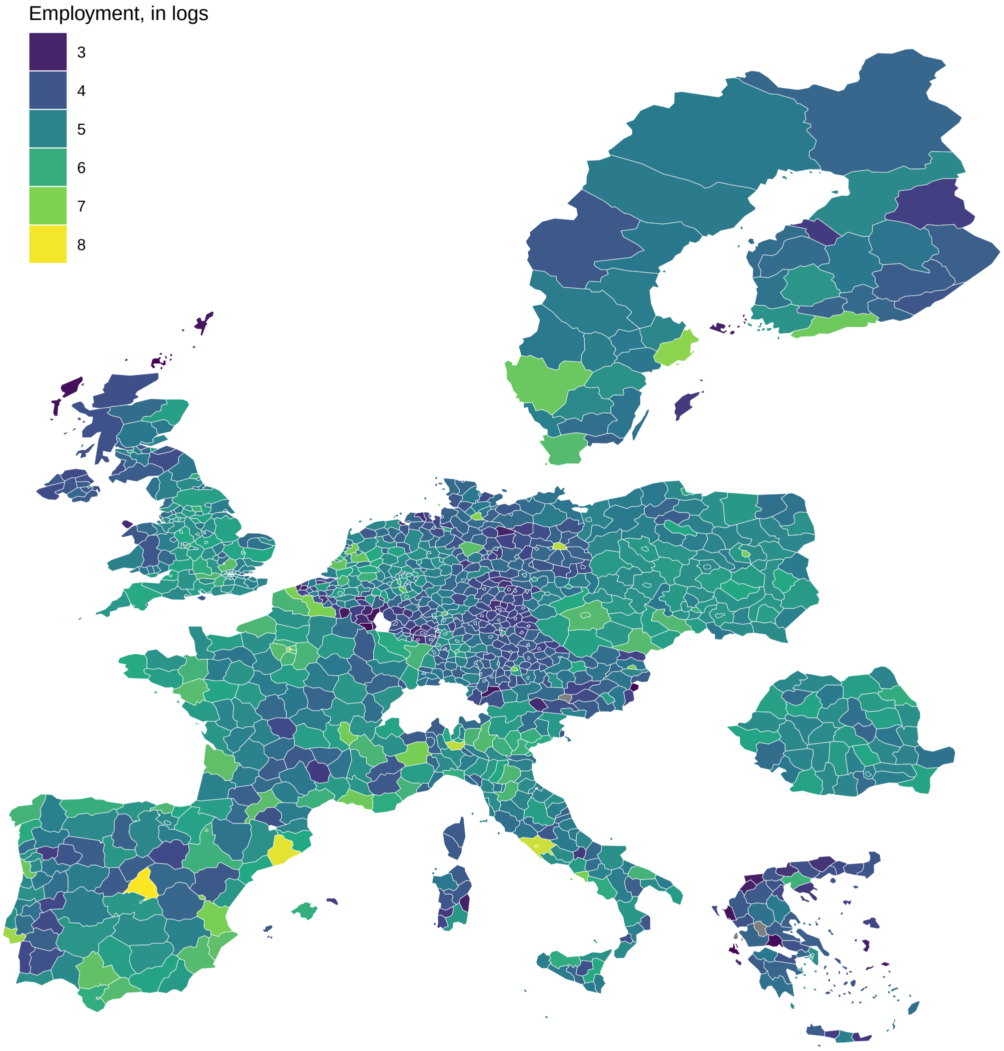
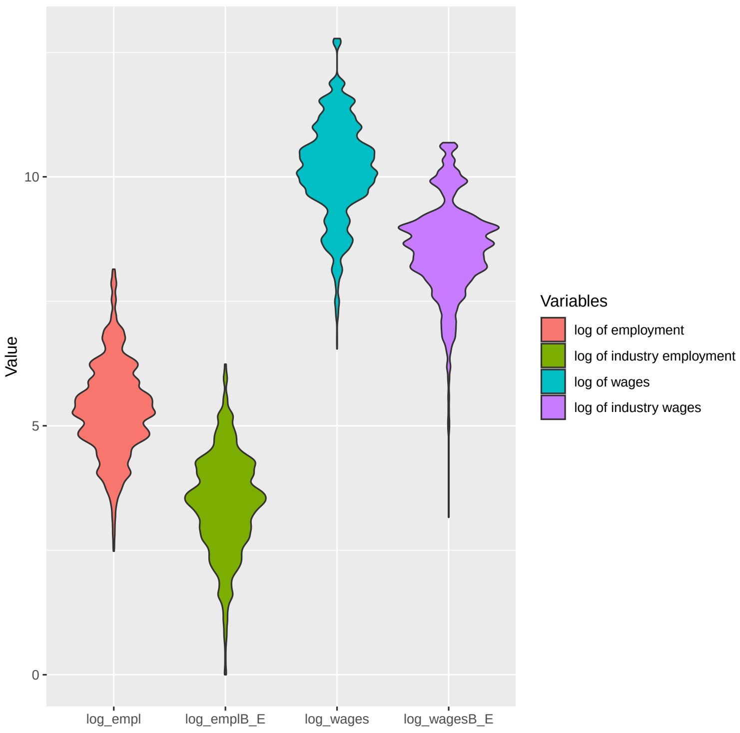
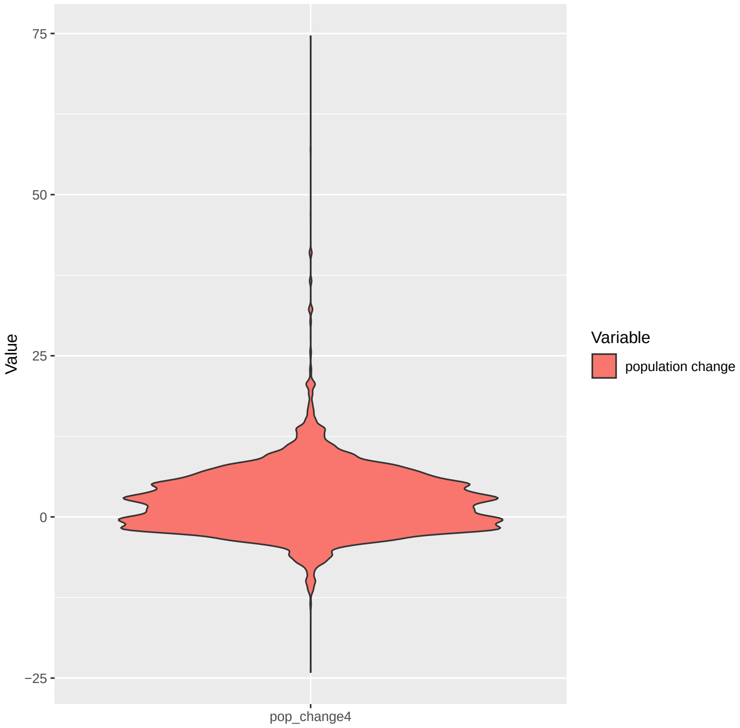


Figure 7: Regional map of employment levels in 15 European countries, in logs, at NUTS-3 level, averaged across 2007-2018, showing the 15 countries in our sample. Source: Own calculation based on Cambridge Econometrics.



(a) Variables expressed in logs from Cambridge Econometrics



(b) Variable expressed in changes from Eurostat

Figure 8: Violin plots for (a) employment, industry employment, wages, industry wages, in logs; and (b) population changes evaluated over the last four years. The descriptives refer to the average across 2007-2018.

3 Details on estimation results

	Indirect Effects on Employment and Wages									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dep. Var:	**Total Employment**					**Total Wages**				
Quantile (%):	10	25	50	75	90	10	25	50	75	90
Log(Sectoral toxic pollution)	-0.000**	-0.000***	-0.001***	-0.001***	-0.001***	0.000	-0.005*	-0.008***	-0.010***	-0.008***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.004]	[0.002]	[0.002]	[0.003]	[0.002]
Indicator censored regions	-0.002	-0.002***	-0.000	0.003**	0.004**	0.132***	0.025	0.100***	0.103***	0.096***
	[0.002]	[0.001]	[0.001]	[0.001]	[0.002]	[0.022]	[0.024]	[0.018]	[0.020]	[0.018]
Log(gva per capita) lagged	0.009***	0.011***	0.015***	0.018***	0.020***	0.143***	0.237***	0.382***	0.450***	0.509***
	[0.002]	[0.001]	[0.001]	[0.002]	[0.003]	[0.031]	[0.026]	[0.018]	[0.022]	[0.030]
Log(employment) lagged	1.010***	1.008***	1.007***	1.003***	0.999***	0.418***	0.381***	0.294***	0.258***	0.135***
	[0.001]	[0.001]	[0.000]	[0.001]	[0.001]	[0.015]	[0.011]	[0.012]	[0.011]	[0.009]
Country Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	23,087	23,087	23,087	23,087	23,087	21,718	21,718	21,718	21,718	21,718
Pseudo R2	0.9473	0.949	0.949	0.9489	0.95	0.4021	0.3737	0.3324	0.3225	0.3578

Notes: Standard errors are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Indirect effects of toxic pollution on total regional labour markets, baseline

	Indirect Effects on Demography				
	(1)	(2)	(3)	(4)	(5)
Dep. Var:	**Net Migration, Changes**				
Quantile (%):	10	25	50	75	90
Log(Sectoral toxic pollution)	-0.057***	-0.074***	-0.106***	-0.094***	-0.098***
	[0.019]	[0.011]	[0.012]	[0.016]	[0.024]
Indicator censored regions	-1.093***	-0.564***	0.120	0.683***	1.217***
	[0.178]	[0.111]	[0.156]	[0.094]	[0.196]
Log(gva per capita) lagged	1.502***	2.578***	3.478***	3.559***	4.236***
	[0.204]	[0.155]	[0.160]	[0.133]	[0.235]
Log(employment) lagged	0.457***	0.230***	0.100	0.017	-0.277***
	[0.072]	[0.055]	[0.062]	[0.075]	[0.102]
Country Effects	Yes	Yes	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes	Yes	Yes
Obs.	23,087	23,087	23,087	23,087	23,087
Pseudo R2	0.1383	0.1605	0.1683	0.1492	0.1304

Notes: Standard errors are bootstrapped. *** p<0.01, ** p<0.05, * p<0.1

Table 10: Indirect effects of toxic pollution on regional demographic change, baseline