Environmental Impacts and Housing Deprivation: A Study of the Effects of Industrial Polluting Sites in the Italian Context

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Abstract. The disadvantaged populations often bear a disproportionate burden of environmental pollution, especially when air quality exceeds regulatory standards. This link is particularly pronounced in areas with housing deprivation. As deprivation levels rise, the number of people exposed to excessive pollution increases. The industrial sector is one of the major contributors to air pollution and greenhouse gas emissions. Given the close relationship between industrial sites and socioeconomic, environmental, and health factors in cities, analyzing the real estate market can provide valuable insights for guiding sustainable development strategies. The present research aims to determine if a correlation exists between residential property prices and polluting sites, by considering factors that could represent housing deprivation. By examining the type of relationship and changes in property prices, the study intends to inform decision-making on housing deprivation policies. Through a genetic algorithm (Multi-Case Strategy of Evolutionary Polynomial Regression) applied to a sample of a limited available sample of polluting sites in Italy, first results have been obtained, that align with empirical observations and local user expectations. The results highlight the importance of implementing effective housing deprivation policies that address the environmental impacts of polluting industrial sites on real estate market dynamics. The innovative contribution of this work lies in identifying critical 'pollution-poverty' areas that require urgent remedial action.

Keywords: environmental pollution · sustainable city · real estate market · industrial sites · socio-environmental vulnerability · housing deprivation

1 Introduction

Housing deprivation, a condition where individuals lack adequate and affordable housing, is intricately linked to environmental degradation, particularly in areas surrounding industrial polluting sites. The relationship between these two issues is deeply intertwined, as the proximity to industrial sites often correlates with poor housing conditions, contributing to social inequalities and exacerbating environmental injustices. In

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both international and Italian contexts, comprehensive policies that address both housing and environmental issues are crucial to mitigating the impacts on marginalized populations and creating more equitable urban environments. Industrial polluting sites, particularly those in urban and semi-urban areas, significantly impact the environment, and their presence often correlates with the most disadvantaged communities. These industrial zones emit hazardous pollutants into the air, water, and soil, resulting in long-term health consequences for residents. According to the World Health Organization, exposure to pollutants like particulate matter and nitrogen dioxide can cause respiratory diseases, cardiovascular problems, and even premature death [1]. This is often compounded by the fact that low-income populations, who face housing deprivation, are more likely to live near such hazardous sites. Countries such as the United States and China have seen clear links between environmental degradation and housing inequality. In the U.S., for instance, neighborhoods near polluting industries, often inhabited by minority and low-income groups, face higher levels of exposure to toxic chemicals, a phenomenon sometimes referred to as "environmental racism" [2]. Similar patterns are seen in developing countries where rapid industrialization has led to the creation of informal settlements close to polluting industries. These residents live in substandard housing, face environmental health risks, and suffer from systemic neglect by both market forces and policy-makers.

Addressing housing deprivation and its links to environmental degradation require comprehensive policy action. On an international level, organizations like the United Nations have emphasized the need for sustainable urban development, which incorporates both affordable housing and environmental protection. Italy has also begun to take steps to address these issues. The European Union's Green Deal and Italy's National Recovery and Resilience Plan (PNRR) aim to promote sustainable industry while addressing environmental injustices by improving housing conditions and reducing pollution. The Italian context mirrors many of these international trends. Industrial hubs such as Taranto in southern Italy, which hosts one of Europe's largest steel plants, have long been associated with both pollution and housing challenges. The "Ilva" steel plant in Taranto has been a notorious source of air and soil contamination, contributing to higher cancer rates and respiratory diseases among the local population. In evaluating the literature surrounding the environmental and health impacts of the Ilva steel plant, [3] have analyzed the linkages between pollution from the industrial site and adverse health outcomes, such as increased cancer rates and respiratory diseases. This work aligns with other studies that have examined the broader environmental crisis in Taranto, particularly the SENTIERI report, which also found elevated mortality rates linked to industrial pollutants in the area. Local residents, often from lower socioeconomic backgrounds, live in deteriorating housing conditions, trapped in a cycle where property values have plummeted due to environmental degradation, making relocation unaffordable. However, there are diverging perspectives regarding the socioeconomic trade-offs. Some literature highlights the tension between economic dependence on the Ilva plant and the public health crisis it has caused. For example, [4] describes a polarized debate between those prioritizing jobs and those advocating for environmental health. This dichotomy often complicates policy responses, as both health and economic stability are essential for local residents.

Housing markets play a significant role in perpetuating environmental inequalities. In many urban areas, real estate prices tend to be lower near industrial zones, making such locations more accessible to economically disadvantaged populations. For instance, in many cities, properties located near highways or industrial zones are cheaper due to pollution, noise, and other environmental nuisances. As a result, low-income households tend to live in these areas, despite the associated health risks.

A good key for studying and interpreting the effects of the environmental impacts produced by industrial polluting sites on the housing deprivation issues is represented by the analysis of the variation of the residential market dynamics due to the presence of polluting activities. The present research aims to determine if a correlation exists between residential property prices and 41 industrial polluting sites located in the Italian territory, by considering different factors of local housing deprivation conditions. The presence and the type of the functional relationships are investigated through the implementation of a genetic algorithm based on a multi-case strategy (Multi-Case Strategy of Evolutionary Polynomial Regression), that is able to provide a unique generalized interpretative model for the following three case studies: i) 11 still active industrial plants, ii) 23 dismissed industrial polluting sites and iii) 7 partially dismissed industrial polluting sites. Even if the total sample is limited for a statistical reliability of the model obtained, by using the property prices as a proxy of the inhabitants' preferences, the outputs allow to raise first but relevant considerations concerning the qualitative effects of different typologies of industrial polluting sites on the local housing deprivation. According to the mentioned subdivision, the genetic algorithm searches for the existing relationships and their typology between the dependent variable, that is the differential between the municipal average residential prices and the average property selling prices detected in the urban area in which the industrial site is located, and a set of seven housing deprivation factors as independent variables.

The sections of the work are articulated as follows. Section 2 consists of a review of the main literature on the environmental impacts and housing deprivation issues, in order to justify the choice of specific explanatory variables in the next step of the elaboration. Section 3 describes the methodology based on the application of a multi-case strategy genetic algorithm to the Italian territory and it presents the case study. Section 4 provides the discussion of the results obtained. Section 5 contains the conclusions and future insights of the research.

2 Literature Review

The relationship between environmental impacts and housing deprivation has been explored extensively in academic literature, revealing a complex interaction that often results in severe social and health consequences. Housing deprivation, defined as inadequate, insecure, or unaffordable housing, often coexists with environmental degradation, particularly in areas near industrial sites and other polluting activities. This issue is well-documented both in developed and developing countries, illustrating global environmental inequality.

A significant body of research highlights the disproportionate burden of environmental hazards on marginalized populations. [2] coined the term "environmental racism" to

describe the phenomenon in which racial minorities and low-income populations bear the brunt of industrial pollution. Bullard's research in the United States revealed that low-income African American and Latin communities are more likely to live near hazardous waste sites, which correlates with higher rates of respiratory diseases and cancers. This environmental inequality is rooted in historical and systemic discrimination in housing markets, which forces marginalized groups to live in less desirable and more polluted areas.

Internationally, studies in both the Global North and South reinforce this trend. [5] found that industrial zones, particularly in urban areas, are often situated near poor neighborhoods where housing conditions are inadequate. These communities are exposed to pollutants from factories, vehicle emissions, and contaminated water sources, which exacerbate housing deprivation and contribute to long-term health issues, such as cardiovascular diseases and asthma. The Authors emphasize that the health risks are not only related to physical proximity to pollution but are also magnified by poor housing conditions, such as lack of insulation, overcrowding, and poor ventilation, which increase the vulnerability to environmental hazards.

The role of the housing market in perpetuating environmental injustice has been widely studied. Scholars such as [6] argue that housing affordability often dictates where vulnerable populations live, with the cheapest properties frequently located in environmentally degraded areas. As property values decline near polluting sites, low-income residents are disproportionately exposed to environmental hazards. In regions like the Po Valley in Italy, known for its high levels of air pollution, housing is more affordable, but residents face significant health risks due to poor air quality [3]. This trend is also seen in rapidly urbanizing cities in developing countries, where informal settlements emerge near industrial areas due to the lack of affordable housing options.

Literature consistently links environmental impacts and housing deprivation to increased mortality rates. The [1] has highlighted how inadequate housing in polluted areas contributes to a range of health issues, including respiratory diseases, cardiovascular problems, and premature death. Studies like those by [7] show that areas with high levels of air pollution, often corresponding with low-income housing, experience significantly higher mortality rates due to chronic exposure to harmful pollutants. Supporting Lelieveld et al.'s findings, several studies highlight the severe health impacts of air pollution, including cardiovascular and respiratory diseases. For instance, [8] applied the Global Exposure Mortality Model (GEMM), showing that air pollution causes an even greater global mortality burden than previously thought, with 8.9 million deaths annually. Similar to Lelieveld's work, Burnett also underscored the cardiovascular system's vulnerability to particulate matter exposure.

The literature on environmental impacts and housing deprivation illustrates a clear link between social inequality and environmental injustice. Marginalized populations, confined to substandard housing near industrial zones, experience heightened exposure to pollution, leading to adverse health outcomes and higher mortality rates. The intersection of these two issues requires comprehensive policy interventions that address both environmental and housing inequities.

3 Methodology and Case Study

The present research focuses on a case study that concerns the 41 Italian Sites of National Interest (SIN), according to the classification provided by the Ministry of Ecological Transition (MiTE). SIN are characterized by the presence of significant levels of hazardous pollutants that lead to high environmental and health impacts on the surrounding neighborhoods. They include abandoned, active and partially dismissed industrial areas, nor ports, former mines, illegal landfills, sites affected by asbestos production and extraction activities. On these sites, the main exposure is to pollutants like heavy metals and organochlorinated solvents, dioxins, polychlorinated biphenyls and polycyclic aromatic hydrocarbons. After several process of remediation, the SIN are actually – second semester 2023 – 41 and cover a total surface area equal to 248,000 hs, of which 170,000 on land and 78,000 on sea. In all Italian regions there is at least one SIN and the ones with the largest contaminated area are Campania and Sardinia with, respectively, 345,000 and 445,000 hs.

The proposed methodology applies a genetic algorithm (Multi-Case Strategy of Evolutionary Polynomial Regression) for investigating the effects that presence of SIN have on urban environments in the residential market where they are located. In order to perform this output, the selected dependent variable is the differential between the municipal average residential prices and the average property selling prices detected in the urban area in which the SIN is found. This variable has been used as a proxy of the inhabitants' preferences, which change according to the local context considered. It is calculated by consulting the selling price quotations of the second semester 2023 provided by the Real Estate Market Observatoy of the Italian Revenue Agency for each of the trade area to which every SIN pertains. The assumption underlying the work is that the gap (Y) detected between the average real estate values in the reference context and those of the specific urban area in which the SIN is located is associated with the presence of the contaminated site and its specific characteristics. The independent variables chosen are seven, following described:

- age of the industrial plant, computed as the difference between the year (2023) and the construction one (C);
- total surface area of the SIN, expressed in hectares (Su);
- distance from the nearest urban green area, calculated in km on foot (G)
- accessibility degree, considering the distance from the nearest entrance to the high-speed road and calculated in km by car (Ac).
- distance from the city-center, calculated in km on foot (Ce);
- mortality rate from cancer (Mc), expressed in percentage;
- mortality rate from diseases of the nervous system (Mn), reported in percentage.

As illustrated in the previous review of the literature, these variables have been selected in order to effectively represent the possible interactions between environmental impacts of SIN and housing deprivation. Except the construction date (C) and the total surface area of the SIN (Su), the variables related to the distance from the city center (Ce), the nearest urban green area (G) and the accessibility degree (Ac) represent the level of urban facilities of the housing market. Both the mortality rates (Mc and Mn) express the intricated connections among housing deprivation, environmental degradation, and

health impacts. People living in inadequate housing often face greater exposure to environmental hazards, which in turn leads to higher mortality rates. This issue is evident both internationally and within Italy, where the interplay of industrial pollution, housing market dynamics, and social inequality has created severe public health challenges. According to a study by the European Environment Agency (EEA), people living in close proximity to such areas experience a higher risk of respiratory diseases, cardiovascular issues, and cancer, all of which contribute to increased mortality rates [9]. For example, in Italy, a study by the European Heart Journal found that air pollution was responsible for about 80,000 premature deaths annually [7]. These deaths disproportionately affect those living in deprived housing conditions near polluting industries. Starting from the sample data, the technique implemented to identify the effects of the SIN on the residential market prices is represented by the Evolutionary Polynomial Regression (EPR). The technique implements a genetic algorithm to combine numerical and symbolic regression methods using polynomial structures [10–13]. In particular, in the present research a further evolution of EPR that develops generalized prediction models to identify the functional relationships able to simultaneously describe the selling prices mechanism in different study samples (for example, in different territorial contexts), is used. The employed technique is the Multi-Case Strategy of the Evolutionary Polynomial Regression (MCS-EPR). The mathematical logic of the MCS-EPR technique applies a genetic algorithm to identify the polynomial coefficient values for all considered data samples that simultaneously satisfy the three objective functions - maximization of statistical performance, minimization of the number of coefficients and minimization of the number of variables - for all analyzed case studies. It is implemented by taking into account a subdivision of the 41 considered SIN that, according to their activity status, are divided into: i) 11 active ones, ii) 23 dismissed ones and iii) 7 partially dismissed ones. As the total sample is limited for a statistical reliability of the model obtained, the outputs will be analyzed for first considerations about the qualitative effects of different typologies of industrial polluting sites on the local housing deprivation.

The application of the technique has generated several functions. Among them, the generalized model selected is reported in Eq. (1).

$$\begin{aligned} Y = {} & +a_1 \times Ce \times Ac^{0.5} \times Mn^2 + a_2 \times Su \times G^{0.5} \times Ce \times Ac^2 + a_3 \times Su \times G^2 \times Ce \times Mc^{0.5} \\ & \times Mn^2 + a_4 \times Su^2 \times Ce^2 + a_5 \times C \times S^{0.5} \times Mc^2 \times Mn^{0.5} + a_6 \times C^2 \times Ce \times Ac^2 \\ & + a_7 \times C^2 \times Su^{0.5} Ce^2 \times Ac + a_8 \times C^2 \times Su^{0.5} \times G \times Ce^2 + \\ & a_9 \times C^2 \times Su^2 \times G \times Ce^2 \times Ac^2 \times Mn + a_0 \end{aligned} \tag{1}$$

The parameters of the model for the three case studies are reported in Table 1.

4 Results

The obtained results confirm the empirically expected correlations between environmental impacts and housing deprivation factors selected by the multi-strategy technique. In Table 2 a summary of the correlations between the dependent and independent variables and the effects of the explanatory factors on the differential between the municipal average residential prices and the average property selling prices detected in the urban

Table 1. Values of the parameters of the model for each case study

	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
Active SIN	−0.10	3.18	5,290.4	−878.28	−2,393.5	14.02	−42.79	−1,566.0	705.68	−32,078.63
Dismissed SIN	−0.13	−2.96	132.16	0	−1,481.8	1.45	9.53	0	1,057.7	0
Partially dismissed SIN	0.00	6.63	449.10	−13,009	8,583.1	−2.56	−35.13	998.83	214.34	−140,143.76

area in which the SIN is located, is reported. By analyzing the observed results, there are substantial differences among the study cases considered. Only for the accessibility level the same type of correlation (proportionally direct) links the dependent variable with the independent ones in all the three study cases. Five times out of seven the analyzed variables have the same type of correlations in the case where the SIN is active and in those in which it is dismissed. This condition is also found when the SIN is dismissed or partially dismissed (three times out of seven) and when it is active or partially dismissed (one time out of seven). The analysis of the individual results for each independent variable in the three case studies considered is developed in detail as follows to understand the reasons for these situations and verify their consistency with empirical evidence.

4.1 Industrial Plant Age (C)

When the SIN is still active and it is constructed after 1910, the differential is positive. It means that the average property selling prices of the urban area in which the SIN is found are minor than the municipal ones, therefore the presence of active SIN negatively affects the housing real estate market near the industrial active plants. Instead, when the SIN is dismissed or partially dismissed, in the first case, recent industrial plants lead to a negative differential given by the high housing prices of neighboring districts; in the second case, the differential is always negative and, as in the previous case of the SIN dismissed, therefore, the prices are higher than the municipal average and the partially dismissed plant is not perceived negatively by the local real estate market.

4.2 Total Surface Area (Su)

If the surface areas of active and dismissed SIN increase, the dependent variable decreases and, in particular, the differential of housing quotations is always negative, therefore higher selling prices pertain to the area of the SIN. It can happens when the industrial plant's area has become fully urbanized and integrated with the surrounding urban conurbation due to the increase in services and real estate demand over time. The situation is different for the partially dismantled SIN: it is observed that the housing prices are minor than those at the municipal level so maybe the perception of a reduction in the industrial activities causes lower attraction for the surrounding area.

Table 2. Main findings from the application of the MCS-EPR

	Study case					
	Active SIN		Dismissed SIN		Partially dismissed SIN	
Variable	Correlation	Effects on the dependent variable	Correlation	Effects on the dependent variable	Correlation	Effects on the dependent variable
Industrial age	Proportionally direct	Recent SIN increase the differential	Inverse proportionality	Every considered construction date decrease the differential	Inverse proportionality	Every considered construction date decrease the differential
Total surface area	Inverse	Major surface areas of active SIN reduce the differential	Inverse	Major surface of dismissed SIN reduce the differential	Proportionally direct	Major surface areas of partially-dismissed SIN increase the differential
Distance from urban green area	Proportionally direct	If the green area is within 11.39 km, the differential increases	Proportionally direct	Major distance from the green area increases the differential	Inverse proportionality	Major distance of the SIN from the green area decreases the differential
	Inverse	If the green area is over 11.39 km, the differential decreases				
Accessibi-lity degree	Proportionally direct	Major distance from high-speed road increases the differential	Proportionally direct	Major distance of dismissed SIN from high-speed road increases the differential	Proportionally direct	Major distance of partially dismissed SIN from high-speed road increases the differential
Distance from city-center	Inverse	Major distance from city center reduces the differential	Proportionally direct	Major distance of dismissed SIN from city-center rises the differential	Proportionally direct	Major distance of SIN from city-center makes the differential grow
Cancer mortality	Proportionally direct	Higher mortality rate lead to significant differential	Proportionally direct	Higher mortality rate lead to significant differential	Inverse proportionality	Higher mortality rate lead to significant reduction of differential
Neurologi-cal mortality	Inverse	If the rate increases the differential decreases	Inverse	If the rate increases the differential decreases	Direct	A growth of mortality rate increases the differential

4.3 Distance From Urban Green Area (G)

If the green urban area is about 12 km from an active or dismantled SIN, the dependent variable grows. More precisely, the housing quotations of the active SIN's area are greater than the municipal ones when the distance is lower than 5 km. If it is between 5 km and 12 km the municipal quotations are greater than those of the industrial area. Instead, if the distance is more than 12 km the differential remains positive but it is reduced, so the housing prices even if greater than the municipal average, appear to be slighlty affected by the distance. In the case of dismissed SIN the treshold distance is equal to about 6 km: closer green areas increase the prices of the residential market in the SIN area, and vice versa. The independent variable has an inverse proportionality when the SIN is partially dismissed. In fact, a negative differential is observed therefore, even if

the distance increases the quotations near the industrial plant are always greater than the municipal average. This can be due to the influence of other factors not included in the present analysis or the scarce importance of green spaces for the housing market when the industrial plant is partly active.

4.4 Distance from City-Center (Ce)

The situations in which the SIN is dismissed or partially dismissed register the same effects on the dependent variable if an increase of the distance from the city center occurs. Higher and positive differential is observed in both cases; therefore the average municipal quotations are greater than those of the SIN's area. If the SIN is active and the distance from the city center is lower than 8 km, the differential is positive, instead it becomes negative when the distance is greater than 8 km. This phenomenon can be caused by several factors: there are cases in which the industrial plants have been constructed very near the urban centers and other cases where they have been surrounded by a full urbanization that could reduce the appreciation of staying in the city center. Moreover, sometimes the urban centers are degraded or abandoned, and this can affect the housing conditions.

4.5 Cancer Mortality (Mc)

Higher mortality rate of cancer increases the value of the dependent variable when the SIN is active or dismissed. In both cases the average municipal quotations are higher than those of the SIN's area because the differential is always positive. However, this results suggest that health diseases can be reconducted to the industrial plant activities. If the SIN is currently closed, it could be possible that the health effects are still evident from the presence of pollutants in the soil or groundwater. In the case where the SIN is partially dismantled, a reduction in the dependent variable is observed when the mortality rate grows. The differential remains negative so when the mortality rate is low housing prices in the SIN area are much higher than the municipal average when the recorded mortality rate is highest. This means that when mortality is high the attractiveness of other residential areas increases, matching the gap with those near the industrial plant.

4.6 Neurological Mortality (Mn)

A high neurological mortality rate is linked to small differences between the housing quotations of the active and dismissed SIN and the average municipal ones. Vice versa it happens when the SIN is partially dismissed, or a positive differential is observed, and the average municipal quotations are higher than the those of the SIN's area. This can be due to several reasons that takes into account also other factors not included in the present work (e.g. perceived diseases, proximity to other potential source of health damages, type of industrial activity that involve the neurological system etc.).

5 Conclusions

This study explored the correlation between housing deprivation and environmental degradation, particularly in areas near industrial polluting sites. This connection often results in significant social and health inequalities, especially in urban and semi-urban regions where industrial activity is prevalent.

The analysis reveals significant differences in the correlations between the studied variables across the three cases, with only the accessibility level demonstrating a consistently direct relationship with the dependent variable (the "delta" of the market quotations) across all cases. In five out of seven variables, similar relationships exist whether the SIN are active or dismissed. This consistency is observed when the SIN are either dismissed or partially dismissed (three out of seven times) and when active or partially dismissed (one out of seven times). These findings underscore the importance of further analyzing individual variables to assess their empirical consistency. For instance, the age of industrial plants significantly affects housing prices. Active SIN constructed after 1910 tends to negatively impact nearby real estate values, as industrial activity reduces property desirability. Conversely, dismissed or partially dismissed SIN are associated with higher housing prices, suggesting that reduced industrial activity or plant closure may improve the area's perception, leading to increased property demand. Similarly, the total surface area of the SIN also plays a crucial role. Larger SIN, whether active or dismissed, tend to positively affect local property values when they are fully urbanized and integrated into the surrounding city. However, in partially dismantled SIN, housing prices remain lower than the municipal average, possibly due to the perception of ongoing industrial decline. Green spaces also affect housing markets, particularly in active and dismissed SIN areas. Proximity to urban green areas increases housing prices, particularly when the SIN are active, up to a threshold of 12 km. However, this relationship is less pronounced in partially dismantled SIN, where other factors may play a larger role. In contrast, distance from the city center demonstrates a mixed impact. Active SIN located within 8 km of the center negatively impact property values as distance increases, while dismissed or partially dismantled SIN result in a positive differential, with municipal prices exceeding those near the industrial site. Health-related variables such as cancer and neurological mortality further reinforce the complexity of relationships. High cancer mortality rates, particularly in active or dismissed SIN, consistently lead to lower property values, reflecting the perceived health risks associated with industrial pollution. Neurological mortality shows mixed effects, with smaller price differentials for active or dismissed SIN but larger differentials in partially dismantled SIN, highlighting the need for further exploration of these health-related factors.

Even if the total sample is limited for a statistical reliability of the market price function obtained, the outputs allow to raise the previous considerations concerning the qualitative effects of different typologies of industrial polluting sites on the local housing deprivation. Overall, the findings suggest that housing markets are highly sensitive to the presence and status of SIN, influenced by factors such as the plant's operational status, environmental conditions, and health risks. These insights can inform policy interventions aimed at improving environmental quality and public health in industrial areas while addressing housing market disparities. The innovative contribution of this

work lies in identifying critical 'pollution-poverty' areas that require urgent remedial action [14–18].

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