# Health Impact Assessment of the steel plant activities in Taranto as requested by Apulia Region

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# ABSTRACT

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The steel production plant in Taranto, in south-east Italy, has been active since the 1960s and has become one of the major facilities in Europe. It represents an important resource for the region and the country in terms of economy and employment. The plant has been known for several decades for its adverse environmental impacts, with substantial emissions of various pollutants affecting a wide area, including densely populated areas such as the city of Taranto itself. Taranto and surrounding municipalities are included in the government-designated list of sites of interest for environmental contamination. The impacts on human health have been extensively studied over the years. Excesses of occurrence of numerous diseases and mortality have been repeatedly documented, showing a concerning health profile of the local population. Health impacts of the steel plant have been quantified most reliably for the emissions into air, closely monitored for many years. Considering alternative scenarios of industrial production and emissions, previously available estimates were updated by the WHO project described in this report. Findings confirm those estimates and add a monetary evaluation. The estimated mortality and morbidity predictable impacts, and associated costs, are a function of the predicted changes in pollutants concentrations in different scenarios; for example, 26 deaths per year are estimated in Taranto municipality in the pre-AIA 2010 scenario (the least favourable), for men and women older than 30, combined. The figure decreases to 4 deaths in the most favourable scenario. These figures represent a partial view of the overall health impact. Important other pathways, such as the contamination of soil, water, waste and food, are not reliably quantifiable as of date. Also, the important dimension of quality of life, the urban environment, and green spaces are affected by the industrial policies of the plant and the extended area. These aspects require a thorough qualitative impact assessment that has not been attempted so far, but seems urgent in the light of the imperatives of the sustainable development agenda.

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## 1. Introduction

The city of Taranto (191,050 inhabitants, 40°28′0″N 17°14′0″E, area 217.5 km²) is located in southern Italy near the head of the Gulf of Taranto in the Ionian Sea (Istituto Nazionale di Statistica Italia (ISTAT, 2020). The western side of the gulf is dominated by the Apennine Mountains; the eastern side is quite flat and low and forms the northern boundary of the large plain of the Salento peninsula. The city itself (see Figure 1) has a peculiar conformation including two internal sea basins called the "Mar Piccolo and Mar Grande" so that all sides are influenced by the sea, with two distinctive functional areas (Mangia *et al*., 2013; Vigotti *et al*., 2014; ASSET, 2019):

- to the West, the steel plant together with the working-class residential districts of Porta Napoli, Tamburi, Paolo VI and Lido Azzurro;
- to the East, the consolidated historic city (Old Town and Borgo),with a peripheral area that extends up to the coast centers of Lama, San Vito and Talsano, townships in the 1950s and now city districts.

Taranto and surroundings municipalities are the centre of several environmental impacting activities that include: one of the largest steel plant in Europe (former ILVA and currently owed by ArcelorMittal), the ENI oil refinery, two power plants, the CEMENTIR plant with an average annual production of 900,000 tonnes of concrete, the deposit of radioactive material "ex-CEMERAD" (located at Statte, 14.8 km from Taranto city), a mining industry, military installations, and landfills and illegal waste sites, as well as various quarries disused. Further environmentally impacting activities, deeply integrated within the urban area, have to do with the presence of a large harbour that supports industrial and commercial activities (Mangia *et al*., 2013; Lucifora *et al*., 2015; Leogrande *et al*., 2019). Disentangling the relative contributions of these highly polluting activities to health outcomes in the general population poses an important methodological challenge, as different stressors combine through multiple exposure pathways, and their overall effect is further influenced by underlying socio-economic factors.

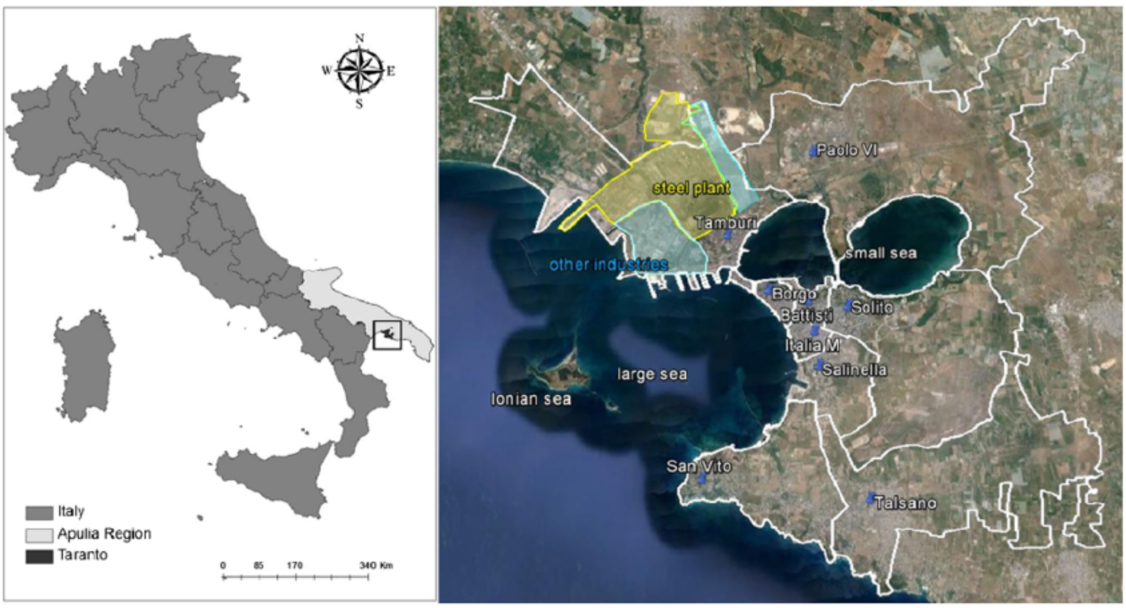



Figure 1: Taranto city, Italy: neighbourhoods and main plants in the industrial area (Vigotti *et al*., 2014)

As a result of the polluting activities described above, Taranto was recognized as a "Site of National Interest" (SIN) by the Decree of the Italian Ministry of the Environment on 10 January 2000, with a total perimeter of just under 117 km (43.8 $km^2$ corresponding to land and 73 $km^2$ to sea), being considered as one of the largest national SIN in extension (ASSET, 2019).[1].

## 1.1. The case of the steel plant at Taranto

The ex-ILVA plant (now ArcelorMittal Italia), established in 1965, is the largest integrated cycle steel complex in Europe, reaching an extension of about 15.45 $km^2$ of which about 10.45 $km^2$ are based in the municipality of Taranto and about 5 $km^2$ in the nearby municipality of Statte, located northwest of Taranto (Fig. 1). Its main productions are: coke, sinter, pig iron[2], solid steel, hot rolled coils, cold rolled coils, hot galvanized coils, hot rolled heavy plates, black or coated welded pipes (EP, 2018; Leogrande *et al*., 2019). Ex-ILVA represents the main employer in southern Italy, with about 10,400 people as direct positions (ArcelorMittal website revised on 20.4.2021: https://italia.arcelormittal.com/en/who-we-are), and around 8000 to 10,000 additional workers in satellite activities (Lucifora *et al*., 2015; Leogrande *et al*., 2019).

In July 1997, the Italian Council of Ministers declared the ILVA steel plant in Taranto as "*area at high risk of environmental crisis*"[3] The judiciary opened an investigation, and in 2005 the managers of the steel plant were convicted for the offence of "Dangerous throwing of things", provided for in Article 674 Criminal Code. The managers were found guilty for having spread in the neighbouring areas of the steel plant a large quantity of mineral dust from the deposits existing in the area of the plant, and for not having undertaken actions to prevent the spreading (Arconzo, 2013; Lucifora *et al*., 2015).

On 25th July 2012, the judge for preliminary investigations at the Court of Taranto ordered the seizure and shutdown of the hot working areas of ILVA, following the results of the epidemiological survey showing that ILVA fumes were seriously harming the environment and the health of workers and local residents. However, considering that many jobs were under threat, the government aimed for a solution that would reconcile environmental and health concerns with employment opportunities. In this framework, the Italian government issued a Law Decree (Law Decree No. 207 of 03 December 2012), which allowed ILVA to resume its steel production and at the same time imposed to upgrade, within 36 months, the plant according to the requirements set out in the review of the Integrated Environmental Authorisation (IEA), to ensure a high level of protection of the environment and human health according to the best available techniques (Lucifora *et al*., 2015).

The IEA procedure is operating in Italy since 2004 for complying with the requirements of Part II of the Legislative Decree No. 152 of 3 April 2006, as amended by the Leg. Dec. No. 46 of 4

[1] The Sites of National Interest (SIN), are defined as "*Areas of national territory, classified and recognized by the Italian State, in need of soil, subsoil and/or surface and groundwater remediation to avoid environmental and health damage*". The list of SIN were identified in the Legislative Decree 22 of 5 February 1997 (Ronchi Decree), and in Law no. 426 of 9 December 1998

[2] The coke, together with the agglomerate (granulated iron) is used as a chemical reducing agent for manufacturing pig iron (an iron-carbon alloy, with a carbon content between 1.9% and 5.5%) The steel is the same alloy but containing less than 2% carbon).

[3] Resolution of the Council of Ministers of 11 July 1997.

March 2014, as requested in the Directive 2010/75/EU on industrial emissions[4] (Integrated Pollution Prevention and Control). The steel plant obtained the first IEA in 2011, followed by several reviews as the one ordered by Decree of 26.10.2012, which authorized a maximum production equal to 6 million tons of steel, and the most recent Decree of 09.29.2017 (Galise *et al.,* 2019). Compliance with requested technological improvements in the most recent IEA would allow for the steel production scale up to 8.5 million tonnes per year in 2024, with a reduction of the workforce by five or six thousand redundancies (EP, 2018).

At European level, in its resolution of 13 December 2012, European Parliament (EP) called on the Italian authorities to ensure the environmental rehabilitation of the polluted steel plant site as a matter of extreme urgency, while at the same time ensuring that the costs incurred in relation to the preventive or remedial action taken are covered in accordance with the polluter pays principle, as required by Article 8 of Directive 2004/35/EC[5] on environmental liability (EP, 2012; Lucifora *et al*., 2015).

More recently, on 18-19 July 2017, a delegation of the EP conducted an on-site assessment and a hearings of interested stakeholders (managers and technicians of ex-ILVA, local citizens, NGOs, along with national, regional and local authorities in environment and public health) in order to obtain information about the main ongoing processes that cause pollution and present health and safety issues for workers and residents. They also gathered information on the available industrial options for the implementation of a model able to fully safeguard citizens' health and environment as well as the socio-economic wellbeing of the Taranto area (EP, 2018). As part of this on-site assessment, delegates of EP reported the following existing elements in the plant in July 2017:

- Technicians of ex-ILVA informed the delegation that **a continuous ship unloader** (CSU 1) had been implemented to enable the raw materials arriving by ship to be moved to the east pier without any leakage or scattering from ships' cargo.
- **Large conveyor** belts for transporting the raw material from the east pier in the harbour to the open-air mineral parks at the plant were partly covered. IEA provisions demanded for the conveyor belts to be covered to avoid spread of particulate matter by the wind; in April 2017, 65% of the total extension of the conveyor belt was already covered (38.6 km out of the 59 km).
- A main **open-air mining park of about 70 hectares** for storing raw materials (iron ores and coal) located close to the Tamburi district, and several secondary parks were still in operation. According to the premises of the IEA, these parks should have been covered by the construction of an imposing double arch structure similar to a hangar (a wall approximately 80 m high equivalent to a 25-story building) erected just behind the Tamburi district in order to reduce the risk of particulate matter becoming airborne. It was proposed as an additional measure to the tree-lined "ecological" hills of Via Appia, which already acted as "windbreaks" for the inhabited area. However, the coverage of the mineral parks seems to be repeatedly delayed. As a result, on days when the wind blows towards that district the only protection for the affected population in Tamburi

[4] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) Text with EEA relevance. OJ L 334, 17.12.2010, p. 17–119

[5] Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage. *OJ L 143, 30.4.2004, p. 56–75*

consists of shutting the windows, and keeping children at home. At the time of the EP visit, constructions were not yet initiated.
- By July 2017, the **use of fog cannons** in the process of dampening the piles of raw materials to the mining parks was the only mitigation measured applied waiting for the parks to be covered.
- **Ten coke oven batteries were present,** four of which were working during the on-site visit.
- **Five blast furnaces** for the production of pig iron and the steel, three of which (numbers 1, 2 and 4) were in operation, while the other two remained switched off. The control room of Furnace 1 was upgraded in August 2015 in a EUR 130 million renovation, and operates automatically (workers only intervene in the event of a malfunction). Furnace 5, is one of the largest of its kind in Europe and has been off since March 2015, awaiting extraordinary environmental clean-up and maintenance work in order to fully comply with the provisions of the IEA.
- Furnace 3, was declared, during the delegation visit, to be demolished soon, implementing environmental protection measures, including the removal and disposal of the asbestos (around 4,000 tonnes). The union representatives attending the hearing with EP delegates stated that the environmental clean-up of the plant should be carried out in full, with no more delays. ILVA technicians argued that the organic decontamination process would involve the entire plant, going deep into the subsoil beneath Furnace 3, and would also involve removing waste accumulated over time (such as the railway sleepers, which were impounded back in 2009, and old tires).
- In addition to pig iron, the furnaces also produce gases, which are reused to generate both electrical energy (in the plant's **two power generators**) and liquid slag, which is then ground-granulated and used for manufacturing glass and cement.
- **Two steel mills**, built in 1964 and in the early 1970s, where the pig iron (transported to the steel mills by rail in wagons) is refined in converters via blasts of oxygen from above in a low-carbon alloy, liquid steel, which is poured into large ladles to solidify through continuous casting moulds. There are five of these moulds in the two steel mills. Roughly 70-80% of the finished goods are shipped from the west piers to major ports in Europe, Turkey, North Africa and other overseas destinations.
- Limestone quarry area, with completely covered parks.
- Outdoor landfills with non-hazardous waste and hazardous waste located within the perimeter of the areas conferred to the new owner. The unauthorised discharge of hazardous waste was under a new judicial investigation at the moment of the visit.

On 4 September 2017, the Regional Environmental Protection Agency (ARPA) issued observations on the IEA application for new measures and changes to the planned environmental and health protection measures and activities approved by a Prime Ministerial Decree of 14 March 2014 for plant operation as well as, where necessary, extensions to the implementation deadlines of the related provisions. In its observations, ARPA underlined that the environmental clean-up measures already provided for under the aforementioned Prime Ministerial Decree – for which the original deadline was June 2017, then extended to September 2017 – will not actually be completed until August 2023. Because the majority of these measures are necessary to comply with best available techniques (BAT) in the sector (see Commission Implementing Decision of 28 February 2012 establishing the BAT under Directive 2010/75/EU on industrial emissions for iron and steel production), ARPA Apulia reiterated that any delay in environmental clean-up at the plant would constitute an advantage for the company and a cost for the environment and public health. It also pointed out that running the steel plant without implementing or only partially implementing BAT could constitute an infringement of EU law (EP, 2018).

Some stakeholders attending the hearing with EP delegates in July 2017 (Peacelink Association) were quite concerned about the environmental plan conceived for the regeneration of the steel plant, which would require five years for its implementation (ending in 2023) for a total sum of EUR 1.14 billion; a scant amount in comparison with the estimated amount of EUR 8.1 billion by the courts made in 2013 (EP, 2018).

The Italian Parliament introduced a regulatory amendment that extends the extraordinary administration's monitoring term to 2024 (corresponding with the end of the current business plan horizon). This would ensure that the new owner abides by its commitments to make the agreed investments, or otherwise relinquish ownership.

At the end of 2019 the Italian Government presented a guideline plan 2020-2023 aiming at making the Taranto plant into a “European leader in the production of eco-sustainable steel", with a planned investments equal to EUR 3.6 billion over the next 5 years to reach an overall annual production of 8 million tons of steel. However, in June 2020, ArcelorMittal presented their own "Post COVID Business Plan 2020-2025" that proposed a downsized production to 6 million tons per year by 2025, foreseeing 3,150 redundancies. In September 2020, the Minister of Economy and Finance announced that a credible and ambitious relaunch project was being defined for the decarbonisation and environmental remediation of the ex-ILVA plant, complying with the target objectives under the European Strategy Green Deal. However, this new industrial plan, presented in December 2020, was developed with limited involvement of the main affected actors, including the Municipality of Taranto (European House-Ambrosetti-Total E&P Italia, 2021).

The ILVA case undoubtedly represents a great challenge for national, regional and local governments, industry and society in achieving a fair balance between the right to health and the protection of the environment, on the one hand, and the right to work and secure an income on the other. This balance cannot be achieved without the participation of all affected parties, and the commitment to an open and fair policy process, oriented towards more sustainable forms of environmental, social and economic development.

## 1.2. Strategic Plan “Taranto futuro prossimo”

The implications of the ILVA case go beyond the steel plant production, and the environmental pollution and associated health damages. The implications also affect urban planning of the city of Taranto and its surroundings, as well as the broader industrial and socio-economic development policies, focused almost exclusively around the steel plant for decades, but now aiming at a diversification of business and jobs in the area. The current economic crisis, exacerbated by COVID-19 pandemic, and the growing lack of competitiveness in the steel sector, make it urgent to seek for comprehensive solutions, where structural and technical improvements in the plant for reducing its environmental impacts are coupled with comprehensive urban redevelopment plans and sustainable development strategies, all critical elements with potential impacts on human health and well-being.

In this context, it is important to highlight the Strategic Plan of development and enhancement of the Taranto area, entitled "**Taranto futuro prossimo**", promoted by the Apulia Region with the Municipality of Taranto, and the support of ASSET - Regional Strategic Agency for the Eco-sustainable Development of the Territory (ASSET, 2019). The Strategic Plan is a concerted tool developed taking into account the contributions that emerged from institutional meetings with public stakeholders from 8 thematic areas and in accordance with the Regional Law 25 January 2018, nº 2 ("Guidelines for development, environmental sustainability and the economic and social cohesion of the Taranto area"). This plan was inspired by the experiences from other cities with a long industrial tradition, where the crisis of the sector, especially the one affecting the steel production, required restructuring and reorganizing the economic and development model. In those cases, the crises were addressed through coordinated actions between all involved actors (public and private actors, citizens), avoiding confrontation to the extent possible, and focusing on the root of the problems and, above all, defining shared, sustainable future horizons, achievable according to the context and actors involved.

This strategic Plan for Taranto identified 4 general objectives:

1. remove obstacles to socio-economic development
2. a new organization of local economy aimed at promoting new employment, especially for young people and women
3. enhancing the potential resources of the territory in economic and social terms
4. foster economic, social and cultural innovation, into the framework of principles and objectives of the 2030 UN Agenda for sustainable development

These 4 objectives drive the overall strategies to be implemented. The subsequent operational Program identified 6 axes: employment and growth; business (new-economy); research and education; environment and health; urban life quality; mobility and accessibility.

## 1.3. Health Impact Assessment: purpose and approaches

For better understanding the approach adopted in this document it is important to clarify the purpose, utility and different approaches of "Health impact assessment" (HIA) applied in the context of contaminated sites. (Martin-Olmedo *et al.,* 2019).

HIA shares some similarities with Environmental Impact Assessment, but there are also important differences, including the fact that HIA is rarely a legal obligation. The Gothenburg consensus paper defined Health Impact Assessment as *"a combination of procedures, methods and tools by which a policy, program or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population*" (WHO Europe, 1999). HIA practise is grounded in the World Health Organization (WHO) definition of health and well-being (WHO, 1948) which encompasses physical, mental and social health and well-being. Its implementation is closely linked to the development of the social determinant of health framework, and to the Health in All Policies strategy (HiAP) promoted by WHO and adopted by the EU in the White Paper "*Together for Health: A Strategic Approach for the EU 2008-2013*" (Ståhl *et al*., 2006; EC, 2007). This framework considers not just the biophysical and environmental health impacts, which can be derived from policies, proposals and plans but also assesses the social factors, which can have an impact and the population groups which are affected. These factors, such as environment, transport, housing, access to services and employment can all interact to a greater or lesser extent with an individual's lifestyle choices and genetic makeup to influence health and wellbeing (Dahlgren and Whitehead, 1991; 2007). Figure 2 below summarises the relationship between these determinants.

HIA's ultimate objective is to support decision-making processes by providing information and scientific evidence on the positive and negative effects that any new proposal may have on health and health equity. Its prospective nature also allows the introduction of corrective measures aimed at managing the estimated impacts and thereby optimizing the health results of the evaluated proposal. There is a broad variety of forms in which HIA is undertaken in practice, depending on the kind of intervention, its extension or complexity, the spatial scale to which it is applied, the timing for conducting the HIA, or the methodology used. Other aspects that have conditioned the practice of HIA are linked to the disciplines from which they were promoted (origin) and the purposes for which they were defined, creating futile disagreements and conflicts among practitioners from different fields (Harris-Roxas and Harris, 2011; Martin-Olmedo and Mekel, 2014).

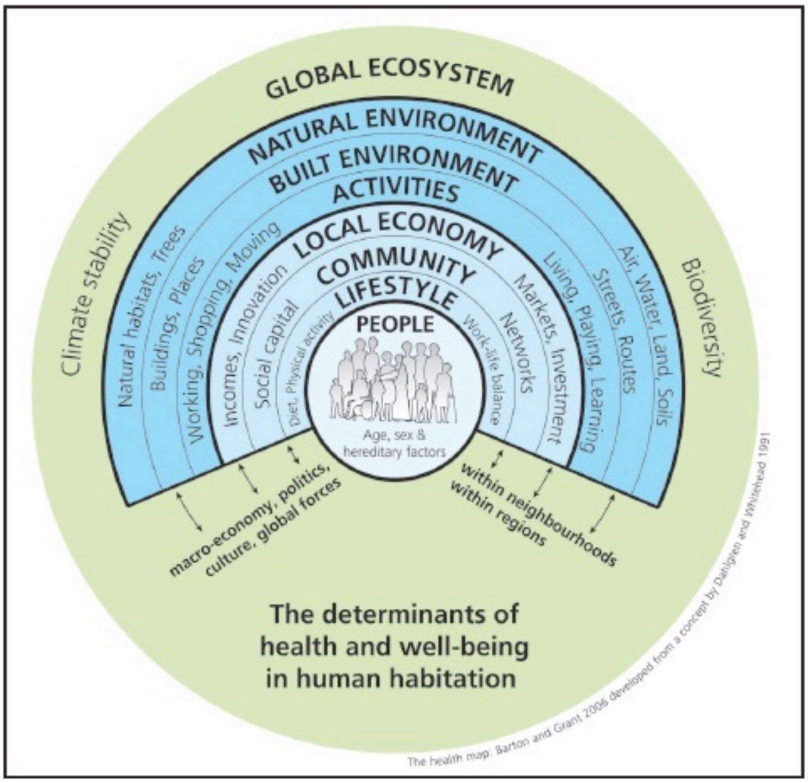



Figure 2: Social determinants of health and well-being framework (Dahlgren and Whitehead, 1991; 2007)

Although there are several proposed operational procedures for carrying out a HIA, most shared a model structured in five stages with some variations in terminology (Chadderton *et al*., 2012; Martin-Olmedo and Mekel, 2014; Cave *et al*., 2020; Winkler *et al.,* 2021):

1. Screening: to determine whether a proposal (project, program, or plan) might have likely significant impacts on population health, and therefore, it requires a HIA.

2. Scoping: to describe baseline situation in terms of most relevant affected health determinants and define resources, timeframes, policy windows, and evidence to be considered.
3. Appraisal or assessment of health impacts: triangulation of qualitative and quantitative evidence and health intelligence to systematically assess the nature, likelihood and significance of potential positive and negative health impacts related to a proposal.
4. Reporting and recommendations: construction of HIA report and any nontechnical summary
5. Monitoring and evaluation: including monitoring and evaluation – did the HIA and any findings have an impact on health and well-being or decision making process

For the central stage of "appraisal or assessment of health impacts", quantitative or qualitative methodologies can be used (Cave *et al*., 2020):

1. QUANTITATIVE APPROACHES provide an indication of the magnitude of health effects, allowing a comparison with existing numerical criteria or thresholds that inform the significance of particular effects and allowing more direct comparisons among alternatives. There are several quantitative methods available to estimate health impacts, but mostly they are grouped in two main categories: human health risk assessment (HHRA) and comparative risk assessment (CRA) or burden of diseases.

    - HHRA, based on toxicological evidence, can be conducted quite quickly at modest expense, providing direct information on the urgency of intervention to protect the health of population, remediate exposure, or identifying appropriate public health actions such as medical monitoring, health education, and/or health surveillance and substance-specific research. HHRA estimates could inform whether or not the population might be at risk of being affected by non-carcinogenic or carcinogenic health effects, but does not quantify the number of health events (in terms of morbidity and mortality) associated to such exposure. A wide variety of guidance on how to conduct HHRA in contaminated sites is offered by different international, national, and regional health and environmental agencies (Martin-Olmedo *et al*., 2019).

    - CRA (also referred to as "integrated environmental HIA") involves calculating the population attributable risk, or where multi-level data are available, a potential impact fraction, defined as the proportion of future burden of disease or injury that could be avoided if current or future exposure levels to a risk factor or group of risk factors were reduced to hypothetical scenarios. This is a population-based approach, which aims to assess changes in the specific studied population, using epidemiological methods and evidence. Such approaches may not be readily applicable to all health determinants and risk factors; it will depend on the availability of robust exposure-response functions obtained from high quality epidemiological studies, and on the effect size and population size, among other factors (Martin-Olmedo *et al*., 2019).

      The metric of burden of disease (BoD) combines mortality and morbidity into one indicator, through summing up the amount of time by which lives of the affected people are shortened and the time they live with diseases. This combination is done using comparative weights, established through expert consensus. The resulting overall picture of the health effects and impacts of environmental risk factors, despite relying on several assumptions that need verification, provides a sound basis for policy response and interventions and can guide priority settings.

In such an increasingly policy-relevant debate, the economic question arises naturally: evidence-informed, health-promoting policies are desirable, but should they not be worth their cost, that is, cost-effective too? Obviously, the answer is a resounding "yes", (although some qualification is needed), and it is no surprise that a whole discipline has flourished, dedicated to the very issue of addressing the economic dimension of the relationship between environment and human health.

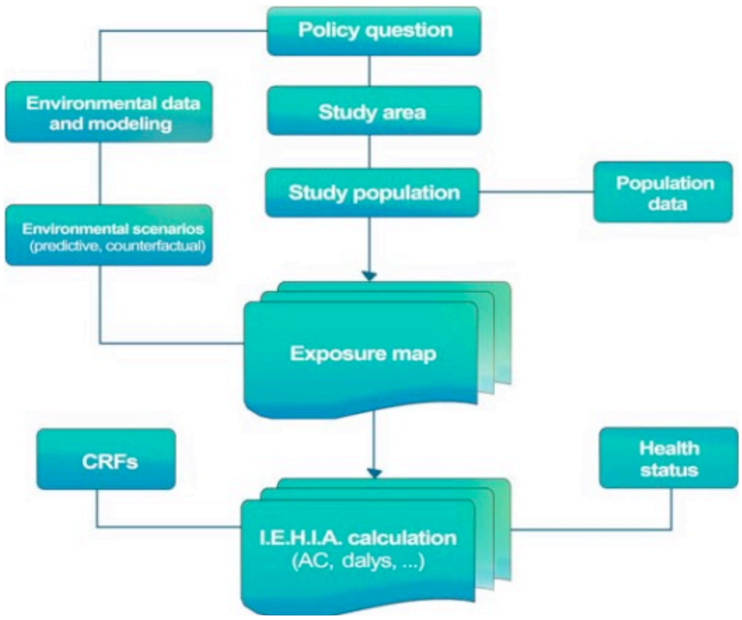



Figure 3: Main steps and data needed to applied CRA approach

2. QUALITATIVE APPROACH: a conceptual model can be constructed for the identification of *likely significant health effects*, considering "likely" as those health effects that, based on the scientific literature, have a plausible link between source–pathway–receptor and which occurrence in the context of the proposal is probable based on professional judgement. "Significant" are considered all those health effects, based on professional judgement, important (a positive or negative effect), desirable (a positive effect) or unacceptable (a negative effect) for population health with regards to changes triggered by the project in question. The likely significant effects can be systematically analysed according to the following criteria (Cave *et al.*, 2020):
    - there is a sufficiently large magnitude of change to a sufficiently sensitive population;
    - the scientific literature shows a relevant causal relationship, or clear association, of sufficient effect size;

- an intrinsic dangerous nature of the identified risk factors. In this regard, any exposure to chemical or physical factors that are proved to cause carcinogenesis, teratogenicity, or endocrine disruption should be carefully evaluated, especially in case of sensitive subgroups (e.g. children or pregnant women);
- relevant health priorities have been set for the study area that are of specific or general relevance;
- the health baseline could experience a substantial change (or even a small change in a large or highly vulnerable population);
- there could be a substantial or influential ability to deliver existing health policy, particularly locally;
- relevant regulatory thresholds or standards could be crossed or approached.

The election of the best methodology should be adjusted to the questions that need to be answered for supporting decision-making and in identifying best actions which ensure a high protection of human health while reducing health inequalities. It will also depend on availability of environmental, health and demographic data, and instrumental and human resources (Martin-Olmedo *et al.*, 2019).

## 2. Aim of the WHO Project in Taranto

The overall objective of the project was to conduct a prospective health impact assessment of the Taranto ex-ILVA steel plant, as requested by Apulia Region. The project was carried out by a group of experts guided by the WHO Regional Office for Europe. At the time of the project onset, certain activities required for a complete HIA were foreseen, such as site visits and the identification and interviews with stakeholders that should have provided the project team with relevant information on the key actions and future scenarios of the industrial plant. Unfortunately, the COVID-19 pandemic made impossible for those interviews and the onsite work to be accomplished, making also quite difficult accessing all necessary data, and causing several unavoidable delays.

The objectives of the project, which are addressed in this document, were:

- Review and evaluate available evidence on health and health determinants related to the activity of the ex-ILVA plant, and those reported under the "*Ambiente e salute*" section of the Strategic plan for Taranto, somehow interlinked to the activity of the steel plant. Special emphasis was placed on how emissions from the ex-ILVA plant have affected the ambient air pollution in Taranto, considering dispersion and concentrations of particulate matters ($PM_{2.5}$), under different scenarios linked to the implementation of measures requested under the IEA 2012.
- Assess the likely most significant health impacts of the above determinants, using qualitative and/or quantitative approaches, depending on data availability. To this respect a quantitative evaluation of the health impacts and related economic costs associated to human exposure to ambient air $PM_{2.5}$ was carried out.
- Assess the likely health implications on other determinants besides air pollution relevant in Taranto and surrounding areas, in order to further characterise the

broad local context and the relevant environmental factors, beyond the direct impact of the industrial emissions. This exercise was guided by the directions outlined by the Strategic Plan *Taranto Futuro Prossimo*, to promote a stronger inclusion of the health sector in future policy development in the area.
- Provide recommendations for follow up work, notably monitoring the identified environmental and health impacts, and for future more comprehensive HIA of those aspects that could not be addressed under current circumstances.

The reference scenario for which the health impacts were characterised, defined for the continuity of the activity of the steel plant and the Strategic plan, are:

- An annual average increment of the green urban spaces of 6.67% up to 2030.
- An annual reduction of 7.4 % of the $PM_{10}$ emissions of the steel plant up to 2030
- An annual increment in the waste segregation of 6.4% up to 2030.

## 3. Methodology

HIA is based on a triangulation of health intelligence, review of the literature, scientific evidence (accessible through existing data or data from *ad hoc* sampling and measuring campaigns related to exposure to risk factors, demographic information and health outcomes) and local knowledge. Overall goal of HIA is to characterise the nature, size, likelihood and distribution of potential health impacts of actions or policies. Due to the limitations imposed by the COVID-19 pandemic, the interactive work with stakeholders was not feasible for this project, nor gathering certain adjusted data to describe precisely the current technological changes adopted by current owners of the ex-ILVA plant and the demographic and baseline health situation of the Taranto population.

Nonetheless, key information for the identification of potentially affected health determinants /risk factors and associated health impacts was gathered through an extensive literature review based on peer review articles related to the context, and on key technical reports (published as "grey literature") published by ARPA, Apulia Strategic Regional Agency for Health and Social (AReSS), Taranto Local Health Authority (ASL Taranto), the Istituto Superiore di Sanità (ISS) (Italy), and Apulia Region Government, among others. More specifically the project team based their judgment on following key documents and datasets produced and/or facilitated by local/regional and national institutions:

1. A **"health damage assessment" (acronym in Italian, VDS)** conducted by ARPA, AReSS, and ASL Taranto (last updated available version, 2018) accomplishing that established at Italian National Law 232/2012 and Apulia Regional Law 21, of 24 July 2012, "*Regulations for the protection of health, the environment and the territory on polluting industrial emissions for the Apulian areas already declared at high environmental risk*", which aims to prevent and avoid a serious danger , immediate or deferred, for the health of living beings for the regional territory. The VDS applied at ex-ILVA plant consisted of two components: a) an epidemiological health baseline description focused in particular at short-latency illnesses, potentially attributable to environmental exposures (e.g. cardiovascular diseases, acute and chronic respiratory diseases, childhood neoplasms); b) a HHRA based on toxicological evidence considering emissions condition prior and after IEA implementation at the steel plant

(emission data of years 2010; 2012 and predictions for 2015). The methodology adopted for the HHRA within the VDS followed Annex C of Regional Regulation no. 24 of 3/10/2012, adopting the procedure proposed by the U.S. Environmental Protection Agency (EPA, 1989; 2019), which includes the recognised 4 phases of HHRA: (i) hazard identification, (ii) exposure assessment, (iii) dose-response assessment, (iv) risk characterization. Seen from a more dynamic perspective, the phases can also be summarized as follows: polluting emissions into the atmosphere ➡ dispersion through diffusional models ➡ population exposure ➡ health impact (exposure per unit risk).

2. The **SENTIERI project** established in 2006 and funded by the Italian Ministry of Health and coordinated by ISS, represents a permanent epidemiological surveillance system of residents in National Priority Contaminated Sites (NPCSs). It focuses specifically on causes of death and hospitalization for which environmental exposure is suspected or ascertained to play an etiologic role. The epidemiological evidence of the causal association is classified into one of these three categories: Sufficient (S), Limited (L), and Inadequate (I). Several reports have been issued for the SIN of Taranto; the last one, published in 2019, is based on data for the period 2006-2013 obtained from the National Institute of Statistics (ISTAT), the Regional Health database and the AIRTUM database, a network of 44 Italian cancer registries of the general population and 6 specialized registers (e.g. congenital malformations registers). The Report focuses on five health outcomes: mortality, cancer incidence, hospital discharges, congenital anomalies, and children, adolescents and young adults' health. Standardized Mortality Ratios (SMRs), Standardized Hospitalisation Ratios (SHRs), and Standardized Incidence Ratios for several cancer (SIRs) were computed, both crude and adjusted by an *ad hoc* built deprivation index (De Santis *et al*., 2011).

3. The **Strategic Plan of development and enhancement of the Taranto area**, entitled "Taranto futuro prossimo", promoted by the Apulia Region, that includes a baseline description of the current status of some key environmental and health related aspects (ASSET, 2019).

4. Although it has not been possible to gather the opinion of the stakeholders under current circumstances, the document **Mission report and recommendations after the visit to Taranto of a delegation of the European Parliament in July 2017**, contains important information contributed by different relevant actors that could be useful for the analysis of the results, though with caution must be taken given the elapsed time since its publication. (EP, 2018).

According to previously described aims and limitations, a prioritisation process of the SCOPE of the HIA was conducted considering and selecting health outcomes and determinants based on the following criteria: evidence of direct impact; high potential extent and / or intensity of the impact pertinent to Taranto area; opportunities for health gain; the availability of data under current circumstances. Using these criteria, the PT narrowed the HIA of this project to the following main categories of health determinants/risk factors:

- Living/environmental conditions affecting health, including:
  - Ambient air pollution, with special emphasis on scenarios linked to the implementation of measures requested under the IEA-2012 for $PM_{2.5}$ reduction: a) real pre-IEA existing emissions rates in 2010; b) emissions rates

as result of implementation of EIA requirements in 2012; c) emissions situation in progress after adaptation of measures in 2015 or after.

- Food safety
- Waste disposal
- Urban green spaces

## 3.1. Study area

The study area for the specific objective of the assessment of health impacts related to long-term exposure to emissions from the ex-ILVA plant (concretely to the dispersion and concentrations of particulate matters ($PM_{2.5}$)), was delimited to the municipalities of Taranto, Massafra (32,381 inhabitants census 2011, source ISTAT), and Statte (14,494 381 inhabitants census 2011, source ISTAT). This territorial domain was specified by the VDS, according to the Resolution of the Council of Ministers of 11 July 1997 as "*area at high risk of environmental crisis*".

Under the broader context, the "Space of action" of the Strategic Plan "Taranto Futuro Prossimo", takes into account a broader perimeter, including the adjacent territories to the Municipality of Taranto, this means: villages of Talsano, Lama San Vito (and the Administrative Island), and also the Municipalities of Leporano, Pulsano, Faggiano, San Giorgio (which in turn overlaps with the territorial quadrant of Roccaforzata, Monteparano and Carosino), Monteiasi, Grottaglie, Montemesola, Crispiano, Statte , Massafra, Palagiano, Palagianello.

## 3.2. Population

For the objective of the HIA related to long-term exposure to emissions from the ex-ILVA plant, updated geo-coded data from the cohort population defined by Galise *et al*., (2019) were taken into account, which include subjects older than 30 years old residing in Taranto, Statte and Massafra for the period 2009-2013 (source ISTAT) for the calculation of health impacts related to premature mortality, and total population for the impacts related to circulatory and respiratory hospital admissions. Figure 4 (online supplementary materials of Galise *et al*., 2019) shows the administrative boundaries of the municipalities that make up the study area, while the dots indicate the geographical location of the subjects recruited in the cohort. In Figure 5 (online supplementary materials of Galise *et al*., 2019) the different neighbourhoods are represented. Table 1 shows information by gender and location on the reference population used for the quantitative HIA and economic cost.

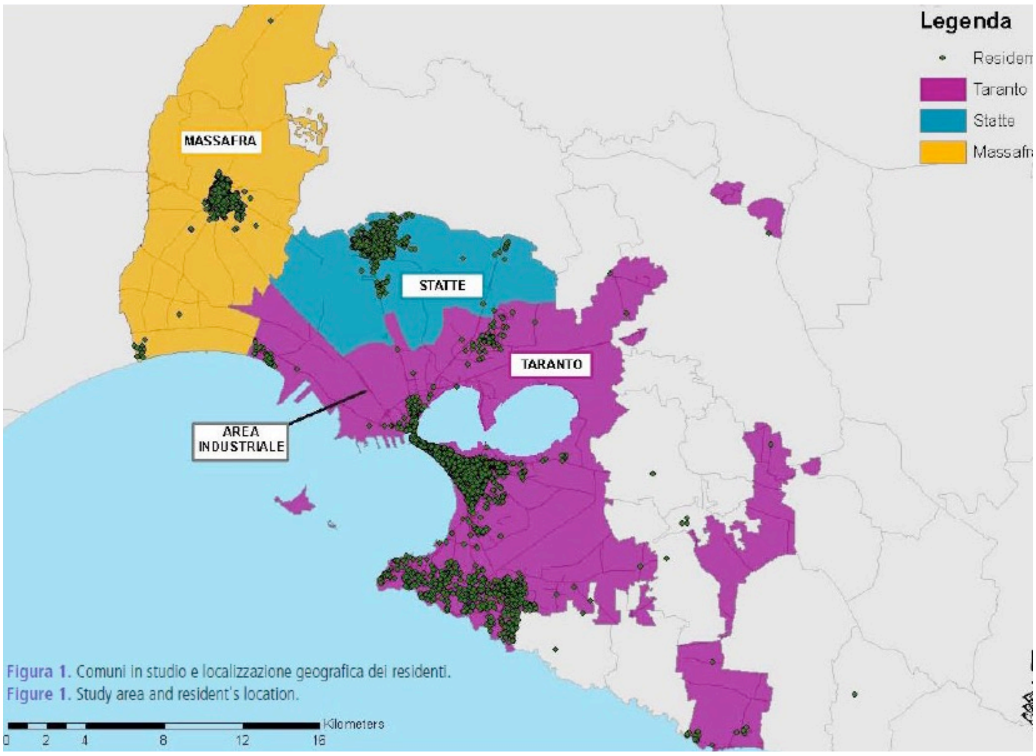



Figure 4: Study area and geographical location of the residents recruited in the cohort for the objective of HIA related to ambient air pollution (online supplementary materials of Galise *et al*., 2019)

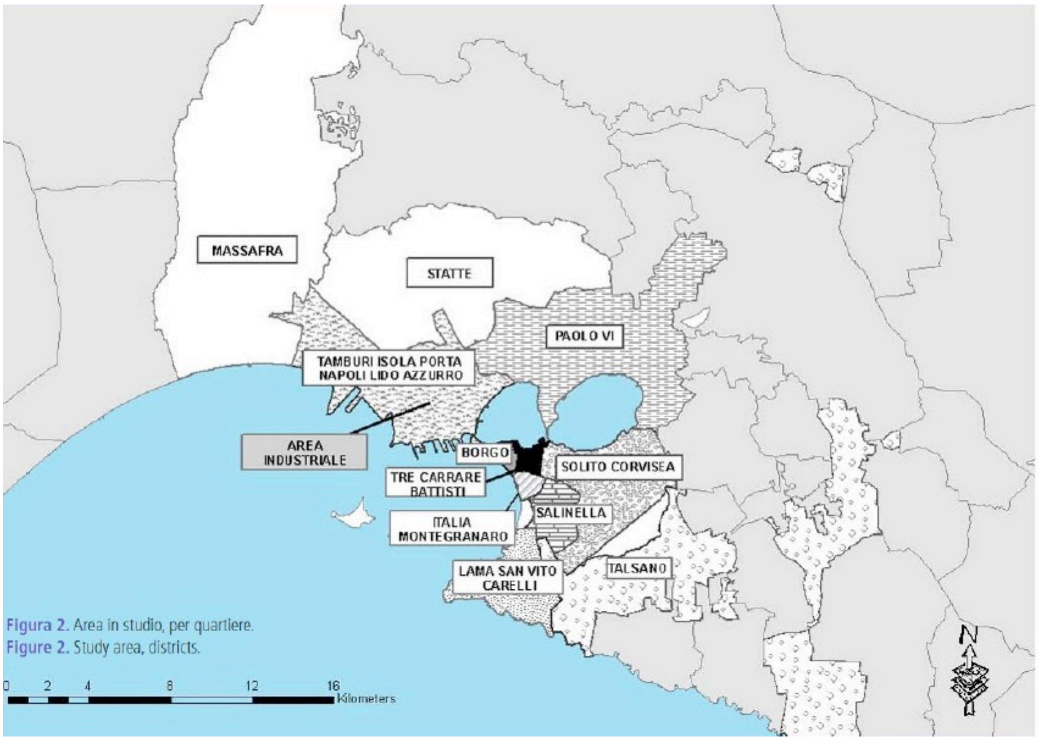



Figure 5: Study area, districts for the objective of HIA related to ambient air pollution (online supplementary materials of Galise *et al*., 2019)

| Scenario ➔ | pre-AIA 2010 concentration | | AIA 2012 concentration | | post-AIA 2015 concentration | |
|---|---|---|---|---|---|---|
| | Population ages 30+ | Population all ages | Population ages 30+ | Population all ages | Population ages 30+ | Population all ages |
| **Gender** | **TARANTO** | | | | | |
| **Male** | 66 186 | 97 979 | 65 071 | 93 531 | 66 203 | 93 531 |
| **Female** | 75 929 | 106 488 | 74 776 | 102 136 | 75 853 | 102 136 |
| **both** | 142 115 | 204 467 | 139 847 | 195 667 | 142 056 | 195 667 |
| **Gender** | **MASSAFRA** | | | | | |
| **Male** | 8 931 | 13 635 | 9 040 | 13 362 | 9 221 | 13 362 |
| **Female** | 9 843 | 14 408 | 9 963 | 14 181 | 10 137 | 14 181 |
| **both** | 18 774 | 28 043 | 19 003 | 27 543 | 19 358 | 27 543 |
| **Gender** | **STATTE** | | | | | |
| **Male** | 4 421 | 6 741 | 4 315 | 6 329 | 4 383 | 6 329 |
| **Female** | 4 703 | 6 841 | 4 653 | 6 540 | 4 726 | 6 540 |
| **both** | 9 124 | 13 582 | 8 968 | 12 869 | 9 109 | 12 869 |
| | **VDS area** | | | | | |
| **Both** | 170 013 | 246 083 | 167 818 | 236 079 | 170 523 | 236 079 |

Table 1: Population data by gender and location used for the quantitative long-term impact of $PM_{2,5}$ on health and the economic cost.

According to data from January 2018, the perimeter of the "Space of action" considered under the HIA related to the Strategic Plan, represents an overall extension of 836.77 km$^2$, and a population of 373,308 residents, out of which almost 55% are in the city of Taranto (ASSET, 2019). By virtue of the settlement morphology and the urban development happened throughout the twentieth century and in particular in the 1960s, many of the population groups included in this area appear as a kind of "island" within an urban "archipelago", perceived as not properly connected internally. Some weaknesses that show the poor accessibility are described by previous studies (ASSET, 2019):

- under usage of the Adriatic motorway towards Bari, due to tolls, in comparison with the SS100 (toll free);
- poor service of the railway lines to and from Bari and Brindisi, long awaiting a network and services upgrade;
- the Ionian railway line for Metaponto and Reggio Calabria is particularly inefficient

Taranto has been experiencing a progressive depopulation; since 2012 the population has decreased by 11.5 thousand units; the internal migration balance is negative (-4.1 individuals per thousand inhabitants); the old-age index is 173.6 people over-65 for every 100 young people under-14 (European House-Ambrosetti-Total E&P Italia, 2021).

## 3.3. Exposure assessment: methods and data

Quantitative HIA requires to identify all people and populations that can be affected by a change in a health determinant and related risk factors (as well as possible interactions between factors), with possible consequences on their health and well-being. In the case of living in an environment conditions with pollutants emitted from a local source (in this case, mainly the steel production process at the ex-ILVA plant), this would involve defining a comprehensive model, investigating how, how much, and for how long a substance comes in contact with individuals of a population, considering all POTENTIAL EXPOSURE PATHWAYS (course that contaminants take from a source to the portal of entry to the human body) (NRC, 2012; Martin-Olmedo *et al*., 2019). In the HHRA approach based on toxicological evidence, exposure pathways are addressed by identifying and charactering the following elements (ATSDR, 2005a; EPA, 2011; 2019; Martin-Olmedo *et al*; 2019):

- SOURCE from which pollutants are discharged or eliminated into the environment (e.g. chimney of an industry, storage tanks, landfills, waste confinement, discharge outfalls, etc.)
- ENVIRONMENTAL MEDIA to which the pollutants are discharged or emitted (e.g. surface water, groundwater, soil, subsoil, biota, air, sediment) as well as the MECHANISMS OF FATE AND TRANSPORT, referring to how contaminants move through, and are transformed in, the environment.
- EXPOSURE POINT, where people get in contact with contaminants (e.g. drinking water, soil from residential yards or parks, food, dust, etc.). They must be identified for each environmental media and contaminant or group of contaminants.
- EXPOSURE ROUTES, or mechanism for the chemical to enter the human body (ingestion, inhalation, or dermal contact), by one or a combination of exposure routes. People might get exposed to the same contaminant present in an exposure point through different exposure route depending on the physic-chemical properties of the compound and bioavailability.
- POTENTIALLY EXPOSED POPULATION, taking into consideration both each exposure pathway and the exposure duration and frequency. In the case of Taranto, it would be important to distinguish between:
    - Residential population, those living for long time in the same place and therefore susceptible to be chronically exposed to persistent pollutants in the area,
    - Normal users of recreation areas such parks, local bathing areas, playgrounds, etc. This probably involved children
    - Workers, especially those whose activities may result in an increased exposure levels related to the area under study (e.g. workers involved in removing soils, potentially exposed by inhalation or dermal route to these contaminants). It is also important to consider the families of these workers because of their possible indirect exposure through clothing and other materials that the workers bring home.
    - Population in transit: tourists, day labourers and other people who visit or reside in the area certain periods over a year.
    - Potentially "high risk" population: population that presents a greater vulnerability or sensitivity to certain pollutants as a consequence of the fact that their organs and immune system are not fully developed (in the case of children, and pregnant women), or are damaged or diminished (case of the sick and the elderly).

  - Population of particular susceptibility for other reasons, such as race, ethnicity, religious or cultural customs and other sociodemographic factors.
- TIMING OF EXPOSURE in terms of chronology, duration and frequency.

A proper characterisation of pollutants' concentrations at the exposure point is crucial in this process. Generally speaking, two approaches are used in exposure assessment (EA): direct and indirect methods. Methods for direct EA involve: 1) measuring concentrations at the interface between the person and the environment as a function of time, using passive or active personal monitoring tools (e.g. diffuse badges); 2) measuring chemicals concentrations or their metabolites in human body tissues or other biological samples (e.g. urine, blood, nails, hair, etc.). This last approach, called HUMAN BIOMONITORING (HBM), allows integrating different sources of contamination, routes of exposures (ingestion, inhalation, dermal absorption) and environmental media (air, soil, water and food-chain contaminants), providing an accurate estimate of cumulative exposures from a past period, ranging from hours (exhaled breath) to years (nails) (NRC, 2006; Martin-Olmedo *et al.,* 2019). Some constraints that need to be considered before planning a HBM study include: technical difficulty, ethical considerations, high cost, frequent lack of a meaningful reference value in bodily material, intra- or interlaboratory variability of methods, potential sources of error or sample contamination, and its difficulty to inform about future exposures (EPA, 2019; Martin-Olmedo *et al*., 2019). There are several experiences on HBM conducted in Taranto that will be summarised in chapters 4 and 5.

INDIRECT EA, secondly, is useful for a better identification and understanding of most relevant exposure pathways contributing to the overall population exposure in contaminated sites such as Taranto. These are conducted either by routine environmental sampling campaigns (e.g. ambient air or drinking water quality monitoring networks) or by specific *ad hoc* sampling campaigns. However, environmental sampling data, even validated, tend to be informative only of limited specific locations and/or time frames. In such circumstances, MODELS OR STATISTICAL TOOLS have proved useful in estimating the nature and extent of contamination for other areas or time.

For the objective of the HIA related to long-term exposure to emissions from the ex-ILVA, concentrations of ambient air particulate matter of 10 µm or less in diameter ($PM_{10}$) from industrial origin for each year of the study period was recorded using the air quality monitoring stations of the ARPA network operating in the study area. $PM_{10}$ was chosen as the exposure variable instead of $PM_{2.5}$ since monitoring data for the entire period of the study were not available for $PM_{2.5}$.

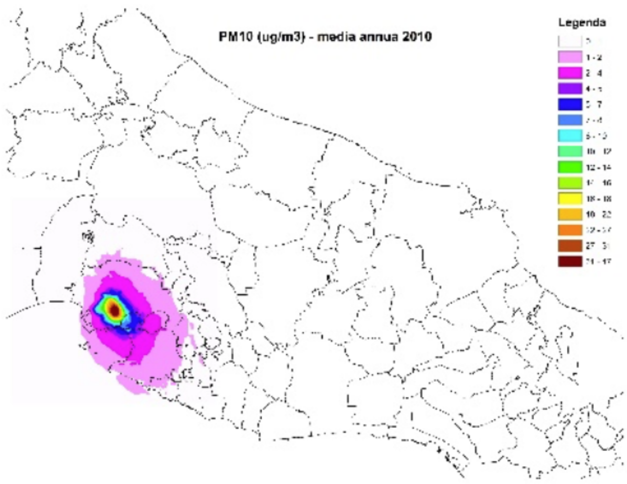
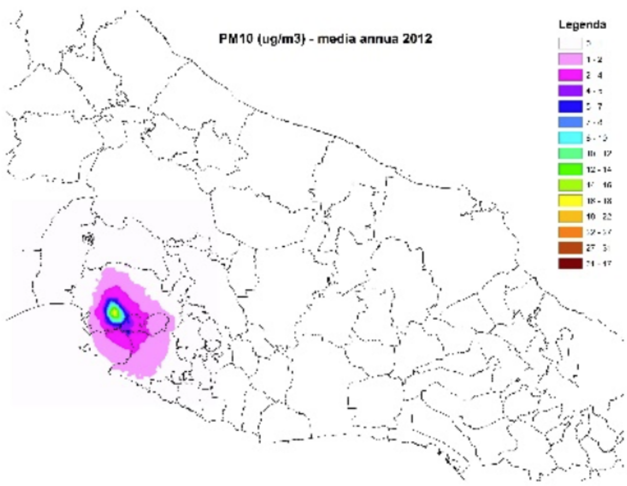
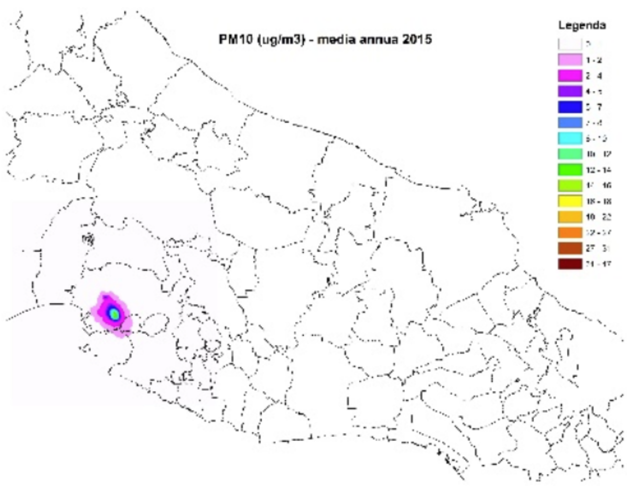
| | |
|---|---|
|   | fallout map of PM10 in the 2010 scenario (pre-AIA 2012)<br><br>yearly mean value (µg/m$^3$) |
|   | fallout map of PM10 in the 2012 scenario (AIA)<br><br>yearly mean value (µg/m$^3$) |
|   | fallout map of PM10 in the 2015 scenario (post-AIA 2012)<br><br>yearly mean value (µg/m$^3$) |

Figure 6: Dispersion models maps for the 3 scenarios consider under objective of the HIA related to ambient air pollution

A Lagrangian particle dispersion model (SPRAY) of $PM_{10}$ emitted from the ex-ILVA steel plant was built based on available information about emissions sources, topography, land use and meteorology (ARPA Apulia, 2013; Galise *et al*., 2019, Leogrande *et al*., 2019). Diffuse emissions estimations were obtained based on production and management data and from technical documentation of the sector. The emissions associated to the park with raw materials and to the handling and transport materials were considered, as well as the emissions from the coking plant, blast furnace, agglomeration and steel mills. Using this dispersion model, both images and shapefiles (GIS files) of the estimated concentration maps for $PM_{10}$ were used for the 3 scenarios under evaluation: 2010 (pre-IEA), 2012 (implementation of the IEA) and 2015 (post-IEA). The three different simulations of fallout maps are depicted in Figure 6.

The most reliable concentration-response coefficients, established by the WHO for estimating the attributable mortality and morbidity due to air pollution, are based on $PM_{2.5}$. In order to estimate the level of exposure to $PM_{2.5}$ in the study area, a conversion coefficient from $PM_{10}$ to $PM_{2.5}$ was used, as suggested in previous assessments in the region, including the above mentioned study by Galise *et al*. (2019). This coefficient, equal to 0.5, was derived based on the analyses of the steel plant emissions into air.

Combining the $PM_{10}$ annual average concentrations, measured by the monitoring stations, and the corresponding average concentrations modelled, with the geo-coded addresses of subjects from the cohort study population, the distributions of exposure values during the 2009-2015 period were calculated (a representation is visualised in Figure 7)

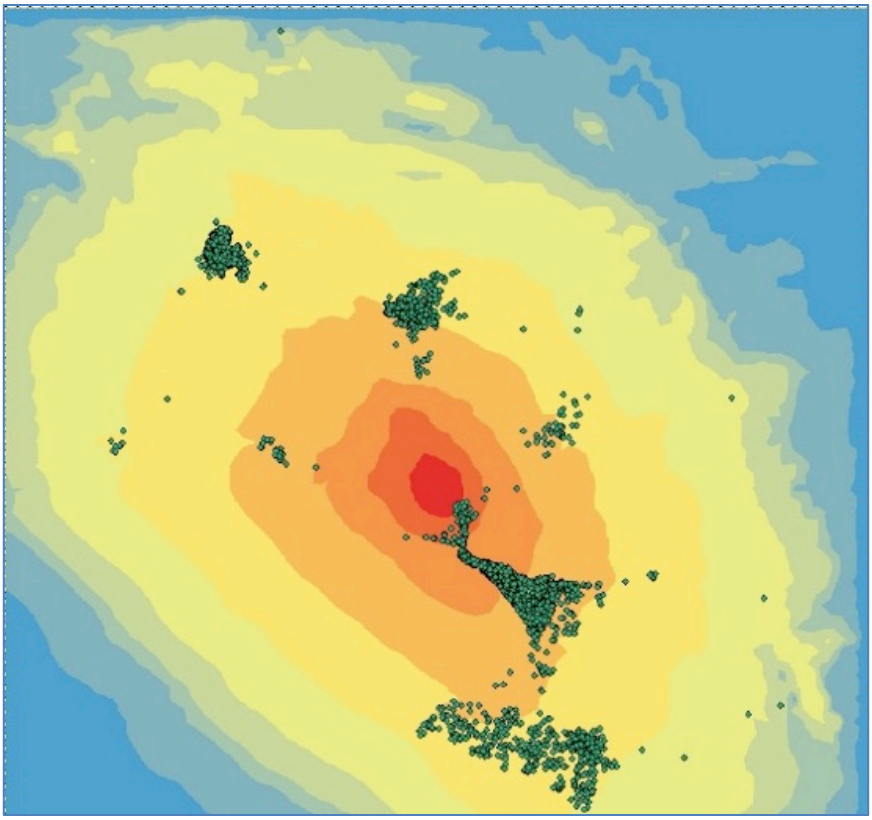


Figure 7: Representation of residential long-term exposure of each subject to $PM_{10}$. The dark dots represent residential homes.

Emissions of contaminants into air from the ex-ILVA plant through the years have undoubtedly affected and altered other health determinants relevant under the scope of this project (e.g. through the food chain). Thus, evaluating fate and transport processes of contaminants is important in order to understand how contaminants released from a source are spread and dispersed from one environmental media to another, until reaching different contact points where people can get exposed to (e.g. recreational soil where children play, groundwater used for drinking water, food chain). In the process of EA it is in principle necessary to account for all possible exposure pathways, considering the different population subgroups and factors such as age and behaviours, and activity patterns that may affect exposure and vulnerability to contaminants. For example, children may have increased vulnerability to some types of toxin and experience of a greater exposure level because of their hand to mouth contact and mouthing behaviours. In this case, description of exposure pathways would need to account for all possible exposures resulting from ingestion, inhalation or dermal contact with soil contaminants (ATSDR, 2005a; Martin-Olmedo *et al*., 2019).

The PT did not have access to data for quantifying how the steel plant has affected locally produced food, waste management or urban development with emphasis on urban green spaces, being these relevant in the broader context of the "Taranto Futuro prossimo" Strategic Plan. The evaluation for these health determinants therefore followed a qualitative approach, based on a review of the published scientific evidence on estimates of the magnitude of the impact, the potentially most vulnerable population affected and the most relevant hazards released in each case.

## 3.4. Health outcomes

For the objective of the HIA related to long-term exposure to emissions from the ex-ILVA, the health outcomes selected were all causes of death associated to ambient air pollution according to the existing epidemiological evidence. This means: standardized mortality rates for all causes and specific causes in people older 30 years for the period 2012-2016 (Sentieri study protocol, De Santi *et al*., 2011); standardized hospitalization rates for all population by cardiovascular and respiratory diseases, both by selecting the first hospitalization for each subject by subject (proxy of the incidence) and by selecting all hospitalizations (burden of disease) for the period 2015-2019 (Sentieri study protocol). Reference population for standardization was the Italian population in 2001; 90% or 95% level was used for confidence intervals (IC).

Mortality data was obtained from the Registry of all causes of death (ReNCaM) and ISTAT. Hospitalization data was obtained from the National database of Hospital discharge forms (SDO) available at the ISS Statistics Office and from the ASL of Taranto.

Under the broader scope of the Strategic Plan, health outcomes relevant to each health determinant were identified through a literature search of peer-reviewed evidence, carried out using PubMed and Google Scholar, with special attention to vulnerable groups. In most cases the evidence is still evolving and there is not a consistent concentration-response functions that relate changes in the health determinants with quantitative changes in the health outcomes, but there are clear indications that there is a relevant aetiological relationship.

## 3.5. Expected outputs for the characterisation of health impacts

### *3.5.1. Quantitative assessment*

Quantification of related health impacts was undertaken for changes in the air concentrations of $PM_{10}$ and $PM_{2,5}$, as follows.

a) Risk based approach

Under the HHRA toxicological approach, the potential health effects associated to harmful substances are categorised as non-carcinogenic or carcinogenic.

The dose-response function, used in the third step of the risk assessment process, quantifies the association between inhalation exposure dose, and the response, in terms of adverse health effects. The carcinogenic effects are presented as the likelihood for humans to develop cancer in a lifetime without a recognized no-effect threshold. The carcinogenic potential of a chemical can be assessed through epidemiological studies (especially in occupational epidemiology) or toxicological studies on experimental animals. The incremental unit risks, estimated through the aforementioned epidemiological or toxicological studies, are expressed as Unit Risk or as Slope Factor. In particular, the Unit Risk (UR) represents the additional risk of developing a tumour over the life-time, within a hypothetical population, in which all individuals are continuously exposed to the concentration of 1 $\mu g/m^3$ of carcinogenic substance in the air they breathe (unit of measurement: $(\mu g/m^3)^{-1}$). The carcinogenic potential (or Slope Factor, SF) of a substance represents the risk of it causing cancer throughout life, per unit of daily intake per unit of body weight (bw) (unit of measurement: $(mg/Kg\ bw\text{-}day)^{-1}$). The Slope Factors (and Unit Risks) are developed through statistical extrapolation models and, in accordance with the EPA, the values chosen correspond to the upper confidence limit of the 95$^{th}$ percentile, thus representing a conservative value (EPA, 2005). In the calculations applied by the VDS study conducted by ARPA, the URs or SFs for the carcinogenic substances detected in the air were chosen according to the following order of priority: 1) WHO; 2) US-EPA; 3) Californian-EPA; 4) Other source (ARPA, AReSS, and ASL Taranto Apulia, 2018).

IARC classification or carcinogenic substances are:

- Group 1, Carcinogenic for humans (based on sufficient evidence in experimental animals);
- Group 2A, Likely carcinogenic to humans (based on limited evidence in humans and sufficient evidence in experimental animals);
- Group 2B, Possible human carcinogen (based on limited evidence in humans and insufficient evidence in experimental animals or sufficient evidence in animals and inadequate evidence in humans);
- Group 3, Not classifiable for carcinogenicity for humans;
- Group 4, Probably not carcinogenic to humans

The calculation of the inhalation carcinogenic risk was carried out according to the following formula (EPA, 2005; ARPA, AReSS, and ASL Taranto Apulia, 2018):

$$\text{Cancer Risk} = \left(\text{Inhalation Dose}\ \frac{\text{mg}}{\text{kg-day}}\right)\left(\text{SF}_{\text{inal}}\ \frac{\text{kg-day}}{\text{mg}}\right)(1 \times 10^{6})$$

At the risk characterisation stage, EPA (1989, 2005) considers an excess risk for cancer below $1\text{x}10^{-6}$ (less than 1 case in 1,000,000 people exposed throughout the life), low enough to be negligible, and risks above $1\text{x}10^{-4}$ (more than 1 case in 10,000) sufficiently high to make some urgent intervention.

For substances with non-carcinogenic effect, a threshold exposure is defined as a dose below which it is not probable that harmful effect occur. The non-carcinogenic risk is expressed in terms of hazard index (HI) given by the sum of the hazard quotients (HQ) expressed as the coefficient between estimated dose of exposure and the non-carcinogenic threshold defined for each substance, health outcome, exposure route and time of exposure. HI less than or equal to 1 are assumed to be acceptable. These estimates are intended as references operational, which can orientate afterwards risk management interventions, including specific public health actions.

b) Burden of diseases and economic impact (only related to emissions of $PM_{2,5}$)

Table 2 summarizes the relative risks that were used to calculate the health impact of $PM_{2.5}$ ambient air pollution on adult mortality (in the population older than 30 years) and health morbidity, more specifically, for respiratory and cardiovascular related hospital admissions in the general population.

The health impact is calculated using the equation:

$$\begin{matrix} \textit{Health} \\ \textit{impact} \end{matrix} = \begin{matrix} \textit{Health} \\ \textit{risk} \end{matrix} \cdot \begin{matrix} \textit{Baseline mortality or morbidity} \\ \textit{in the population group at risk} \end{matrix}$$

For mortality, the health risk or attributable fraction is calculated as:

$$\begin{matrix} \textit{Attributable} \\ \textit{fraction} \end{matrix} = \left(1 - \frac{1}{RR}\right)$$

where,

$$RR = RR_{ref}^{\frac{\Delta C}{10}}$$

$\Delta C$ is the ground-level incremental concentration ($\mu g/m^3$) above the background, that is, the ambient air concentration that would occur in the absence of the emissions of the ex-ILVA steel plant. In this analysis, the concentration change was weighted by the exposed population to account for the exposure spatial distribution. $RR_{ref}$ is a reference relative risk, corresponding to a concentration increase $\Delta C = 10\ \mu g/m^3$. For morbidity, on the other hand, the health risk is calculated as $RR - 1$. The same value of RR is applied to both female and male subpopulations.

| Health outcome | Population at risk | Relative risk $RR = exp(\beta \cdot \Delta C)$ | Source |
|---|---|---|---|
| **Premature mortality (long term)** | Adults (men and women) 30 years and older | $\beta$ = 0.0068 (95%IC: 0.0039–0.0086) $\Delta C$ is the PM2.5 incremental concentration | Galise *et al.* (2019) |
| **Circulatory hospitalisations (CHA)** | Total population (both genders, all ages) | $\beta$ = 0.00091 (95%IC: 0.00017–0.0016) | WHO (2013) |
| **Respiratory hospitalisations (RHA)** | Total population (both genders, all ages) | $\beta$ = 0.0019 (95%IC: 0–0.0039) | WHO (2013) |

Table 2: $PM_{2.5}$ Relative Risks (RR)

The unit cost (cost per case of hospital admission or death) includes both direct and indirect expenditures (market costs) to the health care system and to the patient and family, including out-of-pocket medical costs and productivity loss (cost of illness, COI), as well as intangible or non-market costs arising from loss of personal welfare or quality of life due to pain and suffering. Intangible losses are based on welfare (utility) theory. These costs are generally inferred from people's consumption behaviour or choices (revealed preferences) or elicited from contingent valuation surveys (stated preferences) in which respondents are asked to make trade-offs between different options.

For the economic assessment, premature deaths were monetised using the value of a statistical life (VSL) which represents the money people are willing to pay for a marginal reduction in the probability of dying, or, equivalently, society's willingness to pay to prevent an anonymous fatality (OECD 2012). For this analysis, the Italian VSL is 3 million euros assuming 2015 nominal prices. The VSL variability was modelled using a triangular distribution, with low and high estimates equal to 1.5 and 4.5 million euros at 2015 nominal prices (95% CI: 1.9 and 4.2 million euros)[6]. For valuing hospitalisations, the cost for health care and treatment[7] was applied: 4000 (95%CI: 3200–4800) euros per CHA event, and 2900 (95% CI: 2600–3300) euros per RHA event. Further details on economic methods and unit cost values can be found in Desaigues *et al*. (2011), Hunt *et al*. (2016) and OECD (2012; 2014; 2016; 2018).

[6] The OECD VSL for Italy is 3.85 million USD at 2015 purchasing power parity prices (https://stats.oecd.org). This value was in turn converted to the nominal price for the same base year using the purchasing power parity exchange rate of 0.78155 € to the USD (https://stats.oecd.org).
[7] Source: Own elaboration using data from "ricoveri (infraregionali + autoconsumo), popolazione Taranto - Statte – Massafra" provided by the Apulia Region.

### 3.5.2. *Qualitative assessment*

The approach was applied for charactering possible impacts on health related to those determinants for which we were not able to identify reliable data or an ERFs for quantifying the possible health impacts. That is specifically the case of health impacts related to ambient air concentrations of heavy metals, food safety, waste management and urban green spaces.
The criteria of likelihood and significance were applied, considering for this last element aspect related to the sensitivity of the affected population, the magnitude of the change, and the potential duration of the impacts (Cave *et al*., 2020).

## 4. Identification of affected health determinants

Characterizing the health impacts of complex polluted site such as Taranto is a challenging task due to the release of a combination of multiple chemicals and hazards, the concurrence of several residential and/or occupational exposure pathways, with highly variable time and space patterns, and the multiplicity of aetiologic factors of environmental related diseases where many other concomitant factors are also relevant (e.g. biology, cultural, occupational and socio-economic characteristics). Associated health effects can be acute or chronic, severe or mild, specific or, more often, non-specific. (Pasetto *et al*., 2016, Iavarone and Pasetto, 2018).

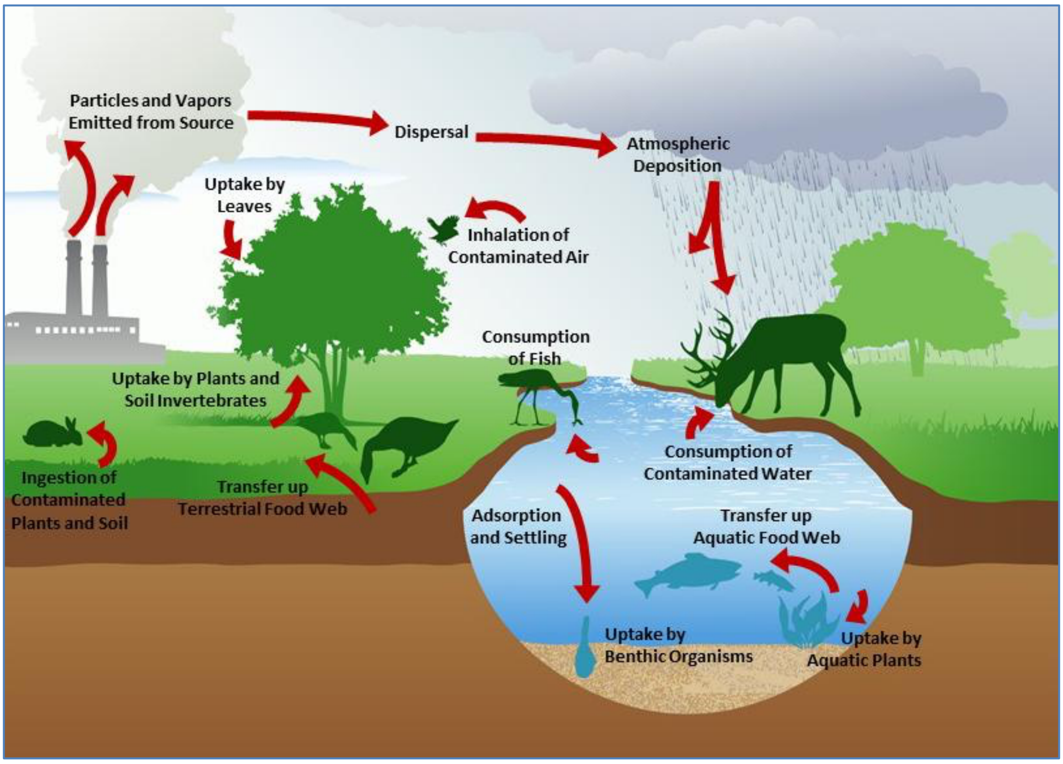



Figure 8: Identifying exposure Pathways of Potential Concern- Multimedia fate and transport mode (EPA, https://www.epa.gov/ecobox/epa-ecobox-tools-exposure-pathways-exposure-pathways-era )

Figure 8 offers an overview of such complexity, showing that although the greatest attention in this case is focused on the analysis of the emissions of ambient air pollutants, many other exposure pathways might take place, being necessary to address them in a comprehensive exposure model. A complete picture of how, when and where exposure occurs or has occurred can be obtained by identifying all possible sources, and by analysing the mechanisms of fate and transport of the released pollutants in the environment. Complete exposure pathways are those where all five elements reported above are clearly identified. Potentially relevant exposure pathways imply that some uncertainty exists about some of those elements, and gathering further information is necessary (Martin-Olmedo *et al*., 2019). In the case of the ex-ILVA plant, several potential sources should be considered such as the chimneys, landfills, the open-air mineral parks, transportation process of the raw and processed material by sea and land, etc. Figure 9 represents an example of the multiple possible exposure pathways when considering the ex-ILVA's chimneys as a source. The importance of those exposure pathways would depend on the physical-chemical properties of the released substances, meteorological and topography characteristics of the site, mechanisms of fate and transport, location and characteristics of natural resources (e.g. drinking water reservoirs), use of the land (e.g. agriculture, fishing farms, recreational parks or bathing areas, etc.), and to the exposure pattern of the population (ATSDR, 2005a, EPA, 2014; Martin-Olmedo *et al*., 2019).

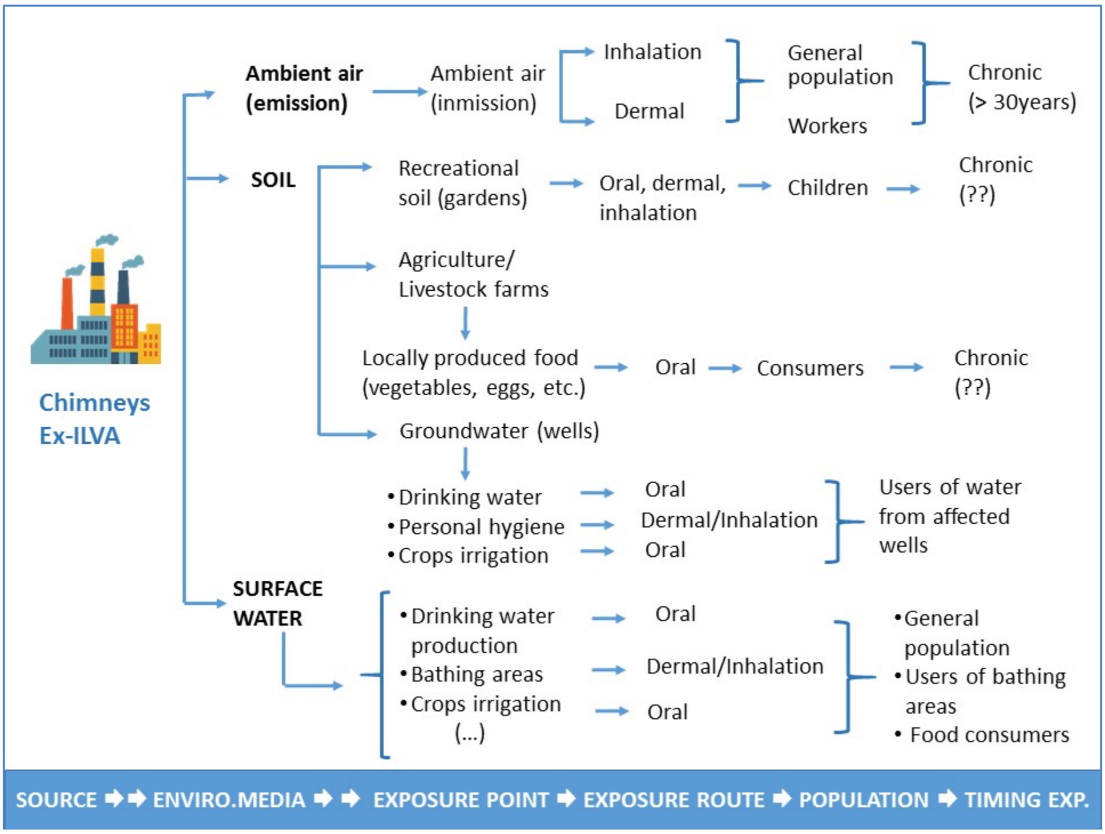



Figure 9: Analysis of possible exposure pathways related to one of the diverse polluting sources that can be identified regarding the steel plant.

Gathering information related to the different elements depicted for each exposure pathway will allow ruling out those that are not significant from the complete exposure pathways which are relevant to public health and that would require a more in-depth analysis. In this specific case, we believe this information is available (e.g. thanks to programs for the quality control of drinking water or presence of contaminants in foodstuff, ambient air quality network, control of contaminated soils, etc.) but might be scattered, and compiled by different services. Progress with this type of approach requires multidisciplinary teams and intersectoral collaboration.

## 4.1. Ambient air pollution

According to the data recorded in the VDS report (ARPA, AReSS, and ASL Taranto Apulia, 2018), approximately 66% of total annual $PM_{10}$ emitted for year 2010 in the area was originated by the ex-ILVA steel complex, which alone represented about 98% of the entire industrial activity in Taranto. The contribution of this industry was even more relevant when atmospheric organic pollutants such as benzo-($\alpha$)-pyrene and PCDD /F were considered, with 99% of their total emissions attributable to ex-ILVA. In addition to the emissions of more traditional pollutants, ILVA and other industrial activities in the area were and still are responsible for the emissions of other very toxic substances such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), organic solvents, polychlorinated biphenyls (PCBs), dioxin, etc., whose concentrations in air are not measured routinely, but only in specific *ad hoc* campaigns. Since the range of the stack heights of industrial plants is quite wide, varying from a few meters to a maximum of 210 m, the scale of transport through the atmosphere is variable, depending on the effective height of the emission source, on meteorological conditions and physical–chemical characteristics of the pollutants (Mangia *et al.*, 2013). In addition to industrial emission sources, maritime transport and urban traffic play an important role in the local air pollution pattern, as confirmed by different studies conducted in the area. In this way, the VDS report (ARPA, AReSS, and ASL Taranto Apulia, 2018), stated that traffic (urban and extra-urban) was responsible for about 11% of total non-methane volatile organic compunds (NMVOC) emitted for year 2010, followed by 10.2 % $NH_3$, 9.4% NOx, 6.2 % $N_2O$, 4.7% $PM_{10}$, 2% $CO_2$. The contribution of activities at the Taranto port to total emissions were also not negligible, especially in relation to NOx (24.1%), $PM_{10}$ (16.5%), $SO_2$ (15.9%) and NMVOC (7.2%) emissions.

The influence of the local meteorological conditions in the period of 2006-2010 and its influence on the spatial variability of air pollutants in the city was investigated by Mangia *et al*. (2013), considering as a reference three main pollutants regularly measured in all stations of the air quality monitoring network of the area: $NO_2$, $SO_2$ and $PM_{10}$. The overall analysis supports the hypothesis that various parts of the city are differently affected by the different emission sources, depending on meteorological conditions. In particular, the analysis revealed that the influence of the industrial site may be primarily identified with the time series of $SO_2$ data which exhibit higher mean concentration values and positive correlations with wind intensity when the monitoring station is downwind from the industrial site. They concluded that $PM_{10}$ cannot be considered a “good” indicator for the evaluation of local anthropic sources due to the large contribution from soil resuspension and regional or long range transportation (e.g. Saharan air mass intrusions). The PAO monitoring station (located at Paolo VI), 5 km north from the industrial site, registered the highest $SO_2$ mean concentration values, which are one and a half times the values registered at the station closest to the industrial site (MAC; Machiavelli). They concluded on the need to geo-reference the city's population in different areas, each one characterized by localized pollutant concentration data; and on taking caution in using the “proximity” to the industrial site as indicator of exposure in front of complexity of pollutants released at different heights.

In the follow- up analysis conducted by ARPA, the annual concentrations of $PM_{10}$ measured in the air quality control units of the city of Taranto showed comparable levels over the years, decreasing since 2012. Such decrease was explained by experts of ARPA by a reduction in the industrial production and to a series of remediation measures established since September 2012, aiming at limiting the industrial emission load in the so-called windy days (days of high winds in which the urban agglomeration is located downwind of the industrial pole). No site of the municipality of Taranto exceeded the annual average $PM_{10}$ concentrations of 40 $\mu g/m^3$, or the maximum number of 35 days of daily $PM_{10}$ concentrations above 50 $\mu g/m^3$, according to national and EU air quality legislation (ARPA, AReSS, and ASL Taranto Apulia, 2018).

The characterization of the $PM_{2.5}$ concentration levels in the air in the municipality of Taranto in 2016 at the stations of the regional air quality network did not show any exceedances for this parameter with respect to the annual Limit Value (VL) for the protection of human health equal to 25 $\mu g/m^3$. The highest annual average concentration was recorded in Machiavelli during months of January, July and December.

In the exercise conducted for this specific project by the PT, Table 3 and Figure 10 show the descriptive statistics annual average concentrations for $PM_{2.5}$ for the three scenarios under evaluation (2010 pre-IEA, 2012 implementation of the IEA and 2015 post-IEA) for Taranto, Massafra and Statte and the VDS area. This data shows that from 2010 to 2012 there was a net decrease for the whole VDS area of 34% in the human exposure levels of $PM_{2,5}$, and an additional decrease of 66% in average for the differences between 2012 scenario and that of year 2015. The overall difference from 2010 to 2015 was around 78 % for the whole VDS area and for the individual municipalities of Taranto, Massafra and Statte. For the uncertainty (Monte Carlo) analysis, concentrations are assumed to follow a lognormal distribution with geometric standard deviation ($\sigma_g$) of 1.10.

ARPA also analysed the evolution of other atmospheric pollutants regarding the IEA implementation for the period 2010-2016. Benzo-($\alpha$)-pyrene (hereinafter BaP) was measured on the $PM_{10}$ filters, sampled daily (sampling time equal to 24 hours) in the stations located in Taranto in the Vie Machiavelli, Alto Adige and in Talsano. The annual average limit value for BaP equal to 1 $ng/m^3$ was not exceeded in any of the monitoring sites since 2012 in any site (ARPA, AReSS, and ASL Taranto Apulia, 2018).

Heavy metals (arsenic, cadmium, nickel, lead), were also analysed in the $PM_{10}$ filters for the stations of Taranto of Machiavelli, Deledda, Adige, and in Talsano and Martina Franca, with a percentage temporal coverage of days measured of 59, 54, 24, 19, and 24, respectively. Table 4 shows average annual values for years 2015 and 2016 for the four metals, registering values lower in all cases than the target values set by the Legislative Decree 155/2010 (ARPA, AReSS, and ASL Taranto Apulia, 2018).

| Scenario ➔ | pre-AIA 2010 concentration | | AIA 2012 concentration | | post-AIA 2015 concentration | |
|---|---|---|---|---|---|---|
| | Population ages 30+ | Population all ages | Population ages 30+ | Population all ages | Population ages 30+ | Population all ages |
| Gender 🡣 | TARANTO | | | | | |
| **Male** | 2.15 | 2.17 | 1.37 | 1.38 | 0.38 | 0.38 |
| **Female** | 2.19 | 2.20 | 1.40 | 1.40 | 0.38 | 0.39 |
| **both** | 2.17 | 2.18 | 1.39 | 1.39 | 0.38 | 0.38 |
| | MASSAFRA | | | | | |
| **Male** | 0.25 | 0.25 | 0.17 | 0.17 | 0.10 | 0.10 |
| **Female** | 0.25 | 0.25 | 0.17 | 0.17 | 0.10 | 0.10 |
| **both** | 0.25 | 0.25 | 0.17 | 0.17 | 0.10 | 0.10 |
| | STATTE | | | | | |
| **Male** | 0.90 | 0.91 | 0.59 | 0.59 | 0.15 | 0.15 |
| **Female** | 0.91 | 0.90 | 0.58 | 0.58 | 0.15 | 0.15 |
| **both** | 0.90 | 0.90 | 0.58 | 0.59 | 0.15 | 0.15 |
| | VDS AREA | | | | | |
| **Both** | 1.97 | 1.98 | 1.30 | 1.30 | 0.44 | 0.44 |

Table 3: Geo-coded population-weighted $PM_{2.5}$ incremental exposure (μg/$m^3$), for adults 30 years and older, and total population, for the three scenarios under evaluation (2010-pre-IEA, 2012-implementation of the IEA and 2015-post-IEA).

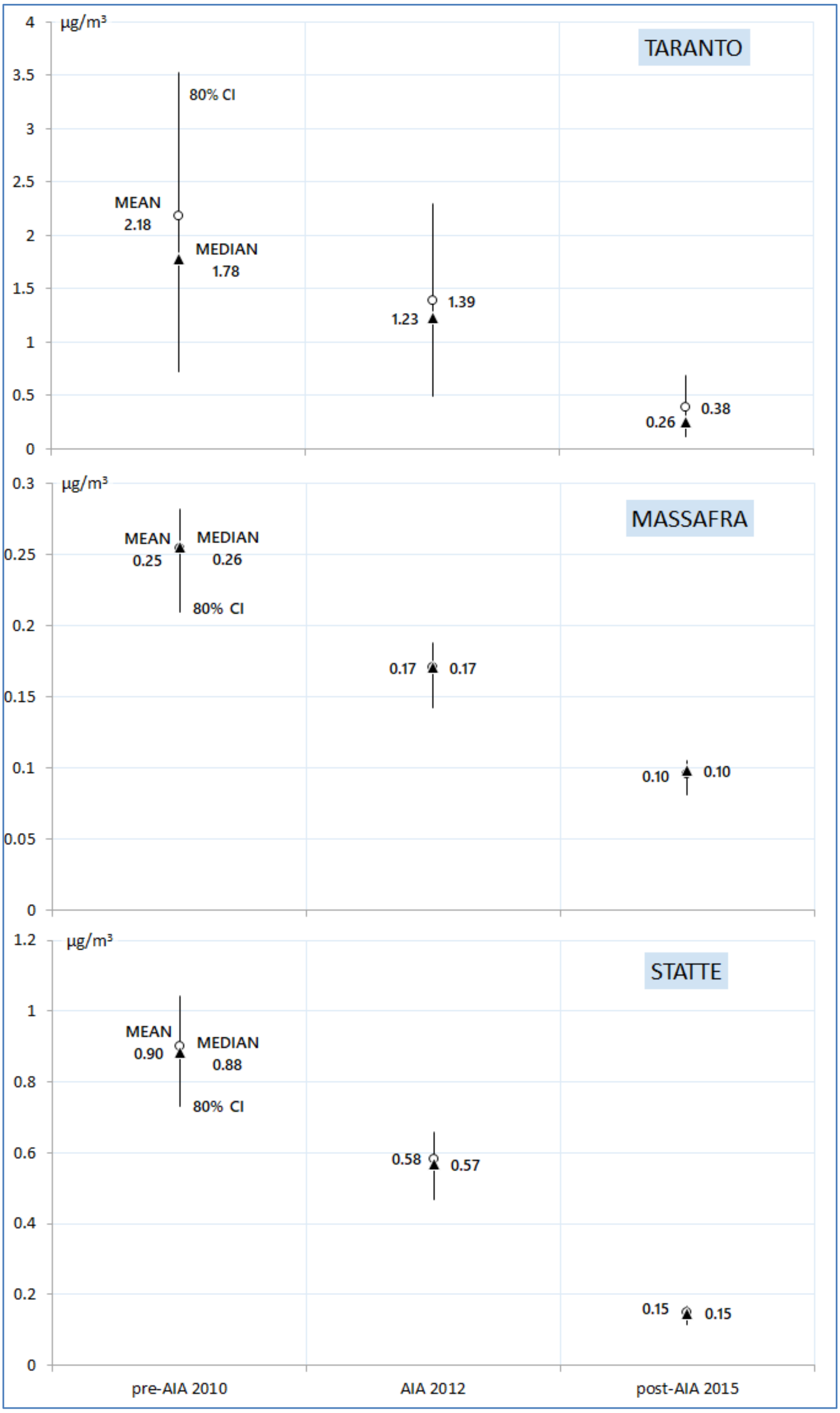



Figure 10: Distribution of ambient air PM2.5 concentration increment by locality and scenario.

Vimercati *et al.* (2016) conducted a biomonitoring cross-sectional study between January 2010 and April 2012, aiming at characterising human exposure to heavy metals by measuring levels of inorganic arsenic (As) and methylated metabolites (MMA + DMA), lead (Pb), cadmium (Cd), chromium (Chr), and manganese (Mn) in the urine samples of 279 subjects residing in Taranto and neighbouring areas. This research revealed higher median urinary concentrations for nearly all heavy metal than the corresponding Italian reference values (SIVR), especially for Chr and Pb. Statistically significant differences were also reported among municipalities, with the highest median values for Chr and Pb in residents from Statte and Paolo VI within Taranto, especially in those who reported to have eaten shellfish and/or seafood in the 48–72 h before sampling. The median urinary concentration for As, Hg and Mn in the entire study population were within the SIVR reference limit although the 95th percentile of urinary excretion of those metals in the population of Statte exceeded such limit, and was significantly higher than for the rest of districts and subgroups. Some environmental factors related to the activity of the steel plant were suggested to be the origin of such human exposure values, but authors concluded that was not possible to correlate the biological monitoring data with the environmental data because the information collected by the official institutions and/or those in the literature were incomplete and only provided by European Monitoring and Evaluation Programme (EMEP). In the future, therefore, they suggested that it would be desirable to carry out an organized environmental monitoring program, taking into consideration all exposure routes to correlate the environmental concentrations of these metals with the biomonitoring results.

| Heavy metal | | MAC | DEL | AD | TAL | MAR-F | Target value |
|---|---|---|---|---|---|---|---|
| Concentrations in ng/m$^3$ | | | | | | | |
| As | 2015 | 0.3 | 0.4 | 0.1 | 0.3 | 0.5 | 6 |
| | 2016 | 0.4 | 0.8 | 0.2 | 0.4 | 2.3 | |
| Cd | 2015 | 0.2 | 0.2 | 0.1 | 0.2 | 0.3 | 5 |
| | 2016 | 0.1 | 0.2 | 0.1 | 0.1 | 0.6 | |
| Ni | 2015 | 1.4 | 1.6 | 1.6 | 1.2 | 1.4 | 20 |
| | 2016 | 2.5 | 2.9 | 1.9 | 1.9 | 3.0 | |
| Pb | 2015 | 4.2 | 5.9 | 3.6 | 4.5 | 3.5 | 500 |
| | 2016 | 4.5 | 6.6 | 2.9 | 3.2 | 3.2 | |

Table 4: Annual average concentrations of heavy metals in ng/m$^3$ (arsenic (As), Cadmium (cd), Nikel (Ni) and Lead (Pb)) measured in $PM_{10}$ filters at different stations of the Taranto air-quality network. Source: VDS report. ARPA, AReSS, and ASL Taranto Apulia (2018)

*MAC: Station of Taranto Machiavelli; DEL: Station of Taranto- Deledda; AD: Station of Taranto- Adige; TAL: Station of Talsano; MAR-F: Station of Martina Franca*

Data for years 2017 and 2018 obtained from the European Pollutant Release and Transfer Register (E-PRTR) ((https://prtr.eea.europa.eu/#/home for the ex-ILVA plant in Taranto, also show an important decrease in the emissions for most of the industrial related parameters comparing with data from 2010 reported in the VDS document (see Table 5), although PT team considers necessary for these data to be confirmed by ARPA Apulia. Such changes are expected to be related to new technological improvements at the plant and/or in a drastic reduction of the steel production.

| | 2010 | 2017 | 2018 |
|---|---|---|---|
| | Tonnes/year | | |
| **NOx** | 10,056 | 3,400 | 3,202 |
| **SOx** | 10,035 | 3,030 | 3,508 |
| **TPM** | 2,343 | 310 | 264 |
| **NMVOCs** | 3,261 | 563 | 243 |
| | kgs/year | | |
| **As** | N.A. | 62.6 | 25.4 |
| **Cd** | N.A | 27 | 17 |
| **Ni** | N.A. | 276 | 277 |
| **Pb** | N.A. | 2230 | 616 |

Table 5: Emission data from the ex-ILVA plant at different years obtained from the INEMAR Apulia for year 2010 (Inventario Regionale Emissioni in Atmosfera) as recorded in the VDS report (ARPA, AReSS, and ASL Taranto Apulia, 2018), and E-PRTR website for years 2017 and 2018.
*NMVOCs: non-methane volatile organic compounds; TPM: total particulate matter; N.A.: Not available*

## 4.2. Food safety

Following the exposure model described above, a plausible human exposure pathway is the one resulting from the atmospheric deposition and rainwater runoff of pollutants released by the steel plant, which can affect agricultural soils, pastures lands or forage crops, as well as fishing. Potential water contamination, both ground and surface water, can also transfer to the soils through irrigation, and result in uptake and accumulation in edible parts of the plant and food of animal origin (milk, eggs, meat), representing a potential threat to human health (ATSDR, 2005a; Martin-Olmedo, *et al.*, 2019). In complex sites as the SIN of Taranto a comprehensive characterisation of this exposure pathway would require monitoring all the foodstuffs grown in the area, in order to assess the potential contaminants intake from all foods, taking into account also the seasonal variability (Vanni *et al.*, 2016).

To this respect, Pascuzzi *et al.* (2013), in their study conducted in the rural territory of Statte, with a remarkable agricultural and animal productions, demonstrated that PCDD and PCB present in the ambient air moved to the agricultural soils and then into ground water, although in this migration path concentrations significantly weaken (99%) because of their low solubility and high propensity to join organic matter of soil. Furthermore their results have highlighted that the PCDDs and PCB existing in the environmental matrices (air, soil, and groundwater) transfer to vegetable tissues of crops and may go into the food chain causing risks for the human health. These findings were within the range of concentrations reported previously by Diletti *et al.* (2009). For this reason, the Local Health Authority established in 2008 a no grazing area within a radius of 20 kilometres from the industrial area, and the culling of two thousands heads of livestock (Esposito *et al.*, 2012).

Emissions of dioxins, benzo-($\alpha$)-pyrene and other carcinogenic chemicals have also affected fishing and farmland for miles around, with serious damage to export activities. The Mar Piccolo basin, located in the Northern area of the Taranto town, is an inner, semi-enclosed basin (surface area of 20.72 $km^2$), with lagoon features, divided into two inlets, called first and second inlet, which have a maximum depth of 13 and 8 m, respectively. Tidal range does not exceed 30–40 cm. The scarce hydrodynamism and the low water exchange with the nearby Mar Grande basin determine, mainly in summer, a high water stratification. Mar Piccolo basin is influenced by urbanization, by harbour activities, by aquaculture and commercial fishing. The main problems of environmental impact include: nine pipes discharge sewages, the shipyard of the Italian Navy with its dry-docks (located in the first inlet), the largest mussel farm distributed in both the inlets, the fishing-boat fleet localized in the first inlet and small rivers and freshwater springs which drain the surrounding agricultural soils in the basin (Di Leo *et al*., 2010).

The production of mussels in the Mar Piccolo is about 30,000 t/y. Only a part of the harvested seafood is used for local consumption, while most is exported to EU countries, in particular to Spain. The high urbanization and the industrialization of the Taranto area have caused, in the years, sediment contamination of Mar Piccolo by different organic compounds and heavy metals. The benthic sediments contain pollutants at concentrations that often exceed those of the overlying water column by several orders of magnitude. In such situation, contaminated sediments can represent a significant, long-term source of contaminants to the overlying water column and the aquatic biota (Giandomenico *et al*., 2016).

A comparison with results from other Mediterranean areas demonstrates that for some heavy metals (such as Cd, Pb, and Hg), the basin represents one of the most polluted areas in the Mediterranean Sea (Spada *et al.* 2012). Moreover, high levels of these chemicals have also been found in the aquatic biota with a significant risk especially for human health (Cardellicchio *et al.* 2010; Giandomenico et al. 2013; Spada *et al.* 2012, 2013). Concerning organic compounds, the exceeding limits in the first inlet of dioxin and dioxin-like PCB TEQs, set by the European Commission regulation (EC 1259/2011; Di Leo *et al.* 2014), have involved, from 2011, the prohibition of commercialization and consumption from this area of mussel *Mytilus galloprovincialis*, with important economic impacts (Giandomenico *et al*., 2016).

In this scenario, special programs have been started in order to plan actions for sediment remediation and pollution reduction. National programs also include actions for the characterization and recovery of surrounding sites that may indirectly influence the quality of the basin, with special emphasis on the RITMARE project (Giandomenico *et al*., 2016)
(http://hydrogeology.ba.irpi.cnr.it/en/ritmare-project/)

## 4.3. Waste management

The presence of outdoor landfills with non-hazardous and hazardous waste in the area, inside and out of the steel plant can pose a threat to human health by dispersion of volatile compounds or re-suspension of particulate matter into the ambient air, due to soil contamination and percolation of contaminants into groundwater which could be used for irrigation or human consumption, or in the event that no physical barriers exist for preventing people from coming into direct contact with such waste materials, especially in the case of children. The discharge of untreated industrial wastewater into surface waters is also a very relevant source of pollution that requires attention. The PT did not have sufficient information to quantify the extent of this risk but certainly both are sources that need to be addressed in relation to potential health impacts.

According to the Environmental Performance Report of Italian cities published annually by Legambiente, the city of Taranto has been classified in the lowest scale in terms of environmental quality, occupying positions 82 and 86 out of 104 cities for years 2017 and 2019, respectively (Legambiente, 2018; 2020). These reports draw particular attention to various aspects related to poor management of both sewage and municipal solid waste (MSW). Specifically it was reported that:

- only 87% of Taranto population has access to the urban sewage system,
- the average production of MSW in 2017 and 2019 was 524 and 553 kg / inhabitant, respectively
- the percentage of MSW segregation for a differentiated treatment and possible recycling reached only 17.2% in 2017, and it was even lower in 2019 (15.2%)
- only 22.4% of Taranto population has access to a MSW collection system.

For reference, according to Eurostat, in 2016 the 28 EU Member States recycled 57% of the MSW generated, and an average of 20% was subjected to energy recovery[8].

The Waste Framework Directive[9] requires that waste be managed without endangering human health and harming the environment, in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the landscape or places of special interest. It also defines a five-step hierarchy for waste management, giving the greatest prioritization to prevention of production, followed by preparing for re-use, recycling, recovery and, if inevitable, disposal. To comply with the objectives of this Directive, EU countries should have adopted the necessary measures to ensure, among other targets, that by 2020 the preparation for re-use, segregation and recycling of different fractions composing the MSW (such as paper, metal, plastic and glass) had increased to a minimum overall of 50 % by weight. The proposed percentage for recycling MSW increases to a minimum of 55 %, 60% and 65% by weight by 2025, 2030 and 2035, respectively. The city of Taranto is quite far from reaching this mandate, which can have important implications for air, soil and water degradation as well as for human health impacts.

## 4.4. Urban green spaces

The relevance of the steel plant as an economic engine not only for the city of Taranto but also for the entire province, and its long history has somehow conditioned the urban development of the city of Taranto and its surroundings, where the construction of urban green spaces was not identified as a priority or necessary at the time.

At the Fifth Ministerial Conference on Environment and Health in Parma, Italy (2010), the Member States of the WHO European Region made a commitment *"…to provide each child by 2020 with access to healthy and safe environments and settings of daily life in which they can walk and cycle to kindergartens and schools, and to green spaces in which to play and*

[8] Eurostat. Waste management indicators - Data extracted November 2019 [Internet]. 2019. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_management_indicators&oldid=461870
[9] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. OJ L 312 22.11.2008, p. 3. Consolidate text available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008L0098-20180705&from=EN

*undertake physical activity*" (WHO-Regional Office for Europe, 2010). Improving access to green spaces in cities is also included in the United Nations Sustainable Development Goal 11.7, which aims to achieve the following: "*By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities*" (United Nations Department of Economic and Social Affairs, 2014). Finally, the WHO Action Plan for the implementation of the European Strategy for the Prevention and Control of Non-communicable Diseases in 2012−2016 includes a call to create health supporting urban environments (WHO Regional Office for Europe, 2012).

The European Urban Atlas[10] includes under the definition of "urban green spaces" public green areas used predominantly for recreation such as gardens, zoos, parks, and suburban natural areas and forests, or green areas bordered by urban areas that are managed or used for recreational purposes open to the public. In the revision of scientific evidence published by WHO in 2016 used as a main source for this section, it was also included the "green/blue" space, which takes into account water edge (e.g. rivers, lakes, beaches or cliffs) as important and attractive feature for people to use and enjoy.

In the reports published by Legambiente on the environmental performance of Italian cities urban green spaces and street trees are also taken into consideration (Legambiente 2018, 2020).

The differences between the data reported by Legambiente for 2017 and 2019 (Table 6) show a small improvement towards the increase of green areas, pedestrian paths or sustainable mobility (cycling), but even so, Taranto is very far from the environmental performance of other cities as shown by the maximum values reached by certain Italian cities for the same indicators.

| | 2017 | 2019 | Min-Max* |
|---|---|---|---|
| **Pedestrian road surface extension ($m^2$/ inhab.)** | 0.1 | 0.1 | 0.0-5.1 |
| **Nº trees/ 100 inhabitants** | 8.0 | 9.0 | 4-203 |
| **Urban green space ($m^2$/inhabitant)** | 6.5 | 13.9 | 3.6-997.2 |
| **Equivalent cycling tracks (meter/100 inhabitants)** | 0.4 | 3.4 | 0.0-44.4 |
| **Total kilometres of cycling paths** | nd | 26.0 | 1-222 |

**Data extracted from Legambiente report for year 2020; nd: not declared*

Table 6: Data on the environmental performance of the city of Taranto for years 2017 and 2019 related to urban green spaces and cycling, compared to the Minim and Maximum reported in other Italian cities for similar indicators (Legambiente, 2018; 2020).

# 5. Characterisation of health impacts

## 5.1. Health impacts related to changes in air pollution

Ambient air pollution is associated with a range of diseases, symptoms and infra-clinic conditions that impair the health and quality of life both under short-term, and long-lasting

[10] European Environmental Agency. Urban Atlas. Access: https://www.eea.europa.eu/data-and-maps/figures/urban-atlas

exposures. Acute exposures have been associated with the onset of acute pathologies such as myocardial infarction or stroke within a few days, or even death in the case of susceptible individuals (Belleudi *et al.* 2010; Basagaña *et al*., 2015; Alessandrini *et al*., 2016; Samoli *et al*., 2016; Renzi *et al*., 2017; Stafoggia *et al*., 2017; SENTIERI, 2019). In Europe, results from the ESCAPE project (European Study of Cohorts for Air Pollution Effects; www.escapeproject.eu), focused on chronic effects in cohorts of adults, highlight the existence of an association between chronic exposure to air pollutants and mortality for all causes (natural) and cardiovascular events (Beelen *et al*., 2014; Cesaroni *et al*., 2014; Stafoggia *et al*., 2014; Fucks *et al*., 2017), and an increased risk of developing cancer of lung, brain, breast and digestive system (Raaschou-Nielsen *et al*., 2013; Andersen *et al*., 2017; 2018; Nagel *et al*., 2018; SENTIERI, 2019). In 2017, the European Respiratory Society and the American Respiratory Society clarify in a joint statement the broad spectrum of adverse health effects of air pollution, including pathologies such as neurological and metabolic diseases previously not reported (Thurston *et al*., 2017). In the global burden of disease report for year 2016, air pollution was considered the fifth leading risk factor of disease and mortality worldwide, behind diet, smoking, hypertension and diabetes, being responsible of more than 4.2 million premature deaths a year globally (GBD 2016 Disease and Injury Incidence and Prevalence Collaborators, 2017). A 2013 assessment by *WHO's International Agency for Research on Cancer* (IARC) concluded that outdoor air pollution is carcinogenic to humans, with the particulate matter component of air pollution most closely associated with increased cancer incidence, especially lung cancer. An association also has been observed between outdoor air pollution and increase in cancer of the urinary tract/bladder (IARC, 2013).

Health effects have been detected at very low levels of air pollutant concentrations, and it is still uncertain whether long-term effects are related simply to annual mean values or to repeated exposures to peak values, and whether a threshold level exists for such substances, below which no health effects are likely, especially in the case of $PM_{2.5}$ (WHO, 2006). The *2005 WHO Air quality guidelines update* (WHO-AQG) offer global guidance on thresholds and limits for key air pollutants that pose health risks, although WHO recommends to achieve the lowest concentrations of PM possible (WHO, 2006). Currently, European air quality standards for PM are still above the WHO-AQG, with a legal annual mean values for $PM_{10}$ and $PM_{2.5}$ established at 40 $\mu g/m^3$ and 20 $\mu g/m^3$, respectively, quite high by comparison with WHO-AQG thresholds, established at 20 $\mu g/m^3$ annual mean for $PM_{10}$ and 10 $\mu g/m^3$ annual mean for $PM_{2.5}$. To this respect, Pascal *et al.* (2013), showed that by complying with the WHO guideline of 10 $\mu g/m^3$ in the annual mean concentrations of $PM_{2.5}$ for the period 2004-2006 in 25 European cities, it would have added an average of 22 months of life expectancy to the population of 30 years old, corresponding to a total of 19,000 delayed deaths. The associated monetary gain would amount to about 31,000 million euros per year, including savings in healthcare costs, absenteeism and intangible costs such as well-being, life expectancy and quality of life.

Review of scientific evidence related to Taranto

Since the late 1980s several epidemiological studies have shown high mortality risks in Taranto, for all causes, all cancers and in particular for lung, pleura, bladder, lympho-hematopoietic system and, respiratory disease and pneumonia (Martuzzi *et al.* 2002; Mitis *et al*. 2005; Vigotti *et al*. 2007; Martinelli *et al*. 2009).

The first analyses conducted in Taranto in the framework of the SENTIERI project explored the health status of the population for the period 1995–2002, and 2003–2009, using regional population as reference for indirect standardization and a list of health outcomes for which it was proved sufficient or limited scientific evidence of possible association with environmental exposure related to the industrial activities of Taranto (Comba *et al*. 2012; Pirastu *et al*., 2013). In both periods a highly compromised situation was described regarding the health of residents in Taranto and Statte. Number of deaths in 2003–2009, adjusted for deprivation (De Santi *et al*., 2011), consistently showed excess risks for a number of causes of death in both genders, among them: all causes, all cancers, lung cancer, and cardiovascular and respiratory diseases, both acute and chronic. The most notable increases in mortality among males were reported for the Paolo VI, with 42% excess for all malignant neoplasms (especially lung cancer, +76%), diseases of the cardiovascular (+28%), respiratory (+64%) and digestive (+47%) systems. In Tamburi, an excess was observed among males for all malignant neoplasms (+11%) and cardiovascular diseases (+10%), specifically ischemic heart diseases (+20%). Among females, in Paolo VI, excesses were present for all cancers (+23%), in particular lung, pleural and liver cancer, cardiovascular diseases (+18%), chronic obstructive pulmonary disease (COPD), and digestive system diseases. In Tamburi, excesses were present among females for cardiovascular diseases (+15%), in particular ischemic heart diseases, COPD (+39%), and renal diseases (+57%) (Comba *et al*. 2012, Pirastu *et al*., 2013). The hospitalization analysis confirms the mortality results, documenting the major health impact on residents of Paolo VI followed by Tamburi areas, where excesses were observed among males for a number of causes such as lung cancer (61% and 29% in Paolo VI and Tamburi, resp.), neurological (43% and 26% in Paolo VI and Tamburi and, resp.), cardiovascular (32% and 18% in Paolo VI and Tamburi, resp.), respiratory (52% and 36% in Paolo VI and Tamburi, resp.), and renal diseases (35% both in Tamburi and PaoloVI). Among females, similar excesses were observed for cardiovascular diseases (31% and 15 in Paolo VI and Tamburi, resp.), respiratory diseases (39% and 28% and Paolo VI and Tamburi, resp.), digestive diseases (25% and 18% in Paolo VI and Tamburi, resp.), and renal diseases (47% and 35% among males in Tamburi and PaoloVI, resp.). In Paolo VI, pleural (235%) and breast cancer (33%) were also in excess among females. The occupational history of many individuals included in this study was traced through the national insurance company (INPS) database, and the subcohort of individuals employed in industries located in the area, indicating a high proportion of past employment at the steel plant among residents in Tamburi and Paolo VI (Pirastu *et al*., 2013).

The VDS conducted by ARPA, AReSS, and ASL Taranto in compliance with Italian National Law 232/2012 and Apulia Regional Law 21, involved an epidemiological study with a double approach: a case crossover analysis on the acute effects of air pollution and a cohort study on the chronic ones. In the latter one, demographic data were linked to registers of cause of death for the years 1998–2008, and of hospital admissions from 1998 to 2010. Mortality and hospitalization risks were calculated by districts and socioeconomic position using Cox models. Results from this cohort study published by Mataloni *et al.* 2012 confirmed findings of the SENTIERI project, showing greater effects on the health of population residing in neighbourhoods closest to the industrial area (Paolo VI, Tamburi and Borgo), with major risks for all malignant neoplasms, cancer of pancreas and lung, cardiac diseases (mainly ischemic), respiratory diseases (mainly acute), and digestive system diseases. Mortality risks were especially high among residents of both genders of the Paolo VI neighbourhood for nearly all pathologies, and among those groups with lower socioeconomic status. That was considered as unexpected because the Tamburi district had always been considered the most at risk for being closer the steel plant. Paolo VI neighbourhood was built in the 1960s to house steel plant workers but citizens from other districts, especially Tamburi and Borgo, would also have moved there over time. Population living in Paolo VI at the time of that study was still relatively young (55–57 % under 34 years of age), with over 65 % of residents in Paolo VI and Tamburi belonging to the lowest socioeconomic index, by comparison to the farther district of San Vito, where 62 % of the residents presented the highest socioeconomic status (Mataloni *et al*., 2012). Those findings could be partially explained by the occupational exposure, smoking habits and low socio-economic class in the case of men but not for women. According to the National Multipurpose Survey, in 2005 the percentage of women smokers in Taranto was 10.4% (10.4 % (95 % CI: 8.4–12.5) while the regional estimate was 10.0 % (95 % CI: 9.1–11.0) (ISCT, 2007 as reported by Vigoti *et al*., 2014). As pointed out in section 4, Mangia *et al.* 2013 revealed that, according to the most prevalent meteorological conditions in Taranto, Paolo VI district suffers more air pollution than other neighbourhoods, and may justify the high mortality values found among women living in this area. Differences on the health impacts among neighbourhoods within Taranto were confirmed by a follow up study conducted by Vigotti *et al*. (2014).

The Fifth SENTIERI Report published in 2019 updated the analysis of mortality, hospitalization and oncology incidence concerning the population residing at the SIN sites (including that of Taranto) not only for the adult population, as in previous reports, but also for paediatric (<1 years old), adolescent (0-14 and 15-19 years old) and youth (20-24, 25-29 years old) populations, including also the analysis of occurrence of congenital malformations. The period of study for this fifth report was 2003-2013 for mortality data and 2002-2015 for hospitalization and oncology (SENTIERI, 2019). The results reported for the adult population in Taranto were similar to those previously described (Mataloni *et al*., 2012; Pirastu *et al*., 2013), with an excess of mortality for the different causes under analysis, but especially due to hypertension (men: SMR[11]= 131; 90%CI 122-141 - women: SMR = 121; 90% CI 114-128), ischemic heart disease (men: SMR = 119; 90% CI 113-125 - women: SMR = 110; 90% CI 104-115), cirrhosis and other chronic liver diseases (men: SMR = 138; 90% CI 123-155 - women: SMR = 125; 90%CI 109-143), cancer of lung (men: SMR= 126; 90% CI 119-134 - women: SMR = 137; 90% CI 122-155) and mesothelioma (men: SMR= 403; 90% CI 330-494 - women: SMR = 228; 90% CI 148-353), as well as for diseases of the respiratory system, in particular for acute respiratory diseases among men (SMR= 124; 90% CI (103-150) and chronic ones among women (SMR = 112; 90% CI 101-124). The high uncertainty of the estimates did not allow to outline a clear mortality profile for the paediatrician-adolescent- youth subgroups of the population (SENTIERI, 2019).

Among adult population of both genders, it was also recorded in the Fifth SENTIERI Report an excess in the hospitalization rates for all major disease groups, including those related to lung cancer and mesothelioma, but not for diseases of the respiratory and urinary systems. The most prominent findings in other age groups were the excess of hospitalizations for Hodgkin lymphomas in the paediatric age, as well as the excess of hospitalizations for myeloid

[11] *SMR: Standardized Mortality ratio*

leukaemia and lymphoid among the young population, although these estimates were imprecise. Regarding oncology incidence, an excess was reported among adult resident men for cancer of liver, pancreas, melanoma and other malignant tumours of the skin, breast, kidney, bladder and thyroid; among resident women an excess was reported for cancer of stomach, liver, melanoma and other malignant tumours of the skin, breast, uterus, thyroid and leukaemia, lymphoid and acute lymphoblastic. In paediatric age and children (5-9 years old), an excess incidence of systemic cancers was observed, with a total of 22 lymphoedematous cases (SMR = 132; 90% CI 90-189), out of which, 7 cases were non-Hodgkin's lymphomas (SMR = 275; 90% CI 129-516). Six new cases of soft tissue sarcomas and bone tissue (diagnosed only among men) contributed to the excess incidence of cancer in the population aged 0 to 19 years (men: SMR = 356; 90% CI 155-704). In the subgroup of 20-29 years old, it was reported an excess of 70% in the incidence of thyroid cancers, with 30 new cases, mainly among women (25 cases, SMR= 151; 90% CI 127-256). Also at a young age, excesses of germ, trophoblastic and gonadal cell tumours were reported, but exclusively among 20-24 year old men (11 cases; SMR = 183; 90% CI 103-303) and among young women aged 25-29 (4 cases; SMR = 401; 90% CI 137-918). From the total number of 25,853 pregnant women for the period of 2002-2015 in Taranto, 600 cases of congenital malformations (CM) were reported, revealing a high prevalence in comparison with the regional mean (observed/expected: 109; 90% CI 101- 116), affecting mainly the nervous system and limbs, and confirming the results observed in a previous analysis (Santoro *et al*, 2017). The 24% excess observed for CM related to the urinary tract were borderline statistical significant. A very recent survey looking at the association between environmental conditions and pregnancy outcomes for the period 2003-2013, revealed also that the city of Taranto showed the highest relative risk (RR) of newborns with low birthweight (< 2500 g), (RR 1.47, 95% CI 1.38-1.56) by comparison with data from the whole Apulia region (Trerotoli *et al*., 2020).

Findings from the Fifth SENTIERI Report were mainly attributed to exposure to air pollution, mainly $PM_{2.5}$, $SO_2$ and heavy metals (e.g. cadmium) released from the industrial activity (SENTIERI, 2019). Another publication by Minerba *et al*. (2018) provides an updated and detailed mapping of the mortality, hospitalizations and cancer incidence in the municipalities of the province of Taranto and in the districts of the city of Taranto. This study, once again, shows how the neoplasms, heart, respiratory and digestive diseases tend to be concentrated in the neighbourhoods close to the industrial pole, confirming previous findings.

In all these studies (ecological and cohorts design), the characterisation of the human exposure was based on the description of the historical pollution of the site and the distance to the main polluting sources, with special emphasis on the steel plant (indirect indicators of exposures). Another updated epidemiological study conducted in the same cohort defined under the VDS framework, linked residence with mortality data for years 2006-1014, and hospital admissions for years 2013-2016, but assigning an exposure value ($PM_{10}$ and $SO_2$ concentrations) for each subject in the cohort. The individual exposure of the cohort subjects was reconstructed from 1965 (year of start of the steel plant) to 2014 by integrating the results of an air dispersion model with the ILVA productivity data, five-year emissions data from the plant (source ISPRA), data from the Taranto air quality monitoring network, and individual residential history (ARPA, AReSS, and ASL Taranto Apulia, 2018). Results of this study indicated the persistence of some health criticalities compared to previous analysis, with a slightly significant increase overtime and in excess respect to regional figures for males and females for the mortality rates of all causes, pleura cancer, multiple myeloma, pancreatic cancer, disease of the cardiovascular system (in particular for ischemic diseases and high blood pressure), and diseases of the digestive system. In the case of men, it was also observed an excess of the mortality rate due to all tumours, lung cancer, bladder cancer, kidney cancer, stomach cancer, colorectal cancer, and bronchial asthma. The mortality rate for respiratory diseases in men, showed a decrease overtime, with values of residents in the risk and SIN area always higher that those reported for the regional population. Figures for pleural mesothelioma (a rare cancer caused by exposure to asbestos, which develops a long time after exposure) are striking: reported rates were four to five times above the expected level (with around 20 cases diagnosed per year instead of four or five cases, over a population of 200 000). For this reason, it was argued, for the sake of future generations above all, it is essential that the asbestos be totally removed from the dumps linked to the industrial site (EP, 2018).

Regarding hospital admissions for the period 2013-2016, it was reported in the updated VDS that increments of 10 μg/m$^3$ of $PM_{10}$ and $SO_2$ concentrations resulted in statistically significant excesses by comparison with the region in the hospitalizations for both genders for neurological diseases, cardiac diseases, thyroid cancer, respiratory infections, digestive tract diseases and kidney diseases. In addition, in the case of men, excesses were reported for prostate cancer, central nervous system and pneumoconiosis, and in the case of women for lung and breast cancer. Excess of abortion in pregnant resident women were associated with exposure to $SO_2$. In the municipalities comprised within the risk area (Taranto, Statte, Massafra, Montemesola, Crispiano), a statistically significant excess in hospitalization for both genders was observed for all malignant and lung cancers, and excess for pancreatic cancer and non-Hodgkin lymphoma for males. By examining the time trends of the rates over the four years period under study, it was observed a slight decrease in the hospitalizations for all the pathologies although the rates for the municipalities of Taranto and Statte remained always higher than those for the region of Apulia (ARPA, AReSS, and ASL Taranto Apulia, 2018).

Leogrande *et al.* (2019), adopting a "difference in difference" approach, also investigated the relationship between changes in exposure across time associated to the ex-ILVA plant with differences in cause-specific mortality rates in the same Taranto residents cohort enrolled in previous studies (Mataloni *et al.,* 2012), but updating the vital status until 2014. Following this approach, it was assumed that the role of potential individual and behavioural confounder factors (e.g. smoking habits) would be cancelled out as the comparisons were occurring within the same population. Exposure assessment was conducted by combining $PM_{10}$ and $NO_2$ concentrations measured at air quality monitoring stations and the results of a Lagrangian particle dispersion model (SPRAY), generating estimate annual average population weighted exposures to $PM_{10}$ of industrial origin for each year of the period 2008-2014, area unit and age class. Data on causes of death were facilitated by the mortality registry of the Local Health Authority in Taranto for following causes of death: natural causes, diseases of the circulatory system, heart diseases and respiratory diseases. Changes in exposures and in mortality were analysed using Poisson regression. These authors estimated an increased risk in natural mortality (RR=1.86%, 95% CI-0.06, 3.83%) per 1 μg/m$^3$ annual change of industrial $PM_{10}$, mainly driven by respiratory causes (8.74%, 95% CI 1.50, 16.51%). The associations were statistically significant only in the elderly (65+ years), with a 95% narrow confidence intervals, suggesting that at least for short-term exposure to particulate matter, older persons experience the highest risk of mortality, consistently with other studies (Bell *et al.,* 2013)

A previous study conducted by Benedetti *et al*., (2017), looked at the spatial distribution of kidney diseases, calculating the standardized hospitalization ratios (SHRs) of Taranto residents with a first hospital discharge diagnosis of kidney disease, differentiating between low and high exposure areas based on residential geocoding and annual concentrations maps of Cadmium and $PM_{2.5}$ estimated by a modelling system. The results showed a statistically significant excess of 28% of hospitalization for the renal diseases studied in males aged 20-59 years, and a non-statistically significant excess of 25% in females of the same age group, residing at diagnosis in the high exposure area. No excesses were observed in subjects aged 60 years and over, and conflicting findings were observed in subjects aged 0-19 years. In the low exposure area SHRs ranged between 0.82 and 1.04 with no statistically significant findings. The high exposure area included the densely populated district of Paolo VI and the district of Tamburi-Isola-Porta Napoli-Lido Azzurro closer to the industrial area. The excess of hospitalization in men aged 20-59 years was suggestive of a possible concurrent occupational component. In this respect, it should be noted that in workers, the nephrotoxic effect of environmental and/or occupational exposure to heavy metals may be exacerbated by co-exposure to other nephrotoxic substances such as solvents or hydrocarbons (Jakubowski, 2005; Jacob *et al.,* 2007). This results are also in agreement with those reported in the biomonitoring cross-sectional study by Vimercati *et al.* (2016) described in section 4.

The association of the co-exposure to ambient heavy metals and poor socio-economic status with neurocognitive effects among schoolchildren (aged 6–12, 50% males/females) in Taranto was studied by Lucchini *et al.,* (2019). Exposure was assessed with human biomonitoring (Pb and Se in blood samples, As and Cd in urine, and Hg and Mn in hair) and the distance between the home address to the exposure point source. Five different sub-areas of Tamburi, Statte, Paolo VI, Taranto, Talsano, were identified at incremental distance from the industrial site, based on the average annual air monitoring data and particles deposition of urban pollutants measured in 2010 by the Environmental Agency (ARPA) of the Apulia Region. Children's cognitive functions were examined using the Wechsler Intelligence Scale for Children (WISC) and the Cambridge Neuropsychological Test Automated Battery (CANTAB). Linear mixed models were chosen to assess the association between metal exposure, socio-economic status and neurocognitive outcomes. Urinary arsenic, hair cadmium and manganese resulted inversely related to the distance from the industrial emission source (β: -0.04, 95% CI -0.06, -0.01; β: -0.02, 95% CI -0.05, -0.001; β: -0.02, 95% CI -0.05, -0.003, respectively) while the WISC intellectual quotient and its sub-scores (except processing speed index) showed a positive association with distance. Blood lead and urinary cadmium were negatively associated with the IQ total score and all sub-scores, although not reaching the significance level. Hair manganese and blood lead was positively associated with the CANTAB between errors of spatial working memory (β: 2.2, 95% CI 0.3, 3.9) and the reaction time of stop signal task (β: 0.05, 95% CI 0.02, 0.1), respectively. All the other CANTAB neurocognitive tests did not show to be significantly influenced by metal exposure. The highest socio-economic status showed about five points intellectual quotient more than the lowest level on average (β: 4.8, 95% CI 0.3, 9.6); the interaction term between blood lead and the socio-economic status showed a significant negative impact of lead on working memory at the lowest socio-economic status level (β: -4.0, 95% CI -6.9, -1.1). It was proved the negative cognitive impacts of the ambient exposure to heavy metals in those children. Lead exposure had neurocognitive effect even at very low levels of blood lead concentration when socio-economic status was low, and this should further address the importance and prioritize preventive and regulatory interventions.

Quantitative estimates of air pollution health impacts have become an increasingly critical input to policy decisions. An increasing number of health risk assessments (HRA) of air pollution are being developed for a variety of policy scenarios, using different methodologies, spatial and temporal scales. There is a need to: (a) consider available state-of-the-art methodology in the fields of exposure quantification, risk characterization and disease burden estimation, which will contribute to a more comprehensive and consistent HRA of air pollution, and (b) identify general principles for applying HRA methods at a local, national and international level (WHO, 2014).

As reported in section 3, risk assessment is one of the approaches for quantifying potential health impacts. In parallel to the epidemiological approach described above, the VDS also adopted a HHRA based on toxicological evidence considering emissions conditions prior and after IEA implementation at the steel plant. As regard for the non-carcinogenic risk by inhalation, a Hazard Index (HI) higher than 1 was reported for the diseases of the respiratory system, affecting a population equal to 582 inhabitants. In particular, it was suggested that the arsenic concentrations generated by the ex-ILVA plant and $H_2S$ produced mainly by the ENI plant and, with minor contributions, from the Vergine and Italcave landfills, were the major contributors to this finding (ARPA, AReSS, and ASL Taranto Apulia, 2018).

| | | Excess of inhalation cancer cases per 10.000 inhabitants in a lifetime | |
|---|---|---|---|
| **Pollutants** | **Health outcome** | **Ex-ILVA** | **TOTAL*** |
| **Benzene** | Leukaemia[1] | 5.74 | 8.4 |
| **Naphthalene** | Respiratory system (laryngeal, alveolar/bronchiolar adenomas and carcinomas[2] | 2.58 | 2.58 |
| **Benzo (□) pyrene** | Tumours of the respiratory and gastrointestinal systems[1] | 111.17 | 111.17 |
| **As** | Lung cancer and other tumours of the respiratory system[1] | 3.54 | 3.57 |
| **Cd** | Tumours of the respiratory system (lung, trachea, bronchus, etc.), and kidney[1] | 4.58 | 4.63 |
| **Cr (VI)** | Lung cancer[1] | 0.69 | 2.38 |
| **Ni** | Lung cancer[2B] | 1.99 | 2.34 |
| **Pb** | Breast cancer, brain cancer, etc.[2A] | 0.72 | 0.72 |
| **Dioxins** | Affect reproduction and development, endocrine disruptor, cancer[3] | 2.06 | 2.08 |

Table 7: Cancer inhalation risk (excess of new cancer cases per 10.000 inhabitants in a lifetime) calculated for different pollutants under a post-IEA scenario, considering emissions from the ex-ILVA plant and the additional cancer risk (total*) calculated adding the cancer risk associated to the emissions from other sources existing in the SIN of Taranto (ENI plant, CISA, etc.). Adapted from ARPA, AReSS, and ASL Taranto Apulia (2018).
*Note: superscript indexes correspond to the IARC classification of carcinogenic substances (see section 2).*

The assessment of the inhalation carcinogenic risk produced by the plant's air emissions showed additional probabilities of developing a tumour over a lifetime greater than 1additonal case per 10,000 inhabitants for several pollutants (see Table 7) for a population of around 14,000 residents in a post-IEA situation (ARPA, AReSS, and ASL Taranto Apulia, 2018). Such risk levels are considered sufficiently high to make some intervention necessary (EPA, 1989, 2005). It is also important to emphasise that the HHRA approach applied was not considering the consequences of additive or synergetic effects due to the exposure to multiple chemicals at the same time, or the additive effects due to exposure to the same contaminants by other exposure pathways (Martin-Olmedo *et al*., 2019). Except for benzene, Ni and Cr (VI), ex-ILVA plant is the largest contributor to cancer inhalation risks, being the Benzo-(α)-pyrene, the one exceeding acceptable cancer risk threshold of 1:10.000 inhabitants more extensively.

Another relevant piece of epidemiological evidence quantifying the health impacts related to exposure to $PM_{2.5}$ emitted from the ex-ILVA plant, is the already mentioned article of Galise *et al.* (2019). The reference population used as well as the exposure assessment approach and the applied CRF values were previously described. Briefly, these authors estimated Population Weighted Exposure (PWE) as the average of the $PM_{2.5}$ concentrations weighted of all census sections by using a SPAY Langragian dispersion model. Available CRFs (OMS/HRAPIE and updates) were used to estimate the number of attributable premature deaths for natural causes, cardiovascular and respiratory diseases, and lung cancer attributable to $PM_{2.5}$, as well as the associated incremental lifetime cumulative risks (ILCRs) for lung cancer considering the three emissions scenarios related to the IEA implementation at the ex-ILVA plant (years 2010, 2012 and 2015). In general, these authors observed a reduction in the estimated impacts related to $PM_{2.5}$ emissions between the pre and post IEA scenarios, calculated for the SIN of Taranto in an average decrease of 82% for the total number of attributable deaths for natural causes (from 28 cases to 5 cases), and of 69.3% for deaths from cardiovascular diseases (from 15 cases to 4.6). In the case of the specific District of Tamburi, those decreases accounted for 77.6% and 76%, respectively. A reduction in the total number of attributable deaths related to lung cancer and respiratory diseases were also reported, but numbers were quite small (2 to 0 or 3 to 0, respectively, in the case of the VDS of Taranto). However, ILCRs above the acceptability threshold of 1 extra case per 10,000 inhabitants were reported for the scenario of 2010 ($4.3 \times 10^{-4}$ in the SIN area and $2.6 \times 10^{-3}$ in Tamburi) and 2012 ($2.7 \times 10^{-4}$ in the SIN area and $1.1 \times 10^{-3}$ in Tamburi). At Tamburi, ILCR values was also greater of $1 \times 10^{-4}$ in the post-IEA (2015) scenario although authors recognised that planned interventions for reducing emissions were not completed yet at the time of preparing this assessment. Those findings emphasise those reported in the VDS reports by HHRA.

<u>Quantitative Health and Economic Impact Assessment conducted in the present project</u>

$PM_{2.5}$ premature non-accidental mortality (natural causes) by locality, by gender for age group 30 years and older, and by impact scenario are summarised in Table 8. The 95% confidence interval was determined using a Monte Carlo simulation considering the uncertainty in the mortality baseline rate in the population 30 years and older, the population exposure and the relative risk association. The $PM_{2.5}$ mortality rate is the combined (both sexes) deaths normalised per million population 30+ in each municipality or area.

For the VDS area, under the pre-AIA (2010) scenario, 27 (95%CI: 14–43) premature deaths are calculated, and this figure is expected to decrease by 82% to 5 (95%CI: 2–8) deaths for the post-AIA (2015). Males account for 59% of the total mortality. Impact estimates for the AIA 2012 scenario are 255% larger than post-AIA (2015) results, but 37% below pre-AIA (2010) values. The central results are very similar to the impacts calculated by Galise *et al*. (2019).

| **Gender** | **Scenario** | | |
|---|---|---|---|
| | **pre-AIA (2010)** | **AIA 2012** | **post-AIA (2015)** |

| | | | |
|---|---|---|---|
| **TARANTO** | | | |
| Males | 15 (8–24) | 9 (5–15) | 3 (1-4) |
| Females | 11 (6–17) | 7 (3–11) | 2 (1–3) |
| Combined sexes | 26 (13–41) | 16 (8–26) | 4 (2–7) |
| Combined rate (per $10^6$) | 180 | 114 | 31 |
| **MASSAFRA** | | | |
| Males | 0.2 (0.1–0.4) | 0.2 (0.1–0.3) | 0.1 (0.05–0.1) |
| Females | 0.2 (0.1–0.3) | 0.1 (0.1–0.2) | 0.1 (0.03–0.1) |
| Combined sexes | 0.4 (0.2–0.6) | 0.3 (0.1–0.4) | 0.2 (0.1–0.2) |
| Combined rate (per $10^6$) | 21 | 14 | 8 |
| **STATTE** | | | |
| Males | 0.4 (0.2–0.7) | 0.3 (0.1–0.4) | 0.1 (0.04–0.1) |
| Females | 0.3 (0.1–0.4) | 0.2 (0.1–0.3) | 0.04 (0.02–0.1) |
| Combined sexes | 0.7 (0.4–1.1) | 0.4 (0.2–0.7) | 0.1 (0.1–0.2) |
| Combined rate (per $10^6$) | 75 | 48 | 12 |
| **VDS area** | | | |
| Males | 16 (8–25) | 10 (5–16) | 3 (1–4) |
| Females | 11 (6–18) | 7 (4–11) | 2 (1–3) |
| Combined sexes | **27 (14–43)** | **17 (9–27)** | **5 (2–8)** |
| Combined rate (per $10^6$) | 156 | 100 | 28 |

Table 8: $PM_{2.5}$ premature non-accidental deaths (95% confidence interval).

Excess hospitalisations for cardiovascular diseases (CHA) (ICD10: I00-99) are presented in Table 9, and for respiratory causes (RHA) (ICD10: J00-99) in Table 10. For hospital admissions, all occurrences would involve the Taranto population. The 95% confidence interval was determined using a Monte Carlo simulation considering the uncertainty in the morbidity baseline rate in the total (all-ages) population, the population exposure and the relative risk association. The $PM_{2.5}$ morbidity rate is the combined (both sexes) CHA or RHA normalised per million total population in each municipality or area. Numbers may not add up due to round-off errors.

| Gender | Scenario | | |
|---|---|---|---|
| | **pre-AIA (2010)** | **AIA 2012** | **post-AIA (2015)** |

| | | | |
|---|---|---|---|
| **TARANTO** | | | |
| Males | 4 (1–9) | 3 (0.4–6) | 1 (0.1-2) |
| Females | 3 (0.4–6) | 2 (0.3–3) | 0.4 (0.1–1) |
| Combined sexes | 7 (1–15) | 4 (1–9) | 1 (0.2–2) |
| Combined rate (per $10^6$) | 34 | 22 | 6 |
| **MASSAFRA** | | | |
| Males | 0.05 (0.01–0.1) | 0.05 (0.01–0.1) | 0.03 (0.004–0.1) |
| Females | 0.04 (0.01–0.1) | 0.03 (0.004–0.1) | 0.02 (0.002–0.03) |
| Combined sexes | 0.1 (0.02–0.2) | 0.1 (0.1–0.4) | 0.04 (0.006–0.1) |
| Combined rate (per $10^6$) | 4 | 3 | 1 |
| **STATTE** | | | |
| Males | 0.1 (0.02–0.3) | 0.1 (0.01–0.2) | 0.02 (0.003–0.04) |
| Females | 0.1 (0.01–0.1) | 0.04 (0.01–0.1) | 0.01 (0.002–0.02) |
| Combined sexes | 0.2 (0.03–0.4) | 0.1 (0.02–0.3) | 0.03 (0.005–0.1) |
| Combined rate (per $10^6$) | 14 | 9 | 2 |
| **VDS area** | | | |
| Males | 5 (1–10) | 3 (0.4–6) | 1 (0.1–2) |
| Females | 3 (0.4–6) | 2 (0.3–4) | 0.5 (0.1–1) |
| Combined sexes | **7 (1–15)** | **4 (1–9)** | **1 (0.2–3)** |
| Combined rate (per $10^6$) | 30 | 19 | 5 |

Table 9: $PM_{2.5}$ related all-cause circulatory hospital admissions (CHA) (95% confidence interval)

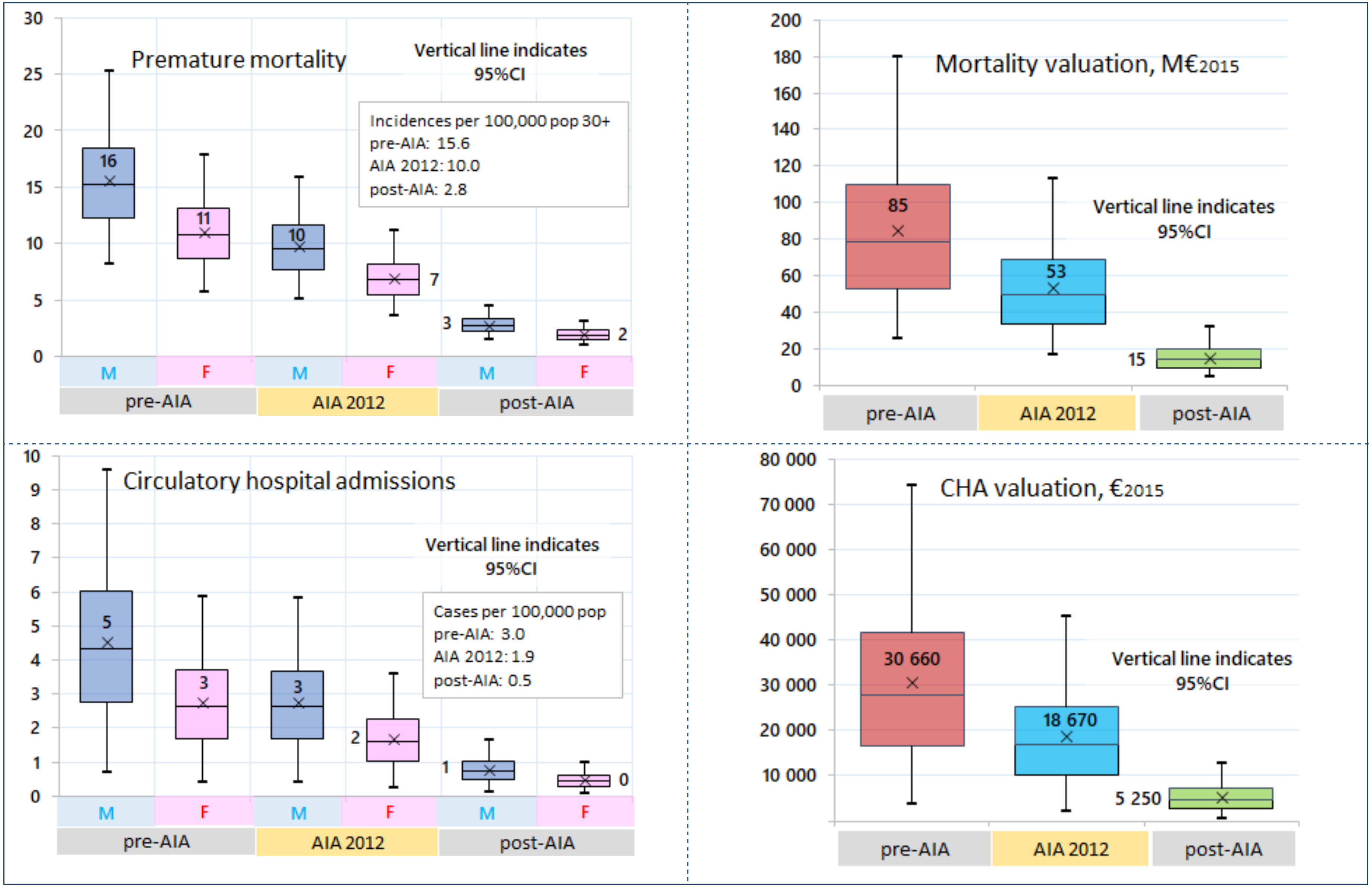
Similar to premature mortality, hospital admissions will decrease by 83% for the transition from the pre-AIA scenario (7, 95%CI: 1–15 circulatory, CHA and 8, 95%CI: 0–19 respiratory RHA incidences) to the post-AIA situation (1, 95% CI: 0.2–3 for both circulatory and respiratory events). Thus, in total, 13 incidences (both sexes) of CHA and RHA could be prevented. On the other hand, 6 fewer hospitalisations are envisioned in the shift to AIA 2012 from the pre-AIA (2010) scenario.

| Gender | Scenario | | |
|---|---|---|---|
| | pre-AIA (2010) | AIA 2012 | post-AIA (2015) |
| **TARANTO** | | | |
| Males | 5 (0–11) | 3 (0–7) | 0.8 (0-2) |
| Females | 3 (0–7) | 2 (0–4) | 0.5 (0–1) |
| Combined sexes | 8 (0–18) | 5 (0–11) | 1.3 (0–3) |
| Combined rate (per $10^6$) | 38 | 24 | 7 |
| **MASSAFRA** | | | |
| Males | 0.08 (0–0.2) | 0.05 (0–0.1) | 0.03 (0–0.1) |
| Females | 0.05 (0–0.1) | 0.03 (0–0.1) | 0.02 (0–0.04) |
| Combined sexes | 0.12 (0–0.3) | 0.08 (0–0.2) | 0.05 (0–0.1) |
| Combined rate (per $10^6$) | 4 | 3 | 2 |
| **STATTE** | | | |
| Males | 0.14 (0–0.3) | 0.08 (0–0.2) | 0.02 (0–0.05) |
| Females | 0.08 (0–0.2) | 0.05 (0–0.1) | 0.01 (0–0.03) |
| Combined sexes | 0.22 (0–0.5) | 0.13 (0–0.3) | 0.03 (0–0.1) |
| Combined rate (per $10^6$) | 16 | 10 | 3 |
| **VDS area** | | | |
| Males | 5 (0–12) | 3 (0–7) | 0.8 (0.1–2) |
| Females | 3 (0–8) | 2 (0–5) | 0.6 (0.1–1) |
| Combined sexes | **8 (0–19)** | **5 (0–12)** | **1 (0.2–3)** |
| Combined rate (per $10^6$) | 33 | 21 | 6 |

Table 10: $PM_{2.5}$ related all-cause respiratory hospital admissions (RHA) (95% confidence interval)

Results of the health impacts are also plotted graphically in Figure 11 (left panels).

Results of the economic valuation (external costs) for the Taranto metropolitan area are presented in Figure 11 (right panels). For mortality, the combined sexes cost is 85 (95%CI: 26–180) million euros for the pre-AIA (2010) case, 53 (95%CI: 16–113) million euros for the AIA 2012 case, and 15 (95%CI: 5–32) million euros for the post-AIA (2015) case. Compared to the pre-AIA situation, a reduction of 70 (95%CI: 21–148) million euros (82% decrease) could be achieved under the post-AIA scenario, annually (280 €/capita). The economic benefit from reduced hospitalisations, by contrast, is much smaller, 46 000 (95%CI: 3000–114 000) euros per year. For the transition pre-AIA to AIA 2012, the economic benefit of the averted mortality is about half as large (32, 95%CI: 10–67) million euros. To put into context the economic benefit for the shift from pre-AIA to post-AIA, the averted health burden is equivalent to 1.5% of the local GDP. It's worth noting that the economic benefit calculated in this analysis is an under-estimation of the total health benefit of reduced ambient air emissions since other categories of averted morbidity have not been considered. Generally, the total cost of morbidity may be 10% or more of the mortality cost (Narain *et al.*, 2016).


Premature mortality
Vertical line indicates 95%CI
Incidences per 100,000 pop 30+
pre-AIA: 15.6
AIA 2012: 10.0
post-AIA: 2.8
16
11
10
7
3
2
M
F
M
F
M
F
pre-AIA
AIA 2012
post-AIA
Mortality valuation, M€2015
85
53
15
Vertical line indicates 95%CI
pre-AIA
AIA 2012
post-AIA
Circulatory hospital admissions
Vertical line indicates 95%CI
Cases per 100,000 pop
pre-AIA: 3.0
AIA 2012: 1.9
post-AIA: 0.5
5
3
3
2
1
0
M
F
M
F
M
F
pre-AIA
AIA 2012
post-AIA
CHA valuation, €2015
30 660
18 670
5 250
Vertical line indicates 95%CI
pre-AIA
AIA 2012
post-AIA

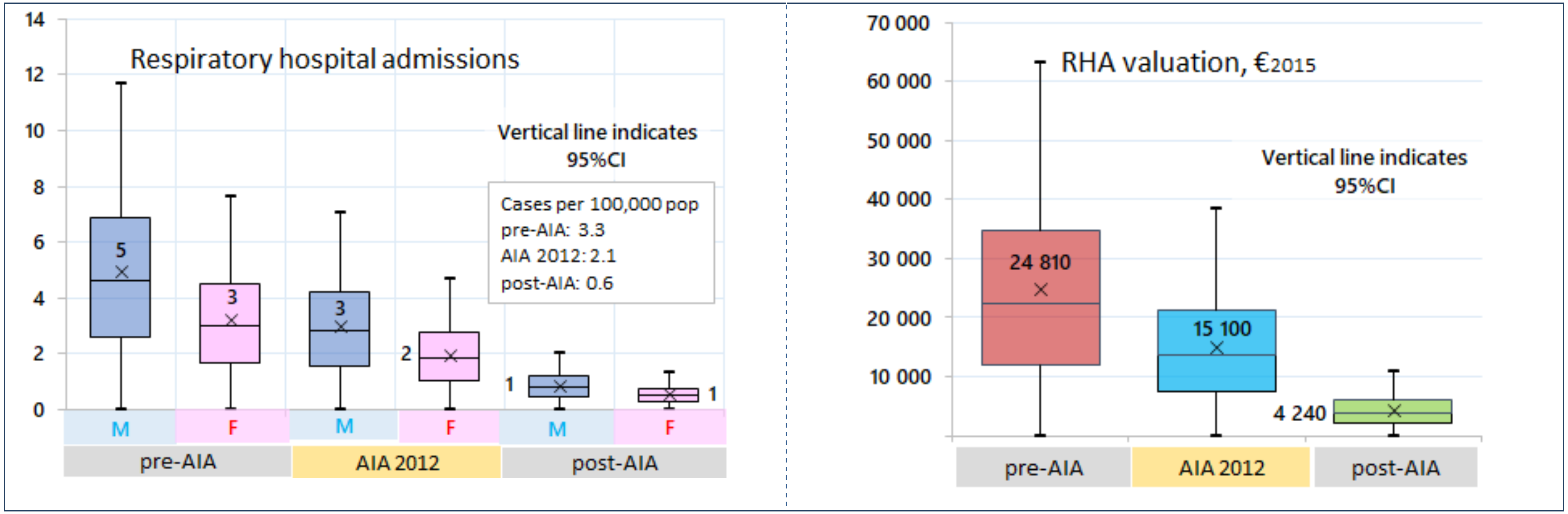



Figure 11 (continued). PM2.5 health and economic impact assessment results for the Taranto metropolitan area by scenario
*Notes: The box and whisker plots show the mean (×), median, interquartile range (IQR) and 95% confidence interval of the impact estimates. F, female; M, male; RHA, respiratory hospital admission*

## 5.2. Health impacts related to Food Safety

As summarised in section 4.2, several research studies have reported the release of persistent bioaccumulative toxic substances such as PCDD, PCB or heavy metals (As, Cd, Hg, Pb, Chr, Zn) from a wide range of polluting sources related to the industrial activity and poor waste management run in Taranto, that have affected during many years to farmlands and seafood production for miles around (Diletti *et al.*, 2009; Cardellicchio *et al.,* 2010; Di Leo *et al*., 2010; Esposito *et al*., 2012; Pacuzzi *et al*., 2013; Spada *et al.,* 2012; 2013; Giandomenico *et al.,* 2013; 2016). A reliable quantitative characterisation of potential human health risk (HHRA approach) related to the consumption of local foodstuff is only possible by conducting a comprehensive monitoring program that addresses the characterisation of chemical concentrations in local foodstuffs taking into account the seasonal variability, and also the consumption pattern of the affected population. This approach would allow to quantify the oral estimated exposure dose ($EED_{oral}$) both for carcinogenic and non-carcinogenic health effects for most relevant pollutants, and relate those $EED_{oral}$ to the health-based guidance value (HBGV), calculating the hazard index and/or excess of cancer risk for oral exposure (ATSDR, 2005a; Martin-Olmedo *et al*., 2019). A complete characterisation of this exposure pathway would also require analysing potential exposure through water consumption, especially in the case of private or public wells used for drinking water consumption, or in the case that the water reservoirs would be located close enough to be affected by dispersion of air pollutants. The PT did not get access to this type of information but presumes that such programmes are conducted by local public health authorities.

Despite lack of access to detailed data on EA for quantifying the health impacts related to the food chain, we summarise below the scientific evidence of most relevant health effects related to the main pollutants identified in the food chain in Taranto, considering oral exposure.

Dioxins (polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and Dioxin-like polychlorinated biphenyls (DL-PCBs)) are toxic chemicals very persistent in the environment, that tend to bioaccumulate in the food chain, notably in animal fat, which represent a relevant exposure pathway for the general population, of high public health concern. Dioxins enter the environment as mixtures containing a variety of individual chlorinated biphenyl components, known as congeners, as well as impurities. Once in the environment, dioxins do not readily break down and therefore may remain for very long periods of time. They can easily cycle between air, water, and soil. Dioxins stick strongly to soil and will not usually be carried deep into the soil with rainwater. Evaporation appears to be an important way by which the lighter dioxins leave soil. Airborne dioxins can accumulate in the leaves and above-ground parts of plants and food crops. Dioxins levels are highest in tissues of animals high up in the food chain, especially fish and marine mammals (such as seals and whales) reaching levels that may be many thousands of times higher than in water. (ATSDR, 2000). Many studies have looked at how dioxins can affect human health both in workers and in the general population, although in the latter case the results are less consistent. Chloracne is the most unequivocal toxicity outcome observed in accidental, occupational and unresolved poisoning cases with dioxins, children appearing to be particularly sensitive. However, chloracne only occurs after high exposures (resulting in serum levels > 20,000 pg/g fat), not relevant for deriving a health-based guidance value (HBGV) for the general population (EFSA, 2018). Exposure to PCDD/Fs and DL-PCBs have also been related to several endocrine disruption effects such as impaired semen quality, cryptorchidism, endometriosis, and other female reproductive effects (menstrual cycle disruption, ovarian function, time to pregnancy, uterine leiomyoma, and age at menopause) (ATSDR, 2000; EFSA, 2018). Other studies indicate increased risk of cardiovascular diseases (e.g. hypertension) and mortality, gastrointestinal disorders (e.g. postprandial epigastric distress, epigastric pain with or without a burning sensation, postprandial headache, and intolerance to fatty foods), adverse effects on the immune system at background exposure during development, thyroid morbidity, neurological effects (abnormal reflexes and deficits in memory, learning, and IQ). Based on indications of PCB-related cancer at several sites, particularly the liver, biliary tract, intestines, and skin (melanoma), the human studies provide limited evidence that PCBs are carcinogenic in humans, while there is sufficient evidence that PCBs are hepatocarcinogenic in animals (ATSDR, 2000). However, there was no clear dose–response relationship between exposure and cancer development (EFSA, 2018).

Inorganic-Arsenic (As) is classified as a carcinogenic agent for humans (IARC Group 1), being related to an increase cancer risk of liver, bladder, lungs and skin (IARC, 2012a; ATSDR, 2007, EFSA, 2009a). Long term ingestion of As in humans has been associated with skin lesions, cancer, neurotoxicity, cardiovascular diseases, abnormal glucose metabolism and diabetes. There is emerging evidence of negative impacts on foetal and infant development, particularly reduced birth weight, although there is a need for further evidence regarding the dose-response relationships and critical exposure times for these outcomes (EFSA, 2009a). The EFSA-CONTAM Panel concluded in 2009 that the provisional tolerable weekly intake (PTWI) of 15 µg/kg bw established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) is no longer appropriate as adverse health effects had been reported at exposures lower than those reviewed by the JECFA. The EFSA-CONTAM Panel modelled dose-response data from key epidemiological studies, identifying a lower confidence limit of the reference dose (BMDL01) raging between 0.3 and 8 µg/ kg bw per day for lung, skin and bladder cancers, as well as skin lesions. Estimated dietary exposures to inorganic arsenic for medium and high-level consumers in Europe are within the range of identified BMDL01 values, and therefore there is little or no safe exposure range for certain consumers (EFSA, 2009a). However, several research studies have showed that most As found in fish and seafood is in the less toxic form of organic As, while inorganic As accounts only between 0.02 and 11% (Muñoz *et al.,* 2000, Spada *et al*., 2012). Some evidence suggests that lifetime exposure to methyl compounds can damage the urinary bladder and the kidneys (ATSDR, 2007)

Cadmium (Cd) once absorbed is retained in the human kidney and liver with a very long biological halflife ranging from 10 to 30 years. Cadmium is primarily toxic to the kidney, especially to the proximal tubular cells where it accumulates over time in the cortex. Prolonged and/or high exposure may lead to tubular damage and progress to renal impairment with decreased glomerular filtration rate, and eventually to renal failure. Cadmium can also cause bone demineralization, either through direct bone damage or indirectly as a result of renal dysfunction. Reproductive deficiencies has also been reported in pregnant women exposed to Cd (EFSA, 2009b). The International Agency for Research on Cancer has classified cadmium as human carcinogen (Group 1) on the basis of occupational studies. Newer data on human exposure to cadmium in the general population have found statistical associations with increased risk of cancer such as in the lung, endometrium, bladder, and breast (IARC, 2012b). Cadmium is genotoxic by induction of oxidative stress and inhibition of DNA repair (EFSA, 2009b). The provisional tolerable weekly intake for Cd has been established at 2.5 µg/kg bw per week (EFSA, 2009b). Foodstuffs are the main source of cadmium exposure for the non-smoking population. Cereals and cereals products, vegetables, nuts and pulses, starchy roots and potatoes as well as meat and meat products contribute most to human exposure. High levels has been also found in some foodstuffs such as seaweed, fish and seafood, food supplements, mushrooms and chocolates (EFSA, 2009b).

Zinc (Zn) is an essential element for human health, but in excess may be harmful. To this respect, chronic high zinc intake has been reported to result in severe neurological diseases attributable to copper deficiency (Hedera *et al*., 2009; EFSA NDA Panel, 2014). The Scientific Committee on Food (SCF, 2002) has set a Tolerable Upper Intake Level (UL) of 25 mg/day for adults, including pregnant and lactating women, based on studies of zinc supplementation for up to 14 weeks. According to ATSDR, ingesting high levels of zinc for several months may also cause anemia, damages to the pancreas, and decrease levels of high-density lipoprotein (HDL) cholesterol (ATSDR, 2005b).

Lead (Pb) is a toxic, bio accumulative heavy metal that once absorbed, is transferred to soft tissues, including liver and kidneys and to bone tissue, where it accumulates with a half-lives in blood and bone approximately of 30 days and 10-30 years, respectively (EFSA, 2010; ATSDR, 2020). Epidemiological studies on the toxicity of lead (Pb) rely on internal exposure metrics, rather than measurements of external exposures (e.g., concentration of Pb in water or air) or ingested dose. The most common internal dose metric for Pb is the concentration of Pb in blood (PbB, typically expressed in terms of μg/dL), which reflects mainly the exposure history of the previous few months and not necessarily the larger burden of Pb in bone (ATSDR, 2020). The most extensively studied health outcomes are neurological, renal, cardiovascular, hematological, immunological, reproductive, and developmental effects. Cognitive deficits in children occurring at the lowest PbBs (≤5 μg/dL) are the best substantiated effects, which may result in life-long decrements in neurological function. Infants are born with a Pb burden derived from maternal transfer in utero and subsequently can continue to absorb maternal Pb from ingestion of breast milk. Children are also more vulnerable because of behaviors that increase ingestion of Pb surface dusts (e.g., hand-to-mouth activity) and because gastrointestinal absorption of ingested Pb is higher in children compared to adults, possibly due to a combination of physiological differences and differences in diet and nutrition (ATSDR, 2020). The EFSA-CONTAM Panel concluded that the present PTWI of 25 μg/kg b.w. is no longer appropriate and noted that there was no evidence for a threshold for a number of critical endpoints including developmental neurotoxicity and renal effects in adults (EFSA, 2010).

Mercury (Hg) can enter and bioaccumulate in the food chain, most frequently in the form of methylmercury, and in a lesser extend in the form of inorganic mercury (it does not accumulate to any extent). The EFSA-CONTAM Panel considers that consumption of fish and other seafood is the most relevant dietary exposure to methylmercury from food (other than human milk) in the European population (EFSA, 2012). Larger and older fish living in contaminated waters build up the highest amounts of methylmercury in their bodies. Saltwater fish (especially sharks and swordfish) that live a long time and can grow to a very large size tend to have the highest levels of mercury in their bodies. Plants (such as corn, wheat, and peas) have very low levels of mercury, even if grown in soils containing mercury at significantly higher than background levels. Mushrooms, however, can accumulate high levels if grown in contaminated soils (ATSDR, 1999). The nervous system is very sensitive to mercury. In poisoning incidents where people ate fish contaminated with large amounts of methylmercury or seed grains treated with methylmercury or other organic mercury compounds developed permanent damage to the brain and kidneys. Whether exposure to inorganic mercury results in brain or nerve damage is not as certain, since it does not easily pass from the blood into the brain (ATSDR, 1999). The EFSA-CONTAM Panel established a tolerable weekly intake (TWI) for methylmercury of 1.3 μg/kg bw, expressed as mercury, and for inorganic Hg of 4 μg/ kg bw, expressed as mercury (EFSA, 2012).

Chromium can exist in a variety of oxidation states, with the trivalent (Cr (III)) and hexavalent (Cr (VI)) states being relatively stable and largely predominant. While Cr (III) is a natural dietary component present in a variety of foods and also in dietary supplements, Cr (VI) is commonly associated with industrial processes, which can end up contaminating drinking water and food.

The EFSA-CONTAM Panel concluded that dietary exposure represents the most important contribution to overall Cr (VI) exposure in the general population. The International Agency for Research on Cancer (IARC) has classified Cr (VI) compounds as carcinogenic to humans (Group 1) with respect to lung cancer as well as nose and sinus cancer based on evidence from occupational studies .Other subchronic and chronic toxicity excluding cancer, reported after exposure to Cr (VI) are some haematological and gastrointestinal effects but findings are inconsistence (EFSA, 2014).

In the description of the baseline health status of the Taranto population made by various research groups (Mataloni *et al*., 2012; Pirastu *et al*., 2013; Vigotti *et al*., 2014; Benedetti *et al*., 2017; SENTIERI, 2019), there was consistency in pointing out various critical health aspects that could be related not only to exposure to heavy metals by inhalation (particulate matter), but also via the diet. That could be the case of the excess risk of mortality and morbidity related to kidney diseases associated to the exposure to Cd or Hg, or the neurocognitive effects among children in relation to exposure to lead or methylmercury.

An important aspect, indirectly related to contamination in the food chain, are the related impacts on the local economy and the labour force, which in turn could have an important impact on the mental health of the population (e.g. anxiety, suicidal), difficulties in having access to primary basic needs (e.g. inadequate nutrition), etc. Those aspects would required a more detailed analysis and access to local information.

## 5.3. Health impacts related to Waste Management

Waste has been one of the most important environmental threats to human health since 1980, although they were only prioritized after the sixth European inter-ministerial meeting held in Ostrava (Czech Republic) in June 2017. In this sense, the 53 Member States of the WHO European Region committed themselves in Ostrava to: "*prevent and eliminate adverse effects on the environment and health, costs and health inequalities related to waste management and contaminated sites, moving towards the elimination of uncontrolled and illegal waste disposal and trafficking, and the rational management of waste and contaminated sites in the context of the transition to a circular economy*".

The great variability in the composition of MSW and hazardous waste (HW), and the release into the environment of toxic compounds present in these waste materials in low concentrations, even below the established legal limits, has made quite difficult the systematic assessment of health effects related to the human exposure to waste (WHO, 2015; Fazzo *et al.,* 2017; Vinti *et al*., 2021). As reported in previous sections, substances such as Cd, As, Cr (VI), or dioxins have been classified by IARC as carcinogens type 1 on the basis of toxicological studies in experimental animals or on human populations exposed to very high doses. However, the epidemiological evidence related to human exposure to low environmental doses of such substances and cancer is still contradictory (WHO, 2015; Fazzo *et al*., 2017). Other elements that make difficult the identification of significant health effects related to MSW and HW are the possible synergistic or additive effects derived from the exposure to multiple hazards, or the possibility of chronic effects at low doses maintained over time (Kienzler *et al*., 2016; Bopp *et al.,* 2019). WHO proposes, in designing new epidemiological studies, to prioritize those substances with an inherent greater toxicity or virulence (in the case of biological hazards), greater environmental persistence or bioaccumulation power, or other dangerous threats such as high reactivity in contact with water or air (WHO, 2015).

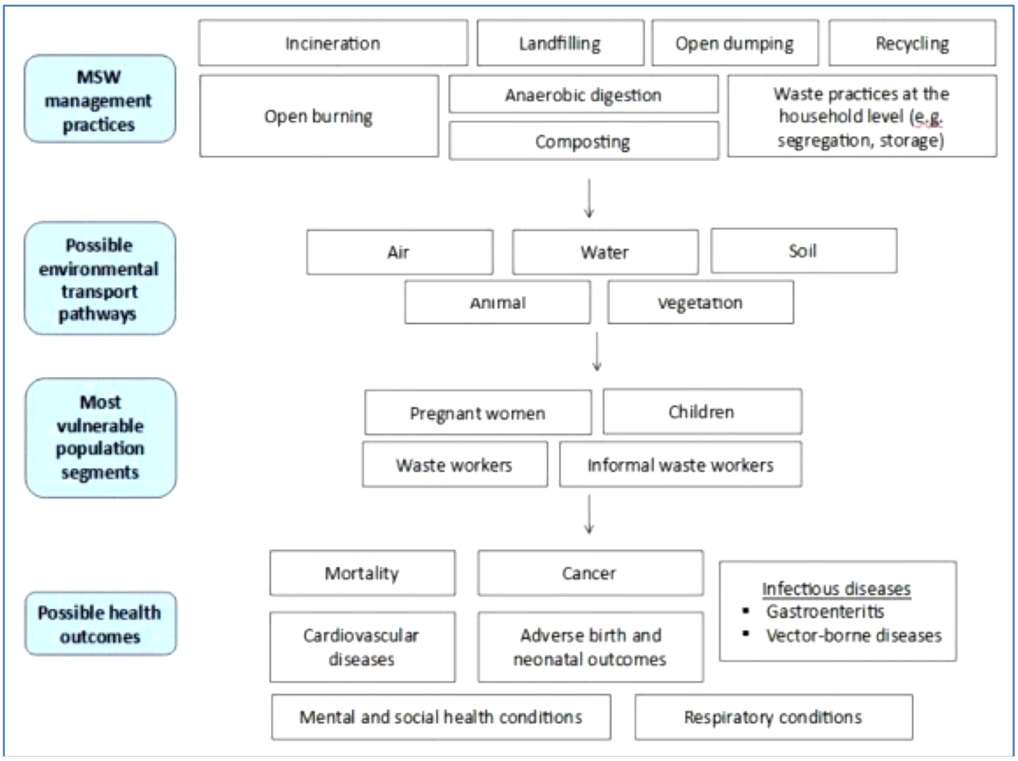



**Figure 8:** Schematic representation of the linkages between solid waste management practices and possible adverse health outcomes (reproduced from Vinti *et al.,* 2021)

Other factors conditioning a proper characterization of health impacts related to MSW and HW are: the size of the affected population, data availability on confounding factors (e.g. sociodemographic characteristics, habits of the exposed population), and insufficient characterization of environmental contamination levels at exposure points (WHO, 2015). Also, different waste management practices can result in the release of different specific substances, affecting different environmental matrices (Vinti *et al*., 2021). For example, air is the first environmental transport pathway for burning waste. By-products such as dioxins can be generated, and the ingestion of contaminated dairy products and other food items can represent an indirect source of exposure (Xu *et al.,* 2019) (see section 4.2 and 5.2.). Other practices, such as waste disposal in landfills or dumpsites are related to the emissions of $H_2S$, $SO_2$, $CH_4$, $NH_3$, mercury vapours, volatile organic compounds, PAHs, dioxins, as well as leachates contaminated with heavy metals, pesticides, pharmaceutical principles and pathogenic microorganisms that can affect groundwater (Wu *et al*., 2018; Yu *et al.,* 2018). In summary, there is a significant difficulty in defining a comprehensive exposure model that encompasses the various exposure pathways that can affect the population (Martin-Olmedo *et al*., 2019). Figure 8 summarised the linkages between MSW management practices and possible adverse health outcomes as reported by Vinti *et al.*, 2021).

Waste treatment and disposal includes recycling, composting, anaerobic digestion, incineration, landfilling, open dumping, and dumping in marine areas.

Landfills

The health effects reported to be associated with residing near a landfill were congenital malformations and birth defects (miscarriages, low birth weight, etc.) (Palmer *et al*., 2006; Elliott *et al*., 2009), some types of lung cancer or non-Hodgkin lymphoma (Giusti, 2009; Porta *et al*, 2009; Mattiello *et al*., 2013; WHO, 2015; Mataloni *et al*., 2016), and negative respiratory conditions in people aged ≤ 14 years, considering both all respiratory diseases and only acute respiratory infections (Mataloni *et al*., 2016), association between increase of $PM_{2.5}$ concentration and reduction of forced vital capacity in children aged 6–12 years (Gumede *et al*., 2017), mucosal irritation and upper respiratory symptoms (Heaney *et al.,* 2011), and other mild symptoms (Kret *et al*., 2018; Yu *et al.,* 2018). There was also some evidence of worsening mental and social health conditions, such as alteration of daily activities or negative mood states (Heaney *et al.,* 2011). However, these associations are not entirely conclusive due to poor geocoding of many landfills, the use of distance as an indirect indicator of exposure leading to a bias in assigning the exposure level, and other concurrence of other confounders such as the high degree of deprivation that affects the exposed population (Giusti, 2009; Ellitot *et al*., 2009; Porta *et al*., 2009; Mattiello *et al*., 2012; WHO, 2015). To this respect, Mataloni *et al*. (2016) did not find evidence of increased mortality for other specific cancers (i.e., colorectal, kidney, liver, pancreas, larynx, bladder, stomach, brain, and lymphatic tissue) as well as for cardiovascular, digestive, ischemic heart, respiratory, and urinary system diseases. For congenital anomalies, no evidence of increased cases was found by Elliott *et al.* (2009). In the recent systematic review of Vinti *et al*. (2021), it is described how the implementation of more restrictive operational standards imposed by EU regulations[12] has reduced the potential environmental impacts and associated health risks related to landfills. However, the same authors pointed out that even modern landfills, with good quality geomembranes can sometimes leak leachate due to thermal expansion of the material, folds generated during installation or initial defect density, causing potential risk for water bodies and its consumers that has not been fully investigated.

<u>Incinerators</u>
Studies carried out in incinerators in the period between 1969–1996 provided quantitative estimates of excess risk for stomach, colon, liver and lung cancer (Elliott *et al*., 1996; 2000) or indicative but not consistent results for non-Hodgkin lymphomas and other soft tissue sarcomas, mainly linked to the emissions of dioxins (Elliott *et al*., 2000; Zambon *et al*., 2007; Viel *et al*., 2000; 2008a). However, these observations on cancer incidence and mortality were no longer consistent in studies carried out on facilities with important technical improvements. In particular, Viel *et al*. (2008b) found no evidence of increased invasive breast cancer in women aged 20–59 years, even founding a significant reduction in invasive breast cancer in women aged 60 years and over. Ranzi *et al*. 2011 found no evidence of increased risk of cardiovascular diseases or respiratory issues, nor cancer incidence both in men and women, while an increase of all cancer mortality among women (for all cancer sites, stomach, colon, liver and breast cancer) was detected. Other health effects on which the evidence is limited but which must continue to be addressed are congenital malformations (urinary tract disorders, orofacial defects, among others) ad birth outcomes (Cordier *et al*., 2010; Candela *et al*., 2013; Ashworth *et al.,* 2014; Ghosh *et al*., 2019; Parker *et al*. 2020). Results on chronic or acute effects of the respiratory system in children or adults are not conclusive, although there are studies that point in this direction (WHO, 2015).

<u>Composting</u>
Health threats related with composting include some greenhouse gas emissions (e.g. $CO_2$, $CH_4$), VOCs, and aerosols that can in turn contain bacteria, fungi, actinomycetes, endotoxin and β-(1-3) glucans that can cause respiratory disorders, and dermal conditions (skin, eyes) (Giusti, 2009) .

[12] EC (European Commission). Council Directive 1999/31/EC of 26 April 1999 on the Landfill of Waste.

Such effects have been more widely studied in composting plant workers, especially in open systems (Sykes et al., 2011). Some studies carried out on a resident population near composting plants have detected an association with irritative respiratory disorders (Domingo *et al*., 2009).

A major gap in the literature exists related to health effects associated with MSW transfer and treatment transfer stations, recycling facilities, composting plants, and anaerobic digesters as they could pose health risks including exposure to toxins, particulate or infectious agents via direct contact, and aerosolization or other pathway (Vinti *et al*., 2021).

## 5.4. Health impacts related to urban green spaces

Preventable non-communicable diseases, such as mental illness, obesity, cardiovascular diseases, type 2 diabetes and cancer, remain major factors affecting health and well-being, while driving up health care costs and reducing the workforce productivity (GBD, 2016). Many such illnesses are linked to chronic stress and lifestyle factors, such as insufficient physical activity, or other health determinants as ambient air pollution. Urban green spaces, as part of a wider environmental context, have the potential to modify those upstream health determinants, helping in preventing and reducing the associated burden of diseases of non-communicable illness (Shortt *et al*., 2014, WHO, 2016).

### 5.4.1. Interaction of urban green spaces with air quality and related health effects

The interaction between vegetation, airflow and pollution is complex. Trees and other plants can decrease levels of air pollutants and reduce atmospheric carbon dioxide through carbon storage and sequestration (Liu and Li, 2012, Baró *et al*., 2014, Calfapietra *et al*., 2016). In this way, green spaces can provide health benefits by improving air quality, reducing mortality and morbidity rates (see section 5.1) especially for cardiovascular diseases. In this way residential proximity to green spaces has been reported to reduce risk of stroke mortality (Hue *et al*., 2008) with higher survival rates after ischemic stroke (Wilker *et al*., 2014). However, a study conducted in Lithuania found that distance to green spaces has little or no influence on levels of known cardiovascular risk factors or the prevalence of coronary heart disease and stroke (Tamosiunas *et al*., 2014). So, this indirect positive impacts is still not consistent, and further research is required.

On the other hand, some indirect negative health impacts could be envisaged if the design of the green areas is not optimized, especially in the case of roads with a high traffic density. Jin *et al.* (2014), consider that in those cases, trees may act as a closed canopy that prevents the localized dispersion of vehicular emissions, causing greater human exposure to air pollutants.

### 5.4.2. Indirect impact by promoting higher level of physical activity

Physical inactivity is recognised as a leading risk factor in the prevalence of non-communicable diseases and the general health of the population worldwide (GBD, 2016). A positive association between the availability of green spaces in the neighbourhood and increased levels of physical activity has been consistently reported by numerous research groups of various countries, involving working age adults, children and senior citizens (e.g. Cochrane *et al.,* 2009; Schipperijn *et al*., 2013; Hartig *et al*., 2014; Lachowycz and Jones, 2014; Sugiyama *et al*., 2014; Gardsjord *et* *al*., 2014; James *et al*., 2015). Some studies made also an emphasis on the quality of the available green spaces, showing that those of higher quality[13] promote greater level of physical activity among citizens and improved self-assessed health (Aspinall *et al*., 2010; Almanza *et al*., 2012; De Jong *et al*., 2012; Lachowycz *et al*., 2012).

An increase in physical activity has been shown to have very beneficial health effects, both qualitative and quantitative, improving cardiovascular health (Alves *et al*., 2016; Young *et al*., 2016), mental health (White *et al*., 2017; Ruegsegger and Booth, 2018), the neurocognitive development (Tandon *et al*., 2016; Álvarez-Bueno, *et al*., 2018) and general well-being. Physical activity has also proved to be very relevant in the prevention of the obesity (Hills *et al*., 2011), type 2 diabetes (Aune *et al*., 2015; Smith *et al*., 2016), cancer (Patel *et al.,* 2019), osteoporosis (McPhee *et al.,* 2016) and frailty or sarcopenia among people aged 65 years and older (Oliveira *et al*., 2020)

Although physical activity in green spaces can have many positive benefits, it can also be associated with an increased risk of accidents and injuries, such as falls and drowning (WHO, 2016).

### 5.4.3. Indirect impact by buffering urban noise

Environmental noise (i.e. road, rail, aircraft and industry) is a major and increasing threat to human health, due to continuing urbanization, rising traffic volumes, industrial activities, and a decreasing availability of quiet places in cities. Long-term exposure to noise can cause a variety of health effects including annoyance, sleep disturbance, negative effects on the cardiovascular and metabolic system, as well as cognitive impairment in children (WHO, 2018). According to the most recent report of the European Environmental Agency (EEA), environmental noise contributes to 48,000 new cases of ischaemic heart disease a year as well as 12,000 premature deaths. In addition, EEA estimates that 22 million people suffer chronic high annoyance and 6.5 million people suffer chronic high sleep disturbance (EEA, 2020).

The strongest base of evidence regarding cause-effect relationships between noise and health has been published by the WHO-Regional Office for Europe, as guidelines for the European region (WHO, 2018). This guidance proposes recommendations for maximum exposure levels above which a significant increase in negative health effects might occur. These threshold values are based on the evidence that reducing noise to the stated levels will outweigh the potential adverse consequences. However, the guidelines do not include recommendations for locations exposed to noise from a combination of sources or for vulnerable groups. This guidance also proposed several health outcomes that can be used for the quantification of health impacts related to noise depending on the source (road, rails, air) (WHO, 2018).

Evidence suggests that a well-designed urban green space can buffer the noise, or the negative perception of noise emanating from non-natural sources such as traffic, and provide relief from city noise, but without a quantitative estimation of the impact (WHO, 2016). Some studies has also investigated the positive effects that natural sounds from fountains or birds have in masking noise pollution from traffic, reducing the perceived loudness of road traffic noise (Coensel *et al*., 2011; Galbrun and Ali, 2013).

[13] High quality green space are defined as having a comparatively high number of recreational attributes, including qualities associated with historical and cultural elements, spaciousness, richness of natural species, peaceful qualities and wildness.

### 5.4.4. Indirect impact by reducing urban heat island effect

The replacement of vegetation with man-made heat-absorbing surfaces in urban areas can generate a "urban heat island effect" (UHIE), which worsen the increasingly frequent heat waves in cities worldwide, with relevant impact on human health. This effect is predicted to be exacerbated in the future, due to climate change.

Heatwaves are among the most dangerous of natural hazards, but rarely receive adequate attention because their death tolls and destruction are not always immediately obvious. From 1998-2017, more than 166 000 people died due to heatwaves, including more than 70 000 who died during the 2003 heatwave in Europe (WHO and WMO, 2015). Exposure to heat causes severe symptoms, such as heat exhaustion and heat stroke – a condition which causes faintness, as well as dry, warm skin, due to the inability of the body to control high temperatures. Other symptoms include swelling in the lower limbs, heat rash on the neck, cramps, headache, irritability, lethargy and weakness. Heat can cause severe dehydration, acute cerebrovascular accidents and contribute to thrombogenesis (blood clots). The associated health impacts are more notorious in vulnerable subpopulations such as the elderly (WHO and WMO, 2015).

One way to mitigate the UHIE is to use the urban green infrastructure as a way to promote the cooling island effect. The systematic review conducted by Aram *et al*. (2019), combining information derived from satellite imagery data and field studies, showed that large parks with areas of more than 10ha have the highest average cooling effect intensity and cooling effect distance; that is 1 to 2 ºC temperature reduction that extends over a 350m distance from the park boundary. In addition to the area, these scholars found out that the natural elements and qualities of the urban green spaces, as well as climate characteristics, can strongly affect the urban green space cooling effect. A more recent study by Grilo *et al*. (2020) showed that even green spaces with reduced areas can regulate microclimate, alleviating temperature by 1-3 °C and increasing moisture by 2-8%, on average, to a distance up to 60 m away from the parks' limits. Specific features influencing the cooling effects reported in this case were the density of trees as well as the morphology, aspect and level of exposure of grey surfaces to the solar radiation (Grilo *et al*., 2020).

### 5.4.5. Direct positive health effects related to urban green spaces

One of the most widely documented effects about urban green spaces and health refers to mental health benefits and stress reduction from contact with nature and green spaces. Short-term restorative benefits and relaxation has been observed after short walks in green spaces (Aspinal *et al*., 2015), proving that walking in natural environments produces stronger short-term cognitive benefits than walking in the residential urban environment (Gidlow *et al*., 2016a). Evidence of psychoneuroendocrine responses to woodland environments are based on observed associations with lower concentrations of cortisol, lower pulse rate, lower blood pressure, greater parasympathetic nerve activity and lower sympathetic nerve activity when compared to city environments (WHO, 2016). Cortisol measurements as a biomarker have also demonstrated that exposure to green space reduces chronic stress (Honold *et al*., 2016; Gidlow *et al*., 2016b).

The systematic review conducted by Vanaken and Danckaerts (2018) informed of a limited evidence on the beneficial association between exposure to green spaces with mental well-being in children and depressive symptoms in adolescents and young adults. These beneficial associations persisted after adjustment by demographic and socio-economic confounders.

A cross-sectional study including 958 adults from Barcelona whose residences were exposed to different green indicators [surrounding greenness (NDVI), amount of green land-cover and access to major green spaces] at different buffer distance (100m, 300m and 500m), showed that increasing surrounding greenness was associated with reduced odds of self-reported history of benzodiazepines consumption [Odds ratio - OR (95%CI) = 0.62 (0.43, 0.89) for 1-interquartile range (IQR) increase in NDVI in a 300m buffer], and access to major green spaces was associated with less self-reported history of depression [OR (95%CI) = 0.18 (0.06, 0.58)]. These findings suggest a potential protective role of green spaces on depression and anxiety in adults, but further studies, especially longitudinal studies, are needed to provide further evidence of these benefits (Gascon *et al*., 2018).

Another beneficial effect related to the access to green spaces refers to that by increasing people's exposure to natural patterns of daylight, helps in maintaining circadian rhythms and better sleep patterns. Adequate sleep is crucial for good health, while sleep deprivation has been linked to adverse health outcomes, such as metabolic syndrome, cardiovascular morbidity and mortality, and neurocognitive disorders, such as dementia (WHO, 2016). An Australian study showed that those living in a greener neighbourhood had lower risk of insufficient sleep (less than six hours) (Astell-Burt *et al*., 2013). In the United States, Grigsby-Toussaint *et al*. (2015) found that access to natural environments reduced the prevalence of self-reported insufficient sleep in adults, especially men.

### 5.4.6. Direct negative health effects related to urban green spaces

Although exposure to urban green spaces has numerous direct and indirect positive impacts on human health as reported above, it is important to take into account certain potential negative aspects when designing this type of green infrastructures. One of those elements refers to the increase risk of allergies and asthma especially among children although the existence evidence is still rather inconclusive (Ferrante *et al.,* 2020). An analysis of the base health conditions of the population and prevalence of certain allergies, would allow a better selection of the plants, and trees to be incorporated in future parks and urban green spaces (Cariñanos *et al*., 2019)

Another potential aspects refers to disease vectors and zoonotic infections transmitted by arthropods, such as ticks (e.g. tick-borne encephalitis, Lyme disease), mosquitoes (e.g. Chikungunya fever, Dengue fever), or sandflies (e.g. visceral leishmaniasis) (WHO, 2016). Special concern exist regarding the "Asian Tiger Mosquito" (*Aedes albopictus*), an invasive mosquito species to Europe causing high concern in public health due to its severe nuisance and its vectorial capacity for pathogens such as dengue, chikungunya, yellow fever and Zika. In a study conducted in the Mallorca Island (Spain) to analyse this species' presence/absence at 228 sites in the Island (Sanz-Aguilar *et al.,* 2018) reported that the presence of *Ae. albopictus* was positively associated with swimming pools as a result of associated gardens, plants and sources of fresh water. Bellini *et al*., (2020) proposed a comprehensive practical and technical guidance in organizing vector control activities especially focused on *Ae. albopictus*. This plan includes, coordinated actions such as standardized control measures and quality control activities, monitoring protocols, activities for stakeholders and local communities, and an emergency vector control plan to reduce the risk of an epidemic.

## 6. Implications of the findings

Taranto and the surrounding municipalities (especially Massafra and Statte) have been affected by various environmental impact activities over several decades. Many research studies conducted in the area since the 1990s have shown that the former ILVA plant (now ArcelorMittal Italia) has been by far the largest contributor to the continued deterioration of the environment, affecting the quality of the ambient air, soils and groundwater, as well as local food production, with important consequences for human health. All that led to the declaration in 1997 of that area as of "*high risk of environmental crisis*", and to a series of legal processes aimed at clarifying the responsibility of the former owners of the ex-ILVA. It also resulted in the obligation for the owners of the plant to adopt measures to mitigate / eliminate such environmental and health impacts. The steel plant has been also the largest employer, not only in the city of Taranto but also in the entire province. Therefore, this case has represented a constant challenge for the administration, industry and society in achieving a fair balance between the right to health and the protection of the environment, on the one hand, and the economy and the right to work on the other.

The extensive research performed so far focused on the analysis of the environment degradation (primarily on ambient air quality and the contamination of Mar Piccolo), and on the descriptive evolution of the health status of citizens in the area by comparison with a reference population in less contaminated regions in Italy. Analytical epidemiological studies (case-control and cohorts) tended to put the emphasis on possible associations and impacts between exposure to ambient air pollution and health, mostly to particulate matter ($PM_{10}$ and/or $PM_{2,5}$). The findings provided by all those scholars are extremely valuable, and can be regarded as separated pieces of a complex puzzle. The Health Impact Assessment (HIA) approach adopted for this project, attempts to provide an integrative and holistic view, with the final objective to support the decision-making process by identifying all possible health determinants that might be positively or negatively affected in alternative scenarios (in this case the ex-ILVA steel plant), the possible interactions among all those determinants, and the assessment of their possible impacts on the health and health equity of the population. This approach also allows applying different methodologies (qualitative and quantitative) depending on the existing scientific evidence for each health determinant, and the availability of data.

Unfortunately, the COVID-19 pandemic made impossible for the project team (PT) to conduct on-site visits that would have provided first hand knowledge, which cannot be obtained via virtual meetings. On site activities would have helped develop a more informative context, and organize meetings and interviews with local stakeholders that would have provided additional relevant information on the key actions and future scenarios of the industrial plant, on top and above what the team was able to attain through virtual communications channels and on-line interactions. Under these circumstances, the current HIA was designed around the review of available evidence on how emissions from ex-ILVA plant might affect the ambient air pollution at Taranto, considering dispersion and concentrations of particulate matters ($PM_{2.5}$), under different scenarios linked to the implementation of measures requested under the IEA 2012.

In spite of these limitations, this study advanced the status of current knowledge by:

1. Independently reviewing the epidemiological evidence accumulated to-date (and broadly confirming its findings);
2. Developing new/updated estimates of the health impacts of exposure to PM2.5, to be expected under three different emissions scenarios, that reflect current industrial plans;
3. Providing an economic quantification of the health effects expected under each of these scenarios;

4. Integrating these findings in a broader HIA framework, which also takes into account, albeit qualitatively only, the effects of populations exposures through the food chain, waste management and urban green space;
5. Identifying additional research directions, to clarify the role of additional exposure pathways, which currently appear to be less well documented.

This assessment took into consideration changes in key health determinants reported under the "Ambiente e salute" section of the Strategic plan for Taranto (*Taranto futuro prossimo*), partly connected to the activity of the steel plant, in order to promote a stronger inclusion of the health sector in future policy development in the area. Those additional health determinants were food safety, waste generation and management, and urban green spaces. Finally, this project aimed at characterising likely significant health effects related to the affected health determinants, using most suitable methodological approaches. In this respect, the quantitative evaluation of the health and economic impacts associated to human exposure was undertaken for changes in ambient air $PM_{2.5}$ concentrations. As for the rest of health determinants included under the scope of the exercise, the likely health impacts have been addressed by reviewing scientific evidence on related health effects to those determinants.

A key aspect in HIA is the analysis of all causal pathways that connect upstream health determinants to risk factors and those to health outcomes, as well as the interconnection among different health determinants. This process, applied to contaminated sites, involves the development of a comprehensive exposure model, defining to what pollutants, how, when and where exposure occurs or has occurred (Martin-Olmedo *et al*., 2019). This complete picture can be obtained by identifying all possible exposure pathways and the elements that define each one of those pathways (source, affected environment and destination and transport mechanisms; point of exposure, route of exposure and affected population). In the case of Taranto, great attention has been paid to analysing emissions of air pollutants, specifically particulate matter, but many other exposure pathways could have played an important role or continue to occur.

Several research studies have shown a plausible human exposure via diet resulting from the atmospheric deposition and rainwater runoff of heavy metals, dioxin, and benzo-($\alpha$)-pyrene among other contaminants that have been released by the steel plant affecting agricultural soils, pastures lands or forage crops, as well as fish and seafood production for miles around. Many of these pollutants represent a threat to human health even at very low levels of exposure given their status as carcinogens to humans (IARC-Group 1). To this respect, it is also important to highlight the need to address other sources that might be contributing to the overall human exposure through diet as those related to waste management and sewage disposal on which the PT did not find much published evidence. In the same direction, it would be interesting to gather data on other potentially affected environmental media such as recreational soils, groundwater and reservoirs used for the local consumption of drinking water, to demonstrate that the deposition of atmospheric pollutants is not contributing significantly to the overall health risk through those other environmental media. The PT believes this information is available (e.g. programs for the quality control of drinking water or presence of contaminants in foodstuff, ambient air quality network, control of contaminated soils, etc.) but might be scattered, and compiled by different services.

Regarding major air pollutants emitted from the steel plant, the exercise under this project confirmed the extensive investigations conducted by ARPA, and many other research groups, where particulate matter, dioxins and heavy metals received the greatest attention. The analysis of previous evidence showed the importance of considering the meteorological and climatic conditions in modelling the dispersion of pollutants, and the need to geo-reference the city's population in order to better adjust weighted exposure levels by Districts for further analysis of health impacts. To this respect, research findings from several sources pointed out consistently to the Districts of Paolo VI and Tamburi as the most extensively affected area, followed by Porta Napoli, Lido Azzurro and the close municipality of Statte. Data from the air quality monitoring network, run under supervision of ARPA, showed comparable levels for $PM_{10}$ over the years in the affected areas, decreasing since 2012 as result of reduction in the steel production and to a series of remediation measures adopted by the steel plant since September 2012 as requested in the IEA (ARPA, AReSS, and ASL Taranto Apulia, 2018). The data also showed a net decrease from 2010 to 2015 in $PM_{10}$ and $PM_{2,5}$ exposure levels of around 82 % for the whole VDS area and for the individual municipalities of Taranto, Massafra and Sttate. Higher internal doses related to exposure to several heavy metals were also reported in biomonitoring studies in the population of Paolo VI District by comparison with the rest of districts and in all cases higher than the corresponding reference value for the Italian population (Vimercati *et al.,* 2016).

The review of the existing evidence regarding the health status of residents from Taranto and Statte conducted at different stages of the SENTIERI project and other epidemiological studies (Comba *et al*., 2012; Pirastu *et al*., 2013; Mataloni *et al*., 2012; Minerva *et al*., 2018; SENTIERI, 2019) showed a compromised health profile, with a consistent excess risk for a number of causes of death and hospitalization in both genders, especially for all cancers, lung cancer, and cardiovascular and respiratory diseases, both acute and chronic. Other relevant health impacts referred to increases in mortality and morbidity related to digestive diseases, liver and kidney diseases, mesothelioma, neurological disorders, and reproductive deficiencies, among others. In general for all pathologies, the largest impacts were recorded in residents from Paolo VI district followed by those from Tamburi, where over 65% of the population belong to the lowest socioeconomic index by comparison to farther districts such as San Vito, where 62 % of the residents presented the highest socioeconomic status. Quite concerning are the latest update from the SENTIERI project showing an excess incidence of systemic cancers recorded in the paediatric age and children (5-9 years old), with a total of 22 lymphoedematous cases, out of which, 7 cases were non-Hodgkin's lymphomas (SENTIERI, 2019). This analysis also reported a 70% excess in the incidence of thyroid cancers in population 20-29 years old (mainly women), and excesses of germ, trophoblastic and gonadal cell tumours, but exclusively among 20-24 year old men and among young women aged 25-29. Finally, 600 cases of congenital malformations were reported, revealing a high prevalence in comparison with the regional mean, affecting mainly the nervous system and limbs, and confirming the results observed in a previous analysis (Santoro et al., 2017; SENTIERI, 2019). A very recent survey also revealed that the city of Taranto showed the highest relative risk (RR) of newborns with low birthweight (< 2500 g) by comparison with data from the whole Apulia region (Trerotoli *et al.*, 2020). In all those studies (ecological and cohorts design), the election of the health outcomes was based on proved sufficient o limited scientific evidence of possible association with exposure to environmental pollutants (mainly particulate matter, dioxins, asbestos and heavy metals), and the characterisation of the human exposure on indirect indicators of exposures (e.g. distance to the steel plant).

Recently, important efforts have been made in successive epidemiological studies to advance in the characterization of the possible association between exposure and health by introducing indirect measurements of human exposure to air pollutants. In doing that, data from the Taranto air quality network have been combined with pollutant dispersion models, where emission sources, topography and weather conditions have been taken into account. Results referring to exposure to $PM_{10}$ and $SO_2$, indicated the persistence of similar health criticalities as those reported under the analysis of the health status of the population of Taranto both for mortality and morbidity outcomes, with special emphasis on the excess risk (four to five times above the expected level) of pleural mesothelioma, a rare cancer caused by exposure to asbestos (ARPA, AReSS, and ASL Taranto Apulia, 2018). In the report that followed up to the on-site assessment of a delegation of the European Parliament to the Ex-ILVA plat and Taranto in 2017 it was stated that for the sake of future generations it is essential that the asbestos be totally removed from the dumps linked to the industrial site (EP, 2018).

Leogrande *et al*., (2019), adopting a "*difference in difference approach*" that took into account potential individual and behavioural confounder factors, also estimated an increased risk in natural mortality related to short-term exposure to industrial $PM_{10}$ concentrations, mainly driven by respiratory causes (8.74%, IC95% 1.50, 16.51%), that was statistically significant (95% IC) in the elderly (65+ years).

Epidemiological studies addressing specifically the health impacts related to co-exposure to heavy metals trapped in particulate matter and poor socioeconomic status also confirmed some of the findings reported previously. To this respect a statistically significant excess of 28% of hospitalization for renal diseases was reported in males aged 20-59 years residing at areas diagnosed as of high exposure to Cadmium and $PM_{2,5}$ (Paolo VI and the district of Tamburi-Isola-Porta Napoli-Lido Azzurro) (Benedeti *et al*., 2017). A negative neurocognitive effects among schoolchildren (aged 6–12, 50% males/females) was also observed in a biomonitoring study focused on co-exposure to neurotoxic metals (As, Cd, Mn, Hg, Pb, and Se), being quite relevant the exposure to lead even at very low levels when socio-economic status was low (Lucchini *et al.,* (2019).

Quantitative estimates of air pollution health impacts have become an increasingly critical input to policy decisions, applying a risk based approach or an epidemiological approach (burden of diseases). The HHRA, grounded mainly on toxicological scientific evidence and environmental data measured/estimated at exposure points (modelling), provides direct useful information on whether or not the population might be at risk of being affected by non-carcinogenic or carcinogenic health effects. It supports the decision making process on the need to adopt urgent interventions for protecting the population health, identifying most relevant exposure pathways and the most vulnerable subgroups of the population. Depending on the results it is also possible to define most suitable further public health actions such as medical monitoring, health education, and/or health surveillance and substance-specific research. The HHRA conducted in the framework of the VDS of Taranto, provided consistent results to the parallel epidemiological studies, showing an excess non-carcinogenic risk (HI > 1) for diseases of the respiratory system (mainly related to exposure to arsenic in air-particulate matter). This study also showed an inhalation carcinogenic risk greater than the acceptable cancer risk threshold of 1:10.000 inhabitants for exposure to several pollutants in a post-IEA situation, being the Benzo-($\alpha$)-pyrene the most relevant one contributing to this cancer risk (ARPA, AReSS, and ASL Taranto Apulia, 2018).

Following an epidemiological approach, Galise *et al*., (2019) observed that, despite the partial implementation of mitigation measures at the steel plant that led to a net 82% and 69.3% decrease of the total deaths attributable to natural causes and cardiovascular diseases, respectively, the cumulative incremental lifetime risk (ILCR) was still above the acceptability threshold of 1 additional case per 10,000 inhabitants for the population of Tamburi district.

Similarly, our calculations showed a positive impact on health for the reduction in $PM_{2.5}$ emissions between pre-IEA (2010) and post-IEA (2015), with a similar reduction in premature natural death

(82%), with slightly larger decrease for both CHA and RHA (83%) for the VDS area than Galise *et al.,* (2019). The economic benefit (external cost) for such reduction in emissions accounted for saving up to 70 million euros in the case of premature death and about half as large for hospital admissions (both for circulatory and respiratory diseases). Therefore, it can be concluded that any further actions focused in reducing particulate matter but also many other pollutants such as heavy metals and dioxins, could result in a strong positive health benefit and reduce the associated costs.

It is very important to underline that the health and the economic benefit calculated in this analysis is an under-estimation of the total health benefit of reduced ambient air emissions since other categories of averted morbidity have not been considered (for example child health, cognitive deficit, absenteeism etc). As economic evaluations are based on the relatively small number of deaths that would be averted, the results are orders of magnitude lower than those of the measures that would be needed to reduce the emissions, which are estimated a total sum of EUR 1.14 billion. Taking a broader perspective, considering medium- and long-term sustainability, investment in improving the environmental performance of the plant and general de-carbonisation would bring about a host of health co-benefits, which are currently poorly understood and deserve more research.

Data published by Legambiente proved that the city of Taranto currently presents a low environmental performance by comparison with other Italian cities, occupying positions 82 and 86 out of 104 cities for years 2017 and 2019, respectively (Legambiente, 2018; 2020). These reports draw particular attention to poor management of both sewage and municipal solid waste (MSW), with a waste segregation ratio as low as 15.2 % in 2019, quite far from the minimum of 50% defined under the European Waste Framework Directive for year 2020. Likewise, a broad improvement can also be expected in those elements related to sustainable mobility and availability of green spaces conditioned somehow by the industrial activity, evolving gradually for example from the current 13.9 $m^2$/inhab of green spaces to the maximum reported by Legamabiente for another Italian city of 997 $m^2$/inhab.

The exposure to persistent and heavily toxic substances that might be present in MSW, made this a relevant source to be addressed in the future for the characterisation of health impacts and their contributions to the health criticalities reported under the health status of the population of Taranto. A first steps would imply the characterisation of potential and complete human exposure pathways (from air by inhalation but also oral for contamination of the food chain and dermal in the case of workers), monitoring those environmental media where people might be exposed to.

The presence of important toxic substances in the food chain in Taranto, requires an integrated approach by applying the HHRA methodology. It is also important to emphasise that the HHRA approach applied could not consider the consequences of additive or synergetic effects due to the exposure to multiple chemicals at the same time, or the additive effects due to exposure to the same contaminants by multiple exposure pathways.

Finally, the review of the scientific evidence showed room for improvement by increasing the percentage area dedicated to urban green areas, for their the potential to modify other upstream health determinants (e.g. quality of air quality, buffering urban noise, reducing urban heat island effects, or promoting physical activity). Those indirect impacts and other direct ones (e.g. mental health benefits and stress reduction) would help in preventing and reducing the associated burden of diseases of non-communicable illness.

Given the importance of the ex-ILVA plant for the local economy, it is necessary to address the broader picture, going beyond the geographical boundaries of the city of Taranto and the SIN, as well as adopting a more comprehensive health model, in line with recent orientations in the HIA practice.

In this respect, it is recommended to undertake a systematic assessment of the health implications of ambitious development programmes, such as outlined by *Taranto Futuro Prossimo*.

It must be underlined that "assessment" includes the production of more complete and detailed evidence, but should also be taken to mean a critical participation of the health sector and health advocates in the process of governance of these developments.

## 7. Conclusions – key messages

The data and analyses described in this report are rather extensive and involve a degree of detail and complexity that can make them difficult to convey to different audiences, especially non-technical ones. However, in the light of the acute interest and sometimes controversy surrounding the Taranto case, it is important to formulate the findings as simply as possible. In the following such overall synthetic messages are outlined. Despite some possible over-simplification, it is hoped that they can help informing a constructive public debate, involving all interested parties, the public, the media and the policy community.

The analyses carried out in the framework of the WHO project indicate that:

- The environmental impact of the ex-ILVA plants has been substantial, but not yet fully characterised. While the direct emissions into air are relatively well monitored, other pathways, involving other matrices like soil or water, are less known.
- Emissions into air of the ex-ILVA plant, when translated into PM concentrations, result in additional deaths and other adverse health impacts, with associated economic costs. Such impacts are proportional to the level of emissions under different scenarios considered.
- The estimates of this report are fully in line with previous assessments, carried out by regional authorities and other researchers.
- These impact estimates, however, represent a part of the total health impact of the activities of the plant over the years, and refer to severe outcomes in people older than 30 only.
- The total direct health impact of other forms of contamination, and on children and young people, cannot be quantified with a comparable level of accuracy. In particular, contamination of soil, water, the food chain and waste streams is likely to produce additional health impacts, whose magnitude is unknown.
- Health outcomes and impacts less severe than mortality, or affecting children, are also not captured by the figures presented.
- Assessing the health impact of indirect, "softer" health determinants (such as quality of the urban environment, the compromised opportunities offered by a clean local environment) is even more challenging. This is in part due to lack of data and limitations in the HIA methodology.
- The health impacts of the ex-ILVA occur in a population already negatively affected by different risk factors, over several decades.
- Available data on health indicators such as mortality, morbidity, reproductive effects, have repeatedly shown that the health profile of the people living in Taranto and surroundings is not as good as it should be.

- The extensive literature on the area suggests the presence of strong pressures on human health, in many cases due to the activities of the plant, but not always limited to them.
- Clearly, industrial activities have characterised the environmental degradation of the area, especially until the early year 2000s, after which some improvements are documented.
- Overall, the relative importance of the risk factors due to the ex-ILVA vis-à-vis other activities cannot currently be established.
- Given the importance of the ex-ILVA plant for the local economy, it is necessary to address the broader picture, going beyond the geographical boundaries of the city of Taranto and the SIN, as well as adopting a more comprehensive health model, in line with recent orientations in the HIA practice.
- In this respect, it is recommended to undertake a systematic assessment of the health implications of ambitious development programmes, such as outlined by the strategic plan *Taranto Futuro Prossimo*.
- It must be underlined that "assessment" includes the production of more complete and detailed evidence, but should also be taken to mean a critical participation of the health sector and health advocates in the process of governance of these developments.
- Participation of the health sector and health advocates is also essential to support framing the debate appropriately, in particular in consideration of the goals of the 2030 sustainable development agenda.
- It is desirable that future policies and investments, both specific to the ex-ILVA (such as decarbonisation plans) as well as broader ones, are addressed through the human health "lens", using a comprehensive HIA approach.

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