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Air quality modeling and inhalation health risk assessment for a new generation coal-fired power plant in Central Italy

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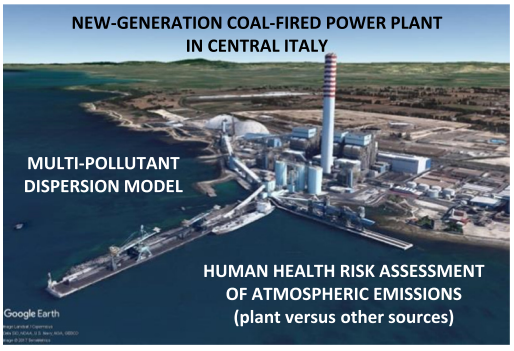
HIGHLIGHTS

- Human health risk assessment of airborne emissions from a coal fired power in Italy
- Multi-pollutant chemical-transport model simulation on year 2010
- Quantification of risks from the plant and from all sources, on impacted target organs
- Cancer risk from the plant below 3 × 10^{-7}, from all sources around 5 × 10^{-5}
- Not-carcinogenic risks from the plant below 0.02, from all sources up to 2.5

GRAPHICAL ABSTRACT



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ABSTRACT

An assessment of potential carcinogenic and toxic health outcomes related to atmospheric emissions from the new-generation coal fired power plant of Torrevaldaliga Nord, in Central Italy, has been conducted. A chemical-transport model was applied on the reference year 2010 in the area of the plant, in order to calculate airborne concentrations of a set of 17 emitted pollutants of health concern. Inhalation cancer risks and hazard quotients, for each pollutant and for each target organ impacted via the inhalation pathway, were calculated and mapped on the study domain for the overall ambient concentrations and for the sole contribution of the plant to airborne concentrations, allowing to assess the relative contribution of the power plant to the risk from all sources. Cancer risks, cumulated on all pollutants, resulted around 5 × 10^{-5} for the concentrations from all sources and below 3 × 10^{-7} for the plant contribution, mainly targeting the respiratory system. On each part of the study domain, the plant contributed for less than 6% to the overall cancer risk. Hazard quotients from all sources, cumulated on all pollutants, reached values of 2.5 for the respiratory and 1.5 for the cardiovascular systems. Hazard quotients of non-carcinogenic risks from the plant, cumulated on all pollutants, resulted below 0.03 for the respiratory system and 0.02 for the cardiovascular system. On each part of the study domain, the plant contributed for less than 5% to the respiratory and cardiovascular risks. Both cancer risks and hazard quotients related to the plant are far below international thresholds for human health protection, while the values from all sources require consideration. The proposed method provides an instrument for prospective health risk assessment of large industrial sources, with some limitations presented and discussed.

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1. Introduction

The health impact assessment (HIA) is a relevant part in the environmental permitting procedures of industrial sources of air pollution. Whether assessing potential health effects of new industrial settlements with a prospective approach, or monitoring health damages due to past and present exposure to pollution with a retrospective approach, the assessment allows public authorities, citizens and industrial companies to know the health impact of polluting activities, in quantitative terms (e.g. number of attributable deaths and diseases, periods of life lost, risk increases). Public authorities can use the health impact evaluations to release and/or revise environmental authorizations to industries (Jardine et al., 2003; Lee, 1990).

In Italy, starting from 2013, the assessment of health damage from air pollution caused by large industrial plants of national strategic relevance has been the subject of several regulatory actions (Law 231, 2013; Decree 24.4.2013, 2013; Law 221, 2016). With Law 221 (2016), the HIA has become mandatory, within the environmental impact assessment procedures, for new large combustion plants and, in general, for all the new industrial settings referred to point 1) and 2) of Annex II of the Decree 152 (2006). The National Institute of Health in Italy drew the guidelines for the HIA related to these new plants (Musmeci and Soggiu, 2017), adopting the human health risk assessment (RA) as "the most appropriate methodology to express a scientific evaluation, based on validated data, of the potential impact that a project will be able to produce in the affected area". The approach is, therefore, the prospective assessment of potential adverse health outcomes, caused in the future by pollutant emissions, and the procedure is based on the assessment of carcinogenic and non-carcinogenic risks through coefficients derived mainly from toxicological research (in vivo and in vitro experiments). The prospective assessment can alternatively be based on an epidemiological procedure, with risk functions (relative risks) which allow to estimate the number of premature deaths and/or years of life lost attributable to specific pollution exposure (Sistema Nazionale per la Protezione dell'Ambiente, 2016). A strong scientific debate is in progress on these issues and strengths and weaknesses of the two approaches have been documented. Generally, when targeting a multipollutant RA, the toxicological approach is more useful, being risk coefficients available in literature for many substances, while the epidemiological approach is usually focused on few species, also due to the higher costs of collecting epidemiological data.

The aim of the present study is to evaluate the impact on air quality and the potential risk for human health from a new generation coal-fired power plant located at Torrevaldaliga Nord, next to the town of Civitavecchia, in Central Italy. Coal-fired power plants may be an important source of air pollution, causing health impacts on resident populations (Kuo et al., 2014; Li and MacDonald Gibson, 2014; Mokhtar et al., 2014; Tang et al., 2013). However, the continuous improvement of emission containment technologies can greatly reduce the environmental impact of such sources. So, nowadays it is important to assess the specific impact of each plant under its own operating conditions and settled in a specific environment. Even though a RA is not clearly identified as mandatory for the revision of an existing environmental integrated authorization, we carried out such an evaluation in collaboration with the plant operators (ENEL s.p.a.), on the basis of a prospective approach following the official Italian guidelines mentioned above and internationally standardized risk assessment procedures. Major changes have been made to the plant in the years 2006–2007, namely the shift from oil to coal firing, which completely modified the industrial layout and atmospheric emissions, and an assessment of the effects of the "new" coal-fired power plant on human health has to be based on the prospective approach with specific attention to many pollutant not yet covered by air quality regulations.

Previous studies have quantified the health outcomes related to air pollution in this area, but no HIA including the new coal-fired layout of the power plant is yet available. A recent epidemiological investigation, covering years from 1996 to 2013, indicated a strong impact of industrial emission (power plant, cement factory, harbour) on cancer mortality, in particular positive associations between estimated PM10 from industrial plants and cancer mortality (pancreas, pleura, kidney) have been found (Ancona et al., 2016; Fano et al., 2006). Another recent study in the same area did not reveal any association between environmental exposure to pollutants and PAHs metabolites in urine (Paolocci et al., 2016).

Many RA studies in areas with industrial sources rely on point measurements of pollutant concentrations (Küçükaçıl Artun et al., 2017; Li and MacDonald Gibson, 2014; McKenzie et al., 2012; Rovira et al., 2014; Sánchez-Soberón et al., 2016; Thepanondh et al., 2011; Xu et al., 2016; You et al., 2016).

In the present study, we adopted an air quality modeling (AQM) procedure. AQM is recommended by the World Health Organization for health damage assessment of air pollution (World Health Organization, 2016b), as it can provide pollutant concentrations with wider time and spatial coverage compared to measurements, and can be used also for assessing hypothetical scenarios with varied pollutant emissions, for studying the impact of mitigation strategies on air quality.

An air quality model, namely a mesoscale chemical-transport model (CTM) with complete inventory of all emissions sources, was used to assess both the general environmental quality of the area and the contribution of the plant. Concentrations of pollutants for year 2010 were calculated and compared with measured concentrations, in order to assess the ambient air quality. The same model was also used "switching off" the power plant, in order to calculate the differential impact on concentrations, taking into account the physical and chemical interaction of the emissions of the plant with the other atmospheric species, including pollutants from other emission sources. In this way, pollutant concentrations due to the sole power plant emissions and the corresponding health impact can be calculated. This kind of approach is more comprehensive than AQM approaches for RA available in literature, as further explained in Section 2.2, since the evaluation of pollutant concentrations both for the entire area and for the individual plant takes into account, at the same time, three demanding aspects: a complete model representation of transport and chemical processes in atmosphere, a complete emission inventory of the area and large computing resources for a long-term simulation. Pollutant concentration maps were obtained for all harmful pollutants emitted by the plant (gaseous pollutants, particulate matter, benzene, polycyclic aromatic hydrocarbons, heavy metals).

As far as RA is concerned, inhalation cancer risk (R) and hazard quotient (HQ) maps for each pollutant and for each target organ or apparatus were constructed for both the overall ambient concentrations and for the sole contribution of the plant, selecting the inhalation unit risks (UR) and reference concentrations (RfC) values among those reported in the most valuable scientific literature on RA.

To the best of our knowledge, this is one of the first studies with an integrated assessment of air quality and potential health risk for an industrial facility, relying on an air quality chemical-transport model procedure, taking into account all emission sectors, the atmospheric chemistry and the specific contribution of the plant. It is therefore a contribution to enhance the integration capability of air quality modeling and human health risk assessment of large industrial sources.

2. Material and methods

2.1. Description of the site

The industrial facility under analysis is the coal-fired power plant of Torrevaldaliga Nord, located in Central Italy about 50 km North-West of Rome, in the town of Civitavecchia (Fig. 1). It is included in the list of industrial plants of national strategic relevance, subjected to the aforementioned regulations on HIA. The plant is conducted by ENEL s.p.a., a world major player in power generation and the largest producer of