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Public risk perception of air pollution in the general population of Italy and Sweden during the COVID-19 pandemic: Environmental and socio-demographic drivers

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A R T I C L E I N F O

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A B S T R A C T

Air pollution is an important anthropogenic hazard due to its effect on human health and the environment. Understanding how the population perceives the risk associated with air pollution is a crucial aspect to inform future policies and communication strategies. The aim of this study is to examine the association between air pollution concentrations and public risk perception of air pollution, also exploring socio-demographic patterns in the general population of Italy and Sweden. To this end, we derived 3-year PM10 average concentrations from ground monitoring stations and integrated with a population-based survey carried out in August 2021 in both countries. Relative perceived likelihood and impact on the individual were considered as domains of risk perception. In addition this, information on direct experience and socio-demographic factors were included as possible determinants of risk perception. Linear regression models were performed to examine the association of PM10 average concentrations at regional level and individual level factors with risk perception domains. In both countries, respondents who live in the most densely populated regions report a higher perceived likelihood of air pollution. Direct experience is the main driver of risk perception in both countries. Being male and smokers in Italy, older age and having left/centre-left political orientation in both countries are associated with a higher perceived likelihood and impact of air pollution. These findings will inform future health and environmental studies regarding the public risk perception of air pollution highlighting individual's awareness and the socio-demographic patterns.

1. Introduction

Understanding public risk perception of air pollution provides valuable insights for authorities and policymakers to develop risk management strategies for public health, disaster risk reduction, and climate change adaptation. Air pollution is a major threat to the environment and human health, causing 6.67 million deaths worldwide in 2019, ranking it as the fourth leading cause of death (Health Effects Institute, 2019). Particulate matter (PM) is a common air pollutant consisting of solid and liquid particles with an aerodynamic diameter of <10 μm (PM10) and <2.5 μm (PM2.5). The WHO's 2021 Air Quality Guidelines recommend new air quality levels such as PM10 concentration limit of 15 μg/m^3 for the annual mean and 45 μg/m^3 for the 24-h mean (World Health Organization, 2021). Exposure to PM10 and PM2.5 is associated with decreased lung function, exacerbation of chronic respiratory and cardio-vascular diseases, respiratory symptoms, and premature death. (Atkinson et al., 2010; Cadelis et al., 2014; Correia et al., 2013; Dominici et al., 2006; Fang et al., 2013; Meister et al., 2012; Samoli et al., 2016). Particulate matter originates from both direct emissions and chemical reactions with precursor pollutants (e.g., oxides of nitrogen, sulphur dioxide) and releases from a wide range of sources such as industrial and agricultural activities, fuel combustion, and road traffic (Srimuruganandam and Shiva Nagendra, 2012). Natural sources such as wildfires, pollen season, volcanic ash, and Saharan dust also

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contribute to PM emissions (European Environment Agency, 2013). PM levels vary worldwide due to local weather variability, topography, particle sources and emitted concentrations (Casati et al., 2007). Northern Europe experiences the least exposure, while Central and Eastern Europe, as well as northern Italy, contend with elevated concentrations. Central and Eastern Europe's high PM levels are due to widespread use of solid fuels and older vehicle fleets (European Environment Agency, 2021b). In northern Italy, the Po Valley, densely populated urban area, is affected by unfavourable geomorphological conformation. Specifically, the pollutants recirculation and release are blocked by the peculiar, closed orography of the flat river valley enclosed between the Alps and Apennines mountains (Giulianelli et al., 2014).

Fig. 1 shows an example on how i) seasonality, ii) emissions, urban concentration along with orography, and iii) concurrent events as the COVID-19 pandemic may affect PM10 concentrations in Sweden and Italy for the period 2018–2020. Both countries showed a seasonal trend in PM10 average concentrations, the concentrations were higher in Italy than in Sweden, due to differences in population density and orography. COVID-19 waves resulted in a reduction of many anthropogenic activities, such as road transport, aviation, shipping, and industrial activity, leading to a reduction of emissions of air pollutants (European Environment Agency, 2021b).

To reduce air pollution, a combination of strategies and preventive public measures can be implemented such as regulatory limits on emissions, stricter air quality standards, reduced energy consumption, land use planning, and cleaner transport and household energy sources (World Health Organization, 2013). These factors influence the risk perception of air pollution and the perception of air quality, the two main components of individuals' perception of environmental stimuli and risks. Perception of risk of air pollution involves assessing potential hazards and health consequences, while perception of air quality is the subjective evaluation of air cleanliness or pollution, influenced by factors like weather, environment, and individual sensitivity. Uncovering both components supports policymakers and researchers in i) identifying barriers to action as low risk perception or misinformation, ii) developing targeted public health strategies, and iii) understanding people's attitudes and responses to air quality concerns.

Despite the increasing importance of risk perception of air pollution, current evidence remains grounded on health effects and air quality related aspects (Brody et al., 2004; Guo et al., 2016; Kim et al., 2012; Mirabelli et al., 2020; Pantavou et al., 2018; Rotko et al., 2002). Next to this, there is no clear consensus on the main drivers of perceived the risk.

This study examines the association between PM10 concentrations and public risk perception of air pollution, also exploring socio-demographic patterns. To this end, we compare the difference in public risk perception of air pollution in the general population of two European countries, Italy and Sweden, with similar welfare state and European regulation on air quality standards, and differing for average air pollutant levels.

2. Material and methods

2.1. Environmental data

Air pollution data were collected from ground monitoring stations provided by the European Environmental Agency (EEA) in Sweden and Italy for the years 2018, 2019 and 2020. We obtained average concentrations of particulate matter (PM10) expressed in μg/m3 from the EEA's E1a datasets (European Environment Agency, 2019), based on reports uploaded by the Member States and EEA countries into EEA's Central Data Repository (CDR) and tested and quality checked by the European Environmental Agency (European Environment Agency, 2021a). 3-year PM10 average concentrations at region level in both countries according to the Nomenclature of Territorial Units for Statistics (NUTS) classification of the European Union (European Union, 2017) were calculated.

Specifically, 118 ground monitoring stations (25 in Sweden and 93 Italy) with more than ≥75% yearly data coverage were encompassed in the study (Katsouyanni et al., 1996; Renzi et al., 2020). To ensure a good representation of air pollution levels at regional level, 5 ground monitoring stations, 2 traffic, 2 background, 1 industrial station were included for each region in Italy, while a 1:1 background/traffic site

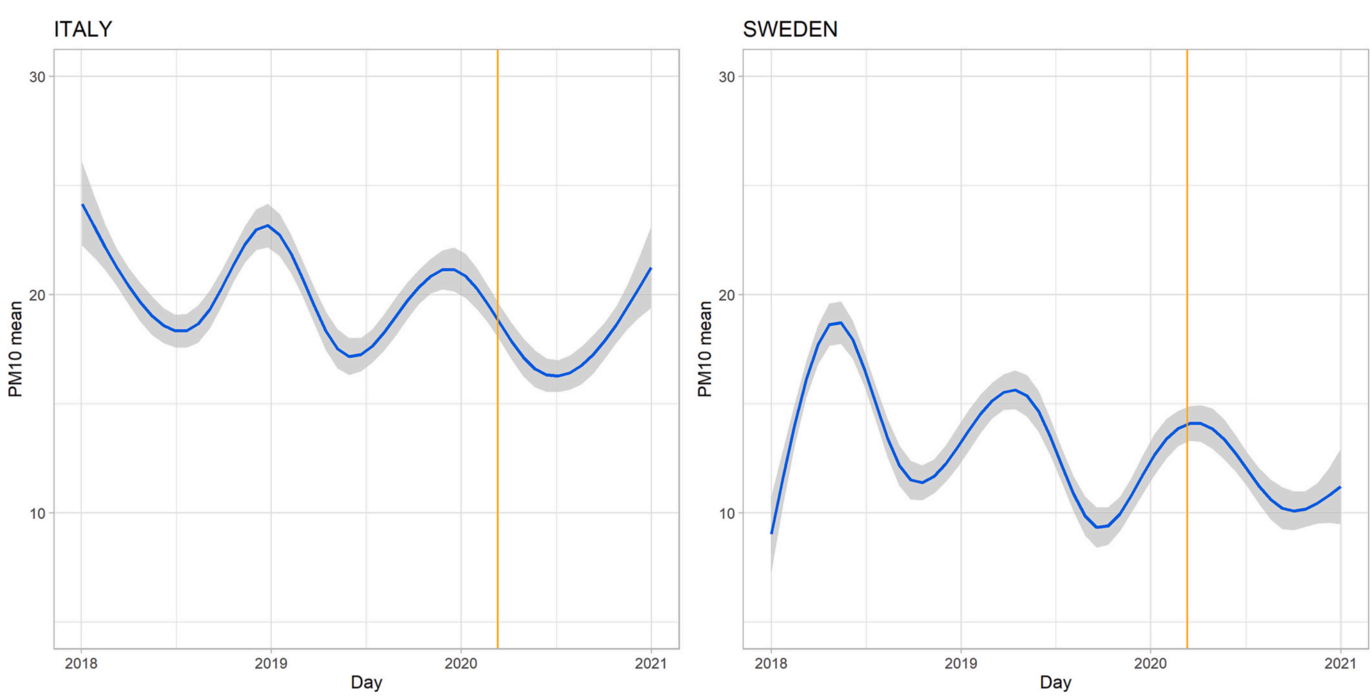

Fig. 1. Spline plots of PM10 average concentrations (μg/m3) in Italy and Sweden (years: 2018, 2019 and 2020) with 95% Confidence Intervals (CIs). The yellow line in both plots represents the day in which COVID-19 was declared as pandemic by WHO (March 11th, 2020). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ratio was applied in Sweden (2 traffic and 2 background stations). If there was no available station in a specific region, values of nearby regions' stations were imputed (i.e., in Sweden, Norra Mellansverige acquired the background station from Östra Mellansverige and Övre Norrland the background station from Mellersta Norrland; in Italy, Molise acquired the background station from Abruzzo). Fig. S1 shows the location of the PM10 monitoring stations.

Measurements were reported in hourly and daily averaging formats. All values were transformed in daily average formats and aggregated to obtain 3-year PM10 average concentrations. Missing values on a specific day and monitoring station were imputed as weighted average of all measured values on that day from the other monitoring stations of the same region. The weight was calculated as the ratio of the yearly PM10 average concentrations in that monitoring station to the yearly PM10 average values for the other monitoring stations. (Renzi et al., 2020; Stafoggia et al., 2010).

We then analysed the spatial distribution of PM10 concentrations data in each region and displayed it in maps created by QGIS 3.10 software.

2.2. Survey data

Data were collected through a nation-wide online survey carried out in Italy and Sweden in August 2021. The marketing research company KANTAR Sifo (KANTAR Sifo, 2020) oversaw data collection. The survey samples were drawn from two existing survey panels in Italy and in Sweden, each including around 100′000 panellists. Panellists were contacted via email and up to two reminders were sent during the data collection period (August 13–23, 2021). Each participant, after being informed that participation was voluntary and anonymous, consented to participate in this study by completing and submitting the survey. The samples are representative of the general population in each country for gender, age, and geographical distribution, with an overrepresentation of the two capital regions by study design, here adjusted using weights. Overall, 4154 respondents were included: 2010 respondents in Italy (53% female, 47% male, mean age 49.1) and 2144 individuals in Sweden (52% female, 48% male, mean age 49.4). This survey data is the third round of a repeated survey. Additional information on the first and second round are presented in Mondino et al. (2020) and Di Baldassarre et al. (2021).

In summary, the survey focuses on risk perception of ten different hazards (epidemics, floods, droughts, earthquakes, wildfires, terror attacks, domestic violence, economic crises, climate change, and air pollution) and also includes information on direct experience and socio-demographic factors. The survey considers seven domains of public risk perception for each hazard (likelihood, impact on the individual and on the population, individual and authority preparedness, individual and authority knowledge) measured with a Likert-type scale ranging from 1, minimum to 5, maximum. The survey form can be found in the supplementary material.

Specifically, the present study included individuals residing in regions with >10 respondents (i.e., residents in the Italian regions of Molise and Valle d'Aosta were excluded) and focused on two domains of air pollution risk perception: the perceived likelihood of its occurrence and perceived impact on the individual. These domains were standardised for the risk perception of the other hazards (e.g., perceived air pollution likelihood/mean perceived likelihood for the other hazards) at individual level.

Information on direct experience of air pollution (yes vs. no), gender (M vs. F), age (subgroups: 18–39, 40–64, >65 years old), employment (yes vs. no), relative income (from 1 not sufficient to 5 more than sufficient to meet the family's needs), university education (yes vs. no), political orientation (left/centre-left, centre, and right/centre-right) and current smoking behaviour (yes vs. no, defined as cigarette smoking during the previous 30 days) were considered as possible determinants of risk perception.

The survey used in this present study was approved by the *Italian Research Ethics and Bioethics Committee* (protocol 0043071/2019) and the *Swedish Ethical Review Authority* (Dnr 2019–03242). All protocols performed were in accordance with the ethical standards set by the European Union under Horizon 2020 (EU General Data Protection Regulation and FAIR Data Management).

2.3. Statistical analysis

Initially, we calculated the proportion of respondents reporting 4 or 5 for perceived likelihood and impact comparing air pollution with other hazards resulting from the survey in August 2021. We then performed linear regression models to investigate the association between the 3-year PM10 average concentrations (independent variable) and the two domains of risk perception (dependent variables). Finally, we examined the association between possible determinants (direct experience of air pollution and socio-demographic factors) and risk perception of air pollution. We selected the variables a priori based on their relevance to air pollution risk perception. For political orientation we run models considering both left/centre-left and centre as the reference. Checking the model residuals with a QQplot and Shapiro-Wilk Test, we didn't detect any major departure from the linear assumption. All the analyses applied specific weights to take into consideration the overrepresentation of the respondents who live in the capital region. All statistical analyses were stratified by country and the results were expressed in terms of percentage Beta coefficients (coeff) and 95% Confidence Intervals (CIs) as reported in Table S1 and Table S2. The results of each model were graphically presented in forest plots.

RStudio 3.6.1 software was used to elaborate the dataset and process all the statistical analyses.

3. Results

3.1. Perceived risk of air pollution in relation to other hazards in Italy and Sweden

Air pollution and climate change are seen as the most impactful and likely hazards in both countries (Fig. 2). On average, people who think these hazards can cause negative impacts to themselves also perceive them as highly probable. Air pollution and climate change evoke similar levels of concern in Italy, while in Sweden the primary concern is climate change.

3.2. Association between PM10 concentrations and the domains of risk perception

Figs. 3 and 4 show the spatial distribution of 3-year PM10 average concentrations and percentage of relative perceived likelihood and impact on the individual standardised for the risk perception of the other hazards for each NUTS2 region in Italy and Sweden.

Italy shows higher concentrations than Sweden, especially in the northern regions belonging to the Po Valley (Piemonte, Lombardia, Emilia Romagna and Veneto), with values >25 μg/m3 (Fig. 3a). Residents of these northern Italian regions report higher perceived likelihood along with other Italian densely populated such as Toscana, Lazio, and Campania (Fig. 3b). Yet, the perception of air pollution impact on the individual is greater in the Italian northern regions (including Liguria and excluding Emilia Romagna regions) (Fig. 3c). In Sweden, the average concentrations of PM10 range between 10 and 15 μg/m3, except for the higher values reported in Småland med öarna and Sydsverige regions (16.6 and 16.4 μg/m3, respectively) (Fig. 4a). The most densely populated regions, which include the four largest cities in Sweden (Stockholm, Goteborg, Malmö, and Uppsala), have a greater perception of air pollution likelihood (Fig. 4b) while the perceived impact on the individual remains uniformly distributed across the entire national territory (Fig. 4c).

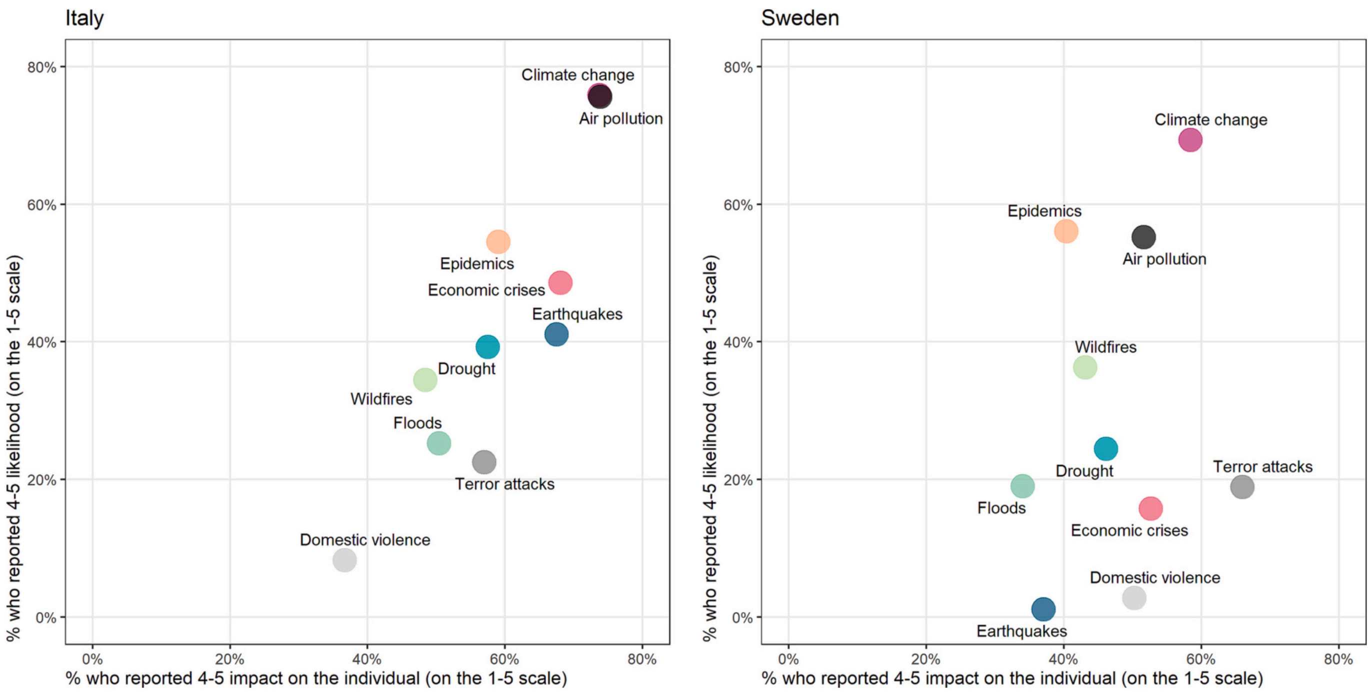

Fig. 2. Perceived impact and likelihood for multiple hazards in Italy and Sweden. Proportion (%) of people who reported 4 or 5 (on the 1–5 scale) on perceived impact on the individual and likelihood.

Next to this, we formally assess the association between PM10 concentrations and the two domains of risk perception using linear regression models (Fig. 5). An increase of 10 units in the concentration of PM10 in μg/m3 is associated with a 18% increase in perceived likelihood in Italy, and with a 6% in Italy and 9% in Sweden increase in perceived impact on the individual. While no statistically significant association is found with perceived likelihood in Sweden.

3.3. Individual experience and socio-demographic factors associated with the domains of risk perception

The results from multivariable linear regression models, graphically reported in Fig. 6, show that direct experience along with age are the main drivers of risk perception in both countries. There is an association with gender in Italy, but not in Sweden.

Having experienced air pollution results in a 17% higher perceived likelihood in Italy and 23% in Sweden, and in a 12% higher perceived impact on the individual in Italy and 11% higher in Sweden.

Being male in Italy and older in both countries are associated with a higher perceived likelihood and impact on the individual of air pollution. Italian smokers compared to non-smokers and individuals with left/centre-left political orientation compared to right/centre-right orientation in both countries have a greater perception of air pollution likelihood. Employment is related to lower odds, although not significant. No other statistically significant associations were found.

4. Discussion

Our study shows that air pollution along with climate change is ranked as the most likely and impactful threat on the individual in Italy while in Sweden, it ranks as the second threat preceded by climate change. Risk perception of air pollution is following a similar pattern as PM10 concentration spatial distribution and direct experience is the main driver among the individual determinants.

Concern for climate change was found to be similar, if not greater, compared to air pollution. This may be partially explained by a different media coverage for these two hazards. Specifically, climate change is receiving a substantial increase in media coverage over the past two decades, both locally and globally (Schmidt et al., 2013) and individual attention especially from the current generation of young people (i.e., Fridays for Future movement). This may be overshadowing the importance of air pollution issues. The level of information about air quality problems is rather low with over 50% of Europeans reporting that they are inadequately informed about air quality in their respective countries (European Commission, 2019).

In both countries, respondents who live in the most densely populated regions report higher perceived likelihood of air pollution. Furthermore, the northern regions of Italy, a well-known polluted area in Europe (European Environment Agency, 2021b), also report a greater perception of air pollution impact on the individual. This may be due to public and media attention at regional level of air pollution and the implementation of policies to reduce pollutant concentrations below the EU limit values (i.e., limits of the urban traffic increase the efficiency of the heating systems). This is in line with the literature also related to other air pollutants (Dons et al., 2018; Rotko et al., 2002).

Focusing on the role of direct experience and sociodemographic factors as determinants of risk perception, individual experience is the main driver of the two perceived risk domains in both countries. This aligns with extensive literature reporting that direct experience influences risk perception of different hazards (Heitz et al., 2009; Miceli et al., 2008; Plapp and Werner, 2006; Siegrist and Gutscher, 2006). Specifically, a personal exposure to a hazard event (i.e., air pollution) can provide an illustration of the hazard and underscores its potential for future risk (Wachinger et al., 2013).

In Italy, being male and in both countries, being of an older age, are linked to higher perceived likelihood and impact on the individual of air pollution. This contrasts with the typical pattern of a lower risk perception among those with higher societal status (Finucane et al., 2010). Generally, men and the elderly perceive lower risks than women and younger people (Howel et al., 2003; Jacquemin et al., 2007; Kim et al., 2012). Risk perception of air pollution may differ from other hazards due to its connection with chronic diseases. This could explain why the elderly and males, at higher cardiovascular risk, reported a greater risk perception for air pollution, aligning with previous

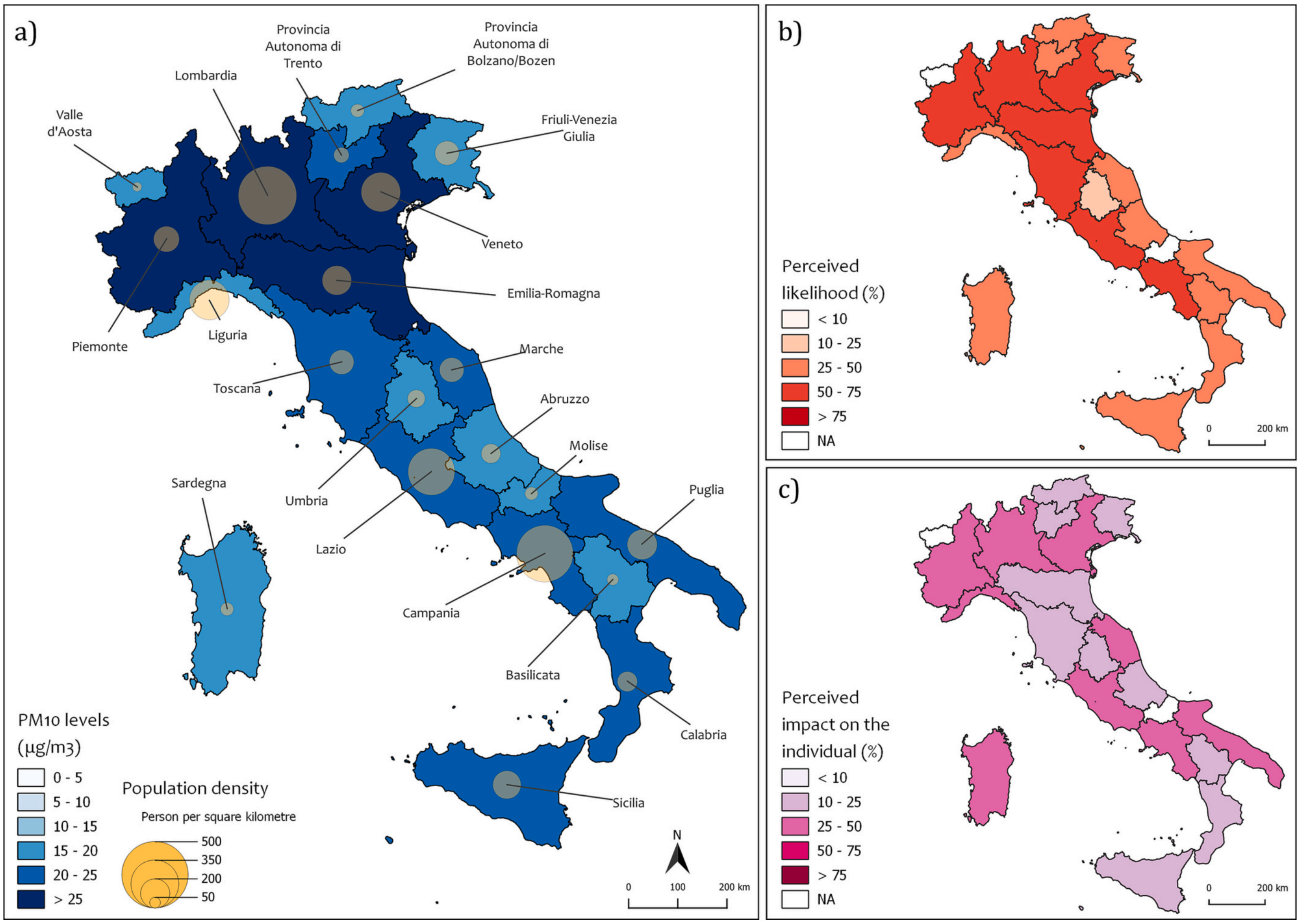

Fig. 3. Maps of PM10 concentrations along with population density (a), percentage of relative perceived likelihood (b), and relative perceived impact on the individual (c) in each NUT2 region of Italy.

literature (Brody et al., 2004; Guo et al., 2016). The greater concern among the elderly may also stem from their experience of rising pollution levels over time.

Smoking is associated with higher perceived likelihood of air pollution in Italy. A similar pattern of association was observed in Greece by Pantavou et al. (2018), where smokers were more likely to perceive the air as containing high levels of dust and particulate matter. Smoking is the primary preventable health risk factor. Smokers may avoid risks related to environmental exposure, and may attribute health effects to external hazards like air pollution rather than their own behavior. This pattern is not observed in Sweden, where smokers and non-smokers might not be directly comparable and could differ in other aspects, such as mental health prevalence. Policies implemented in the last 20 years have increased awareness and limited smoking behavoiour in a more selective sample of the Swedish population. Other findings highlighted that individuals with left/centre-left political orientation compared to right/centre-right orientation in both countries tend to have a greater perception of air pollution likelihood. Left/centre-left political parties are more concerned about environmental issues (i.e., air pollution and climate change) as also reported by Di Baldassarre et al. (2021) and Marquart-Pyatt et al. (2014).

At odds with previous studies, no associations are found with employment, income, and education. For instance, Guo et al. (2016) found that individuals with at least college-level education perceive air quality to be worse than those without. Additionally, lower household income was generally linked to a poorer perception of air quality within local community (Kim et al., 2012). Discrepancies in the findings may result from socio-demographic, cultural and regional differences, and methodological variations across studies.

This is the first study that examines the association between public risk perception of air pollution and air pollution concentration levels comparing representative samples of two European countries, Sweden and Italy. Although the analysis focused only on PM10 concentrations, these results may be generalised to other air pollutants (PM2.5, nitrogen dioxide, sulphur dioxide and carbon monoxide) detrimental to human health. Some potential limitations should be considered when interpreting these results. The measure of PM10 is included as an ecological measure at regional level. PM10 concentration measures for each residential area in which the respondents live or work would enable a more comprehensive examination of the association. This may have resulted in non-differential misclassification of the exposure (air pollution), which could bias the estimated association between air pollution levels and risk perception towards the null. Consequently, the reported estimate should be considered as conservative. Due to the cross-sectional study design, it is not appropriate to interpret the associations related to determinants of risk perception in terms of causality. A higher detail in the respondent spatial distribution and pollutant levels will allow to examine another possible association between perceived air pollution and O3 concentrations, the primary summer pollutant that forms from sunlight-reacting pollutants (World Health Organization, 2021).

Conclusively, the association between individual perception and real-world data of PM10 concentrations is partially positively explained. Differences in individual experience and socio-demographic factors (e.g., gender, age, smoking, political orientation) affect perceived risk.

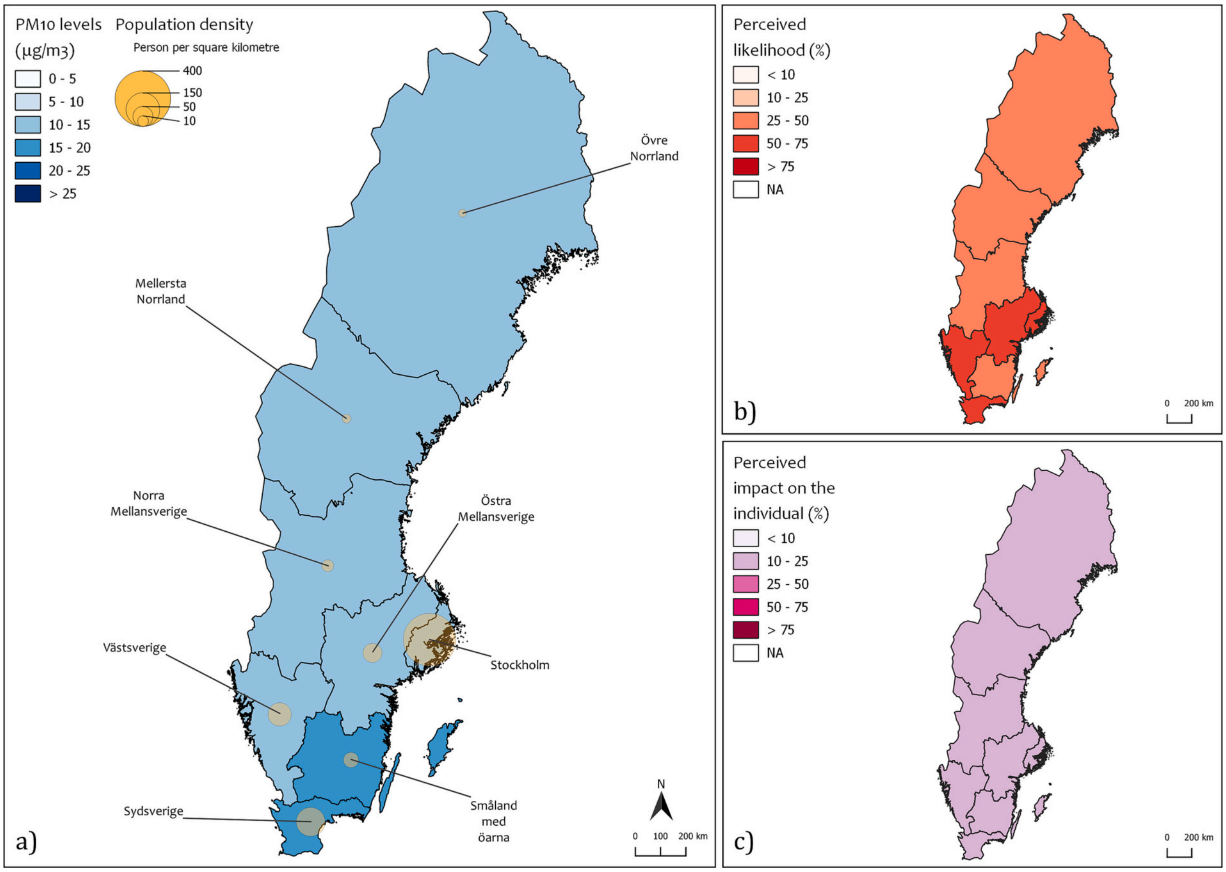

Fig. 4. Maps of PM10 concentrations and population density (a), percentage of relative perceived likelihood (b), and relative perceived impact on the individual (c) in each NUT2 region of Sweden.

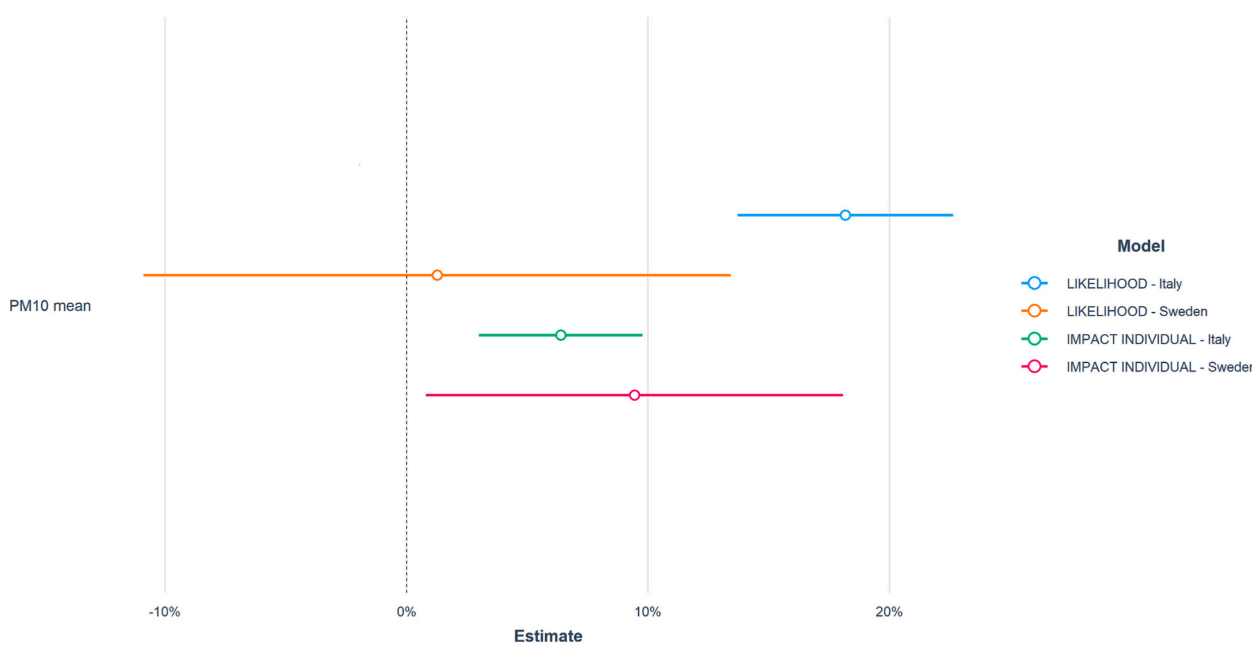

Fig. 5. Forest plot of the effect of PM10 average concentrations on relative perceived likelihood and impact on the individual. Results are expressed in terms of percentage Beta coefficients (symbols) and 95% confidence intervals (horizontal lines). 0% represents the null effect.

These insights can help shape future policy strategies and risk communication related to air pollution, taking into account a world facing multiple hazards and crises, such as the COVID-19 pandemic.

Data and code availability

The dataset resulting from the online survey comes in a CSV format

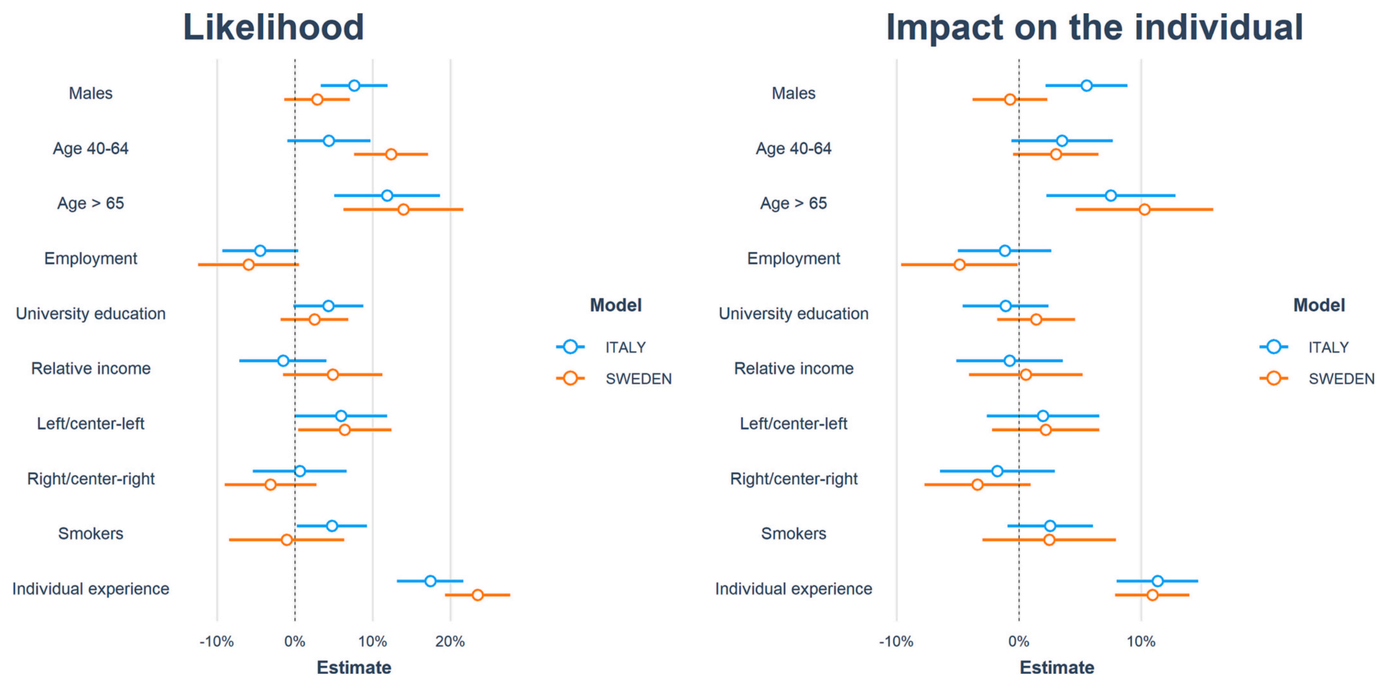

Fig. 6. Forest plot of individual experience and socio-demographic factors related to perceived likelihood and impact on the individual. Results are expressed in terms of percentage Beta coefficients (symbols) and 95% confidence intervals (horizontal lines). 0% represents the null effect.

and is stored open access on Zenodo (https://zenodo.org/record/5653322#.YoI_QVRBzIX).

All code for reading, processing and graphically representing the data is freely available at https://github.com/gianmarcopignocchino/Perception_air-pollution. Information on the packages used are listed in the same repository.

CRediT authorship contribution statement

Gianmarco Pignocchino: Conceptualization, Methodology, Formal analysis, Investigation, Software, Resources, Writing – original draft, Visualization. **Giuliano Di Baldassarre:** Conceptualization, Resources, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Elena Mondino:** Methodology, Resources, Data curation, Writing – review & editing, Supervision. **Elena Raffetti:** Conceptualization, Methodology, Validation, Data curation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2023.107601.

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