Exploring the link between particulate matter pollution and type II Diabetes in Italy and Lombardy using clinical longitudinal data: a comparative analysis

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Abstract

Background:

The association between particulate ambient air pollution and an increased risk of type II Diabetes (T2DM) is well-established. Air pollution, a significant public health concern globally, affects various non-communicable diseases, including T2DM. Italy faces significant challenges with both particulate air pollution and T2DM. No studies in Italy exist assessing the association of particulate and T2DM on a large dataset regarding clinically diagnosed T2DM.

Methods:

This study aims to assess the association between particulate matter (PM2.5 and PM10) and T2DM prevalence, and incidence rate in Lombardy compared to the rest of Italy from 2006 to 2019. The association with Years lived with disability (YLDs) rates has been assessed on data from 2006 to 2016. Data is obtained from the AMD dataset, a comprehensive outpatient longitudinal dataset, while particulate matter data is sourced from European Environment Agency and ARPA Lombardy. The association has been assessed via mixed-effects models.

Results:

The mixed-effects model revealed a significant positive association between particulate matter and T2DM incidence rates in Italy, with notable variations over time and between regions (Lombardy vs the rest of Italy). While no significant effect was observed of particulate on prevalence rates and YLDs rates, there is a positive significant connection between particulate and Incidence rate for Italy. The effect increases with time. The opposite tendency has been observed for Lombardy with a negative association of particulate and incidence. Said effect decreases with time opposing the trend for Italy.

Conclusions:

Particulate matter pollution, specifically PM2.5 and PM10, seems to be significantly associated with T2DM incidence rates in Italy. However, the impact varies between regions, with Lombardy exhibiting a complex relationship influenced by socioeconomic factors. This study underscores the importance of addressing air pollution as a public health priority, particularly in regions with high pollution levels like Lombardy, to mitigate the risk of T2DM and its associated burden.

1. Background

The association between particulate ambient pollution and an increased risk of type II Diabetes (T2DM) is well supported in the literature (Bukart et al., 2022; Yang et al., 2020; Li et al., 2019; Balti et al., 2012).
"Air pollution is one of the great killers of our age," wrote P.J. Landrigan some years ago (Landrigan, 2017) and, as shown, it can affect several non-communicable diseases through a variety of pathways (Schraufnagel et al., 2019). Regarding Diabetes, patients might be more vulnerable to air pollutants exposure via an altered glucose metabolism through the insulin-dependent pathway effect (Teichert and Herder, 2016).

Both particulate ambient pollution and T2DM are globally major public health concerns. In 2019, particulate air pollution was ranked as a leading factor for mortality and disability-adjusted life years (DALYs) globally, according to the Global Burden of Disease Study (Ärnlöv et al., 2020). Specifically, particulate is subdivided for the aerodynamic diameter which implies a different penetration capacity into the lung: PM10 diameter is less than 10 µm and PM2.5 diameter is less than 2.5 µm. Their main sources are combustion processes in domestic heating systems fuelled by wood biomass, vehicles equipped with internal combustion engines, and industrial activities (ISPRA, 2023). As for it, particulate is mainly linked with urbanization and industrialization (Van et al., 2010). T2DM is a top contributor to the global burden of mortality and disability in adults (Ong et al., 2023). It is considered an epidemic, one of the fastest-growing global health emergencies of the 21st century (Lam and LeRoith, 2012) with a high social and financial toll on individuals and society. Its growth is due to the population aging, sedentary lifestyle, overweight, and obesity but also socio-economic contexts (Brown et al., 2004; Webbink et al., 2008; Espelt et al., 2008 and 2011) and urbanization (Robbins and Webb, 2006; Cities Changing Diabetes, 2023).

In Italy, the two phenomena are particularly significant. In 2019, according to the Global Burden of Disease, particulate air pollution accounted for 14.79 deaths and 357.49 DALYs age-standardized for 100000 people (Murray et al., 2020), both slightly reduced from 2011 (Conti et al., 2023). This is mainly due to a time of greater energy efficiency, the spread of renewable sources, and more stringent emission limits in the use of energy for industrial use, for what air pollution, particularly PM2.5, over the period 2011–2019, has shown a decreasing trend. Despite all efforts and resources allocated to reduce air pollution, including the agreement between the Environment Ministry and Italian regions (Clean Air Plan, 2019), Italy still lacks to operate in the substantial effort to cut air pollution, especially in some parts of the country. As for it, Italy is the most air-polluted country in Western Europe (EEA, 2023).

Concerning T2DM, prevalence in Italy is 6.3% of the population. It is estimated, however, that around 1.5 million people are undiagnosed. Prevalence is greater for men than women: 6.6% and 6.1%, apiece (ISTAT, 2021). T2DM is a leading cause of disease burden (Vos et al., 2020; Ong et al., 2023) and although in the last decade, the mortality rate decreased by more than 20%, its risk factors are increasing. In 2021, 34.2% of adults were overweight, 12.0% were obese and 33.7% of Italians were physically inactive (ISTAT, 2021).

The Italian situation bears particular interest with regard to industrialization and urbanization too. Italy suffers from a historical development gap from a North-South dualism (Toth F., 2014a) that carries huge differences between regions. In general, the main component of the Italian industry is manufacturing, particularly machinery and equipment manufacturing, in Europe it is second only to Germany. On a
general level, almost half of the entrepreneurial fabric is concentrated in northern Italy (48.4%), and on a regional level, Lombardy comes first with a weight on the overall picture of 16.7% (Confindustria, 2019). Moreover, Italian regions differ in terms of population and size. Lombardy is the fourth largest, the most populous, and the second among all the 21 Italian regions with the highest population density (ISTAT, 2020).

Italy exhibits three other peculiar traits: it is the oldest country in Europe with an average age of its citizens of 48 years (Eurostat, 2021); mountain municipalities, with a few thousand inhabitants, are almost half of the total of Italian municipalities so flat areas and large cities are heavily populated (ISTAT, 2020); the public health system is going through a transformation on regional basis.

The elderly are frail and at higher risk for accelerated physical and cognitive decline, disability, and death for all diseases, including T2DM (Morley, 1998; Fulop et al., 2010). The total surface area of Italy amounts to 302,073 square kilometers and, due to its orographic conformation, a predominantly hilly terrain characterizes the country, 41.6% of the total surface area, followed by mountainous 35.5% and lowland 23.2% (ISTAT, 2020). Italy’s population is more likely to live in non-mountainous areas, making some of them the most densely populated in Europe (Eurostat, 2021). Finally, the Italian National Health System (NHS) was instituted in 1978 following the Beveridge model, but legislation passed in 1999, 2000, and 2009 put it increasingly on a regional basis. The national government sets guidelines for the provision of health services by the regional governments, oversees it, and provides most of its funding through tax-funded aid allotted by weighted capitation for population age, the remainder being covered by a regional surcharge to the income tax and by VAT sharing (Ferré F. et al, 2014). Each of Italy’s 21 regions has large autonomy in managing its health services: regional governments define their own health plans, allocate the budget, and adopt their own model of governance. Lombardy's “quasi-market” model is founded on public-private competition and it is strongly hospital-centered (Mapelli V., 2000, 2007, 2012; Toth 2014b, Bertini G., 2013, Bordogna M.T., 2011, Neri S., 2008).

Considering that, and well aware that air pollution has long-term negative health effects, the aim of this study is to verify the possible association between T2DM and PM2.5 and PM10 in Lombardy, the most ambient polluted regions in Italy, compared to the rest of the country over the period 2006–2019. T2DM data comes from the AMD dataset, a dataset not publicly available, provided to us thanks to a research collaboration agreement with the Italian Diabetologists Association, a member of the International Diabetes Federation. The AMD dataset is the only existing outpatient national dataset for Italy in which diabetes is not self-reported. Data on PM2.5 and PM10 for Italy comes from European Environment Agency, selected because related to the same period of T2DM data and is comparable, in terms of units, with the data available for Lombardy. The latter, come from the regional environmental agency, ARPA, set up after the reform of Title V of the Italian Constitution, which gave competence in terms of environmental policy to Italian regions.

To our knowledge, this study is the first attempt that aims to calculate the association between T2DM and particulate matter, both PM2.5 and PM10, in Italy and Lombardy with data on T2DM taken directly
from an outpatient dataset in which diabetes is clinically detected according to the American Diabetes Association. Previous evidence was based on estimated prevalence from sample surveys and self-reported disease (Orioli et al., 2018), concentrated just only on one city, such as Milan and Rome (Meroni et al., 2021; Renzi et al., 2018) and on T2DM patients who experience hospitalization (Solimini et al., 2015).

Without pursuing inferential or representative goal, this study provides a comprehensive description of the association between T2DM incidence, prevalence and years lived with disability, YLDs (James et al., 2018) with PM2.5 and PM10. Our contribution fills a gap in the literature by calculating this association with fixed effects models and providing information on the effects of particulate matter on non-communicable diseases.

The remainder of this work is organized as follows. The next two sections describe the two datasets and methods. Section 4 presents descriptive statistics and results. Section 5 discusses our findings while Section 6 concludes.

Every step of our research adhered to the GATHER (Guidelines for Accurate and Transparent Health Estimates Reporting) statement.

2. Data

The AMD dataset is an outpatients national longitudinal dataset collected since 2004 in almost 300 diabetological centers distributed across all 21 Italian regions. In the absence of a national diabetes registry, the AMD dataset is the only tool in existence comparable to a registry (WHO, 2021). Records are organized in an online software system based on computerized medical registration created for each patient. The dataset includes information on: the location of the centers, patient socio-demographic characteristics, and clinical data including follow-up visits. All patients enrolled gave their informed consent for inclusion before they participated. The AMD dataset collection was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of AMD. Patients’ data are anonymized using an ID.

Data for particulate matter in Italy comes from WebDab, the European Environmental Agency dataset. It records emissions of main pollutants, as well as heavy metals, persistent organic pollutants, and contains all emission data officially submitted to the Secretariat of the Air Convention (CLRTAP) by the parties to the convention, including Italy.

Dataset refers to the emission database of the Co-operative programme for monitoring and evaluation of long-range transmission of air pollutants in Europe, EMEP, and it is open to the public for interactive use on the following website: https://www.eea.europa.eu/en/analysis.

ARPA Lombardy data emissions are accounted by macro sector and then summed up. The macro sectors that contribute the most are non-industrial and industrial combustion and road transport. Data are
Total emissions for every pollutant from both datasets are measured in kt.

3 Methods

This study focuses on Lombardy (LOMBARDIA) compared to Italy (ITALIA) as the sum of the other regions except Lombardy.

T2DM prevalence and incidence rates per 100000 inhabitants have been derived from the AMD dataset patients, calculated from 2006 to 2019 and computed based on age classes, sex, and region. YLDs are calculated from 2006 to 2016 by multiplying patients with T2DM and its sequelae by a disability weight (Salomon J.A., 2015). The disability weight, ranging from 0 for full health and 1 for death (Burstein et al., 2015), represents the magnitude of health loss associated with a particular condition. To calculate YLDs for T2DM and its sequelae, we matched the list of all AMD dataset sequelae with the Global Burden of Disease Study classification (Spencer et al., 2017).

Rates for every 100000 inhabitants have been computed using the Italian resident population.

YLDs have been calculated using the following formula:

\[
Y\text{LDs} = P \times Dw
\]

(1)

where,

- \( P \) = Prevalence of a sequela
- \( Dw \) = Disability Weight for the sequela

If more than one sequela is present in a patient then:

\[
Y\text{LDs} = P \times [1 - (1 - DwA) \times (1 - DwB)]
\]

(2)

where

- \( P \) = Prevalence of sequela A and B
- \( DwA \) = Disability Weight for A
- \( DwB \) = Disability Weight for B

YLDs result in numbers and ratios per 100000 inhabitants. For our purpose, in the Results section we report merely the ratios.

To assess the variations of PM2.5 and PM10 over time, we used index numbers with the year 2005 as a reference.
The variables considered in the analysis include particulate matter as the sum of PM2.5 and PM10, year, sex, age in classes, and region (Lombardy and Italy). Few missing data have been replaced by linear interpolation.

The association between the available variables and prevalence, incidence, and YLDs rates is inspected by mixed-effects models with random intercepts. In order to account for potential regional variations and different effects over time, interaction terms involving the 'region' variable (LOMBARDIA vs ITALIA), year, and particulate matter were introduced for all outcomes. The inclusion of a random intercept accommodates for unobserved heterogeneity.

\[ y_{rate} \sim Sex + Region + (PM2.5 + PM10) + Year + Age + (PM2.5 + PM10):Region + Year:Region + (PM2.5 + PM10):Year + (PM2.5 + PM10):Region:Year + (1 \mid id) \]

where

- \( y_{rate} \) is the outcome (incidence rate, prevalence rate, ylds rate)
- Sex, Region, Year, Age and (PM2.5 + PM10) are the fixed effects
- \((PM2.5 + PM10):Region\) is the interaction term between Region, the level of pollution
- \(Year:Region\) is the interaction term between time and Region
- \((PM2.5 + PM10):Year\) is the interaction term between total pollution and time
- \((PM2.5 + PM10):Region:Year\) is the triple interaction between pollution, region and time
- \((1 \mid id)\) is the random intercept for each unique combination of region and sex

Due to the age-related nature of TD2M, this study encompasses only patients aged 45 and above. Analyses have been carried out using R4.2.3. Statistical significance was determined at the 0.05 level and p-values below this threshold were considered significant.

## 4. Results

In 2019, the AMD dataset reports 556567 patients with T2DM. The sex ratio shows a larger prevalence of men, with 31.7% more men than women (Fig. 1).

Geographically, Lombardy counts 36 centers with 48740 T2DM patients while Italy counts 280 centers and 507827 patients.

In 2019, in Lombardy T2DM incidence is 388.28 per 100000 inhabitants for women and 589.61 for men; while in Italy is 861.81 and 1186.1945 for women and men, respectively.

In 2016, the YLDs rate for 100000 in Lombardy amounts to 32.8 years and 51.4 years for women and men whereas in Italy they are 56.4 and 78.0 years respectively.
Regarding particulate matter, in 2019, PM2.5 amounts to 12122 and 150713 kt and PM10 is 14496 and 214519, in Lombardy and Italy, apiece (Table 1).

From 2005 to 2019, both PM10 and PM2.5 levels show a decreasing trend, with reductions observed from 2010 onwards in Lombardy and from 2011–2012 onwards in Italy. In 2019 Lombardy shows levels of PM2.5 and PM10 which are approximately 65% and 66% of the values in 2005. For Italy values for particulate decrease to 81% and 74% of the values observed in 2005.

Concerning the trend of T2DM, despite the difference in starting level and pace of growth, incidence in Lombardy and Italy shows a decreasing tendency whereas prevalence shows an opposite trend (see Fig. 2). The trends are more pronounced for the older population segments. As YLDs also depend on prevalence, their trend exhibits the same pattern.

<table>
<thead>
<tr>
<th>Year</th>
<th>Lombardy</th>
<th>Italy without Lombardy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PM2.5</td>
<td>PM10</td>
</tr>
<tr>
<td>2005</td>
<td>18651</td>
<td>21831</td>
</tr>
<tr>
<td>2006</td>
<td>17185</td>
<td>20458</td>
</tr>
<tr>
<td>2007</td>
<td>15719</td>
<td>19084</td>
</tr>
<tr>
<td>2008</td>
<td>20546</td>
<td>24001</td>
</tr>
<tr>
<td>2009</td>
<td>19538</td>
<td>22666</td>
</tr>
<tr>
<td>2010</td>
<td>18529</td>
<td>21330</td>
</tr>
<tr>
<td>2011</td>
<td>17753</td>
<td>20484</td>
</tr>
<tr>
<td>2012</td>
<td>16976</td>
<td>19638</td>
</tr>
<tr>
<td>2013</td>
<td>16503</td>
<td>19241</td>
</tr>
<tr>
<td>2014</td>
<td>16030</td>
<td>18843</td>
</tr>
<tr>
<td>2015</td>
<td>15700</td>
<td>18503</td>
</tr>
<tr>
<td>2016</td>
<td>15370</td>
<td>18163</td>
</tr>
<tr>
<td>2017</td>
<td>15040</td>
<td>17823</td>
</tr>
<tr>
<td>2018</td>
<td>13581</td>
<td>16160</td>
</tr>
<tr>
<td>2019</td>
<td>12122</td>
<td>14496</td>
</tr>
</tbody>
</table>
Table 2
estimates of mixed effect models for incidence, prevalence and YLDs rates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Incidence Rates</th>
<th>Prevalence Rates</th>
<th>YLDs Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>p-value</td>
<td>Estimate</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>-88428.8160</td>
<td>0.000003</td>
<td>-124512.7951</td>
</tr>
<tr>
<td>Year</td>
<td>-44.2882</td>
<td>0.000003</td>
<td>-62.3014</td>
</tr>
<tr>
<td>Sex = Male</td>
<td>98.6518</td>
<td>0.106967</td>
<td>615.0699</td>
</tr>
<tr>
<td>Region = LOMBARDIA</td>
<td>95703.5791</td>
<td>0.156842</td>
<td>120297.2338</td>
</tr>
<tr>
<td>(pm25 + pm10)</td>
<td>0.1317</td>
<td>0.003162</td>
<td>0.7461</td>
</tr>
<tr>
<td>Age in (54,64]</td>
<td>124.3646</td>
<td>0.000000</td>
<td>724.4109</td>
</tr>
<tr>
<td>Age in (64,74]</td>
<td>210.3136</td>
<td>0.000000</td>
<td>1607.9244</td>
</tr>
<tr>
<td>Age in (74,105]</td>
<td>163.0315</td>
<td>0.000000</td>
<td>1544.7827</td>
</tr>
<tr>
<td>Region = LOMBARDIA: (pm25 + pm10)</td>
<td>-1.1261</td>
<td>0.012710</td>
<td>1.9995</td>
</tr>
<tr>
<td>Year:Region = LOMBARDIA</td>
<td>47.8715</td>
<td>0.000095</td>
<td>60.6713</td>
</tr>
<tr>
<td>Year:(pm25 + pm10)</td>
<td>0.0001</td>
<td>0.003117</td>
<td>0.0004</td>
</tr>
<tr>
<td>Year:Region = LOMBARDIA: (pm25 + pm10)</td>
<td>-0.0006</td>
<td>0.012980</td>
<td>0.0010</td>
</tr>
</tbody>
</table>

The mixed-effect model results are depicted in Table 2. Namely, a significant negative effect of time, all other things being equal, is shown for the T2DM incidence rate in Italy (year coefficient=-44.3, p = 0.000003). The effect of Sex is not significant for incidence, prevalence, and YLDs rates (p = 0.10697; p = 0.12248; p = 0.07642 respectively) and, neither is the effect of Region = LOMBARDIA for all 3 outcomes (incidence, prevalence, and YLDs rates). From a purely descriptive point of view, though, results show, ceteris paribus, a larger prevalence, incidence, and YLDs rates for men. These results confirm what is well-known in the literature about sex differences in risk, pathophysiology, and complications of T2DM (Kautzky-Willer et al., 2016).

Particulate matter shows a significant positive effect on the incidence rate (p = 0.003162) for Italy. The same effects are not significant for prevalence rates and YLDs rates. Age in classes is the only variable
showing significant effects in all three models (prevalence, incidence and YLds), with a positive effect in the increase of incidence, prevalence, and YLDs rates for all age classes above.

With respect to the interaction terms, there is a significant negative result between Region = LOMBARDIA and particulate (p = 0.0127) suggesting a lower level of incidence for Lombardy with respect to Italy for the same increase in pollution.

The interaction between Year and Regione = LOMBARDIA is positive and significant (p = 0.000095). The effect (coefficient = 47.9) more than balances the corresponding negative one for Italy, indicating an increase in the incidence rate for Lombardy over time as opposed to the negative trend for Italy, all other things being equal.

Finally, the interaction between Year and particulate matter is positive and significant (coefficient = 0.0001, p = 0.003117) for Italy while for Lombardy the interaction term between Year, Region = LOMBARDIA and (PM2.5 + PM10) is negative and significant (coefficient=-0.0006, p = 0.01298).

5. Discussion

Our study shows that particulate matter pollution, both PM2.5 and PM.10, is significantly associated with T2DM. Specifically, this association is strongly evident for the incidence in Italy: increases in particulate matter are significantly associated with increases in T2DM.

Our findings are entirely consistent with findings in the literature, particularly those that have demonstrated this association for other countries (Ong et al., 2023; ) and those who have investigated this association for Italy using other data sources (Orioli et al., 2018; Meroni et al., 2021; Renzi et al., 2018; Solimini et al., 2015). In addition, our results are consistent with evidence concerning age (Narasimhan, et al., 2021). As expected, incidence increases with age. Compared to 44–54 years class, classes pertaining to the elderly show a higher incidence rate. Finally, time is crucial since the interaction term between PM2.5 + PM10 and Year carries a worsening effect of pollution on the incidence, confirming what is well known about its long-term effect on health.

No significant association has been found between particulate matter with T2DM prevalence and YLDs rates, probably due to the chronic nature of T2DM together with the long life expectancy of patients that causes prevalence to vary only in the long term. At present, people with T2DM live longer and become part of the stock: effects on prevalence are long-term effects and probably cannot be significantly assessed over a time-span of 15 years. From a purely descriptive point of view, as shown in the section results, PM2.5 and PM10 do exhibit a positive association with prevalence.

With regard to Lombardy, particulate matter does not have any significant effect on prevalence and YLDs. The same effect of age is valid for Lombardy as it is for the rest of Italy.

Nevertheless, contrary to what we expected, particulate matter is negatively associated with incidence. A plausible explanation can be found in the relationship between income and education on health. In fact,
Lombardy is the second region in Italy with the highest average household income along with 45–64 year olds workers wealthiest in Italy. It has the highest percentage of university graduates and the lowest aging index among the northern regions. Plus, it has the second lowest percentage of overweight and obese persons in Italy (ISTAT, 2024). The mechanisms through which education and income have repercussions on health can be multiple and trace back to the effects it has on healthy behaviors, but this may also depend on the family, social, and general context (Friedland, 2003). Indeed, in Lombardy, more than elsewhere, achieving effective health services coverage with equity is more certain. Lombardy counts 36 diabetologic centers while Italy counts 280: Lombardy accounts for 13% of all AMD diabetologic centers spread all over the rest of the country. In addition, unlike other parts of Italy, Lombardy suffers less from social and economic deprivation, inefficient public services, unemployment, and even crime. It is well-known how heavily socioeconomic context affects health (Stringhini et al., 2017) and shapes health inequity. A combination of multiple factors, where awareness of one's own health and the risks associated with it prevails. Together with easy access to health services, it creates a systemic condition whereby new cases of diabetes can not be associated with the increase in particulate matter. These concomitant factors can create a synergistic effect so that awareness of risk factors, their potential increase, and their consequences are associated with a decrease in the incidence.

This study has several strengths that contribute to its significance. Firstly, it represents the first-ever investigation conducted in Italy on the association between particulate matter and T2DM using an outpatient longitudinal dataset. The AMD dataset enables us to calculate incidence and prevalence directly from clinical data, unlike other available national sources in Italy, which rely on self-reported diagnoses through sample surveys.

Nevertheless, the most notable limitation of this investigation refers to some characteristics of the data used. Firstly, the AMD dataset does not uniformly cover all of Italy’s geographical areas and it does not account for T2DM patients whose conditions require hospitalization (registered by hospital discharge form extensively) or are care managed by general practitioners. Secondly, particulate matter data are calculated in total emissions and cannot be considered as a measure of exposure to pollutants.

In addition, this study has an exclusive observational nature. As a matter of fact, the assessment of causality between T2DM and PM2.5 and PM10 is difficult due to the confounding factors, reverse causality, and other sources of uncertainty. This issue is well resumed by the concept of the ‘exposome’, which refers to the totality of exposures, and cumulative effects, from a variety of external and internal sources, starting from conception and throughout life. Indeed, our investigation can provide useful information on external factors that could affect T2DM but, given the issue and the characterization of the data, may not adequately capture the complexity and variability of exposures over time.

T2DM in Italy has become a relevant issue both from an economic and a social point of view. The size of the population of persons living with diabetes is difficult to estimate also because people may be undiagnosed for a long time before symptoms start to appear. The life span of patients living with diabetes contributes to the variability in the diabetic population, which may only exhibit significant
changes over the long term. Therefore the observational window size used in the study is probably not wide enough to observe connections between variations of particulate matter and variation in the size of the population of patients with T2DM. Although the results suggest, from a descriptive and noninferential point of view, a positive connection between particulate and incidence rates as well. On the other hand, a significant connection has been observed between the variations of particulates and variations of incidence rates since the latter can be observed in the short term. No causation has been implied in this study since this would imply using lagged data for particulate matter which are not available from official sources at the time of this study.

6. Conclusion

This study has examined the association between particulate matter, both PM2.5 and PM10, and T2DM in Lombardy and Italy, considered as the sum of remaining regions excluded Lombardy. The empirical analysis conducted by mixed effects model and based on a longitudinal dataset where T2DM is clinically diagnosed, demonstrates the coexistent positive and negative association between particulate matter and T2DM incidence in Italy and Lombardy, respectively. The explanation deals with the nature of phenomena and the income and awareness effects on health.

Our findings constitute an important contribution by providing insights into an issue never investigated using outpatient data on T2DM that are not self-reported. It emphasizes the need to address more research on the effect of air pollution on T2DM, which could represent a barrier to achieving health equity. Our results show the need to implement public health measures to prevent T2DM by reducing risk factors and increasing awareness, especially for air pollution, strengthening the effort to foster responsible and sustainable individual behaviors toward the environment.

Future developments may involve using particulate matter data to investigate the causal relationship between particulate matter and T2DM, considering several potential confounding factors thanks to a collaboration research agreement with ISPRA which is being signed.

Declarations

Declaration of competing interest

None

Declaration of funding

No external funds were received

Data Availability

The data that support the findings of this study are available from AMD but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly
available. Data are however available from the authors upon reasonable request and with permission from AMD.

Particulate matter pollution data are available here: https://www.eea.europa.eu/en/analysis for Italy and here

https://www.arpalombardia.it/dati-e-indicatori/aria/ for Lombardy

**Author Contribution**

Both authors provided: Conceptualization, Methodology, Visualization, Investigation, Writing- Original draft preparation, reviewing and editing.

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### Figures

#### Scatterplots of prevalence rate by year, age in classes, sex and region

<table>
<thead>
<tr>
<th>Age Class</th>
<th>Year</th>
<th>Prevalence Rate</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>[44,54]</td>
<td>2010</td>
<td>1000</td>
<td>ITALIA</td>
</tr>
<tr>
<td></td>
<td>2015</td>
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<td>2010</td>
<td>2000</td>
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#### Figure 1

Prevalence rates for T2DM by age classes, regione (Lombardy vs Italy) and year.
Figure 2

Incidence rates for T2DM by age classes, region (Lombardy vs Italy) and year.
Figure 3

YLDs rates for T2DM by age classes, region (Lombardy vs Italy) and year.