Swiss TPH
Swiss Tropical and Public Health Institute
Schweizerisches Tropen- und Public Health-Institut
Institut Tropical et de Santé Publique Suisse

Associated Institute of the University of Basel

Baudirektion
Kanton Zürich
AWEL Amt für
Abfall, Wasser, Energie und Luft

Study of the effect of particulate matter (PM10) on emergency hospital admissions and mortality for the period of 2001 to 2010 and of nitrogen dioxide on mortality for the period of 1995 to 2010

Final report

Under the mandate of the cantons:

Aargau, Appenzell-Innerrhoden, Appenzell-Ausserrhoden, Basel-Landschaft, Basel-Stadt, Bern, Freiburg, Graubünden, Luzern, Nidwalden, Obwalden, Schaffhausen, Schwyz, Solothurn, St. Gallen, Tessin, Thurgau, Uri, Wallis, Zug, Zürich and Fürstentum Liechtenstein

Authors:
Dr. Laura Perez, Swiss TPH
Dr. Leticia Grize, Swiss TPH
PD Dr. Christian Schindler, Swiss TPH
Dr. Denis Infanger, Swiss TPH
Dr. Hansjörg Sommer, AWEL
Gian-Marco Alt, AWEL
Roy Eugster, AWEL
Dr. Robert Gehrig, Empa

Basel/Zürich, November 2013

Preliminary notes:

- The report consists of two documents:
  - The report itself, containing the relevant tables and figures in an appendix. This document stands by itself.
  - An annex which contains additional figures and tables with information that might be of interest for readers. Reference to figures and tables in the annex are preceeded by the letter A.

- All results are given for a 10 µg/m^3 increment in the respective exposure measurement (e.g. two-day mean of the pollutant concentration).

- The notions 'effect of PM10' or 'effect of NO_2' are used in the report to simplify terminology. They actually refer to the association between the respective pollutant and the outcome under consideration (number of emergency hospital admissions or deaths).

- The forest plots showing the results of the meta-analysis also show the uncorrected regional estimates for the effect of a pollutant. It is advised to use the 'combined' results also given in the plots rather than the respective region-specific estimates which are strongly influenced by chance.

- A glossary of terms which may not be clear to the reader is given at the end of the text, before the reference list.

Index

1 Short summary

This study was mandated by a consortium of 21 Swiss Cantons and coordinated by the Office of Waste, Water, Energy and Air (WWEA/AWEL) of the canton of Zurich. It aimed to evaluate the short term effects of PM10 and NO_2 on daily deaths and of PM10 on emergency hospital admissions for any medical, cardiovascular and respiratory causes.

The study was conducted over 13 geographical regions across Switzerland during the period 2001-2010 and included separate analyses for different age categories (entire population, population of persons between 15 and 65 years, population of persons above 65 years and population of persons above 75 years). This study was focused on the evaluation of short-term effects of air pollution only.

We found that despite a decline in levels of PM10 through the study period across most of the study regions, the associations between PM10 and daily emergency hospital admissions persisted. For the entire population, there was a 0.17% (95%-CI: 0.01 to 0.33%) increase in medical emergency hospitalizations for a 10 µg/m^3-increment in the two day mean of PM10. When extrapolated to the whole of Switzerland, this corresponds to 1 to 2 additional cases of medical emergency admissions per day. The daily number of cardiovascular emergency admissions increased by 0.43% (95%-CI: 0.12 to 0.73%) for a 10 µg/m^3 increment in the two day mean of PM10. The daily number of respiratory emergency admissions increased by 0.22% (95%-CI: -0.43 to 0.87%) for a 10 µg/m^3-increment in the four-day mean of PM10. Associations were of considerable size also among persons between 15 and 65 years and they were highest in the subpopulation of persons aged 75 or more. In this subpopulation, a 10 µg/m^3 increment in the four day mean of PM10 was associated with an increase in respiratory emergency admissions of 1.11% (95%-CI: 0 to 2.23%). These associations did not significantly change over the years and thus results from the previous study covering the years 2001 to 2005 were largely reproduced.

Similar estimates were found for daily mortality and PM10 and when using NO_2 as marker of pollution. However, the lag patterns of effects were different for emergency hospital admissions and mortality. While effects of PM10 on daily medical and cardiovascular emergencies occurred within 1 to 2 days, they showed a time lag of about two days for the respective numbers of deaths. On the other hand, immediate effects of PM10 on respiratory deaths could be observed while the corresponding effects on respiratory emergencies showed a time lag of two days.

Altogether, these findings suggest that the toxicity of air pollution has not substantially changed during the last 10 to 15 years in Switzerland, despite various changes in vehicle fleet and engine technology. The fact that short term increases in air pollutant levels were followed by comparable increases in numbers of emergency admissions or deaths from the beginning to the end of the study period, despite some overall improvements in air quality, supports the concept that there is no “safe level of air pollution” or “threshold of no effect”. However, results from cohort studies -such as SAPALDIA conducted over 8 cities in Switzerland- that follow a population over several years and measure changes in health or mortality rates during these periods show that sustainable improvements in air quality have beneficial effects on health in the long-term. It can thus be expected that efforts to further reduce air pollution will result in further acute and long-term health benefits across all regions of Switzerland. In particular, traffic-related air pollution ought to be the target of future policies as only minimal improvements in NO_2 were observed during the last 10 years and the effects of NO_2 on mortality were seen to be quite strong in the present study.

Bref résumé de l'étude sur l'influence à court terme des PM10 sur les hospitalisations d'urgence et la mortalité

La présente étude a été effectuée sur mandat des services de l'environnement de 21 cantons suisses. L'Office pour les déchets, les eaux, l'énergie et l'air du Canton de Zurich a coordonné l'étude, dont le but était d'examiner les effets à court terme des PM10 et du NO_2 sur les taux journaliers de décès, ainsi que l'influence des PM10 sur le nombre journalier d'hospitalisations d'urgences médicales, respiratoires ou cardio-vasculaires. Une étude précédente s'était déjà penchée sur les effets à court terme des PM10 sur les hospitalisations d'urgence dans les années 2001 à 2005.

Cette nouvelle étude se base sur les données de mortalité de la période 1995 à 2010 et sur les données des hospitalisations de 2001 à 2010 dans 13 régions en Suisse. Les analyses ont porté sur les causes médicales en général ainsi que sur les deux sous-groupes des maladies cardio-vasculaires et respiratoires. A côté des analyses détaillées comprenant tous les groupes d'âge, des analyses spécifiques ont été effectuées sur les groupes d'âge entre 15 et 65 ans, au-dessus de 65 et au-dessus de 75 ans. Toutes les analyses ont d'abord été conduites séparément par région, et ensuite les résultats régionaux ont été rassemblés.

Bien qu'en général le niveau des PM10 ait baissé durant la période d'examen, cette étude a relevé encore une fois les corrélations déjà observées dans la précédente étude entre les hospitalisations d'urgence médicale et la concentration des PM10. Ainsi, quoique les niveaux actuels soient plus bas, on a trouvé qu'une hausse de 10 µg/m^3 dans la moyenne sur deux jours de la concentration de PM10 correspondait à une augmentation du nombre des hospitalisations d'urgence médicales de 0.17% (IC 95%: 0.01 – 0.33%) (données totales). Ce chiffre extrapolé pour l'ensemble de la Suisse correspond à 1 à 2 cas d'hospitalisations d'urgence médicales par jour. L'augmentation correspondante pour les urgences cardiovasculaires était de 0.43% (IC 95%: 0.12 – 0.73%). Pour les urgences respiratoires une augmentation de 10 µg/m^3 dans la moyenne sur quatre jours était liée à une hausse de 0.22% (IC 95%: 0.43-0.87%). Les résultats correspondants pour le groupe d'âge de 15 à 65 ans étaient analogues.
Les résultats les plus évidents étaient ceux du groupe d'âge des plus de 75 ans, dans lequel la hausse de 10 µg/m^3 dans la moyenne sur 4 jours correspondait à une augmentation des urgences respiratoires de 1.11% (IC 95%: 0 – 2.23%). Ces corrélations n'ont changé que très peu au cours du temps, ce qui confirme dans une large mesure les résultats de l'étude précédente.

Des corrélations comparables ont été détectées en ce qui concerne les taux journaliers de mortalité.

De plus, les résultats ne changeaient pas de manière importante si l'on observait le NO_2 à la place des PM10 comme indicateur de la pollution atmosphérique. Par contre, les effets observés sur le nombre journalier de décès et sur les hospitalisations d'urgence se distinguaient par rapport à la période de latence. En ce qui concerne les hospitalisations d'urgence pour problèmes médicaux en général et pour les troubles cardio-vasculaires en particulier, les effets d'une augmentation de la concentration des PM10 étaient déjà visibles dans 1 à 2 jours. Par contre, les effets sur le nombre de décès se vérifiaient avec un retard d'au moins 2 jours. En ce qui concerne les urgences et les décès pour problèmes respiratoires, la situation était inversée. Ici, le taux de décès réagissait plus rapidement aux augmentations des PM10 que le nombre d'hospitalisations urgentes.

Ces résultats suggèrent que la toxicité de la pollution atmosphérique en Suisse n'a pas beaucoup changé dans les dernières 10 à 15 années, bien que dans cette même période le parc automobile et la technique des moteurs aient changé considérablement et que les niveaux de concentrations des polluants ait généralement diminué. Le fait que les corrélations entre les fluctuations journalières dans le nombre d'hospitalisations d'urgence et la concentration de polluants dans l'air n'aient pas diminué malgré l'amélioration de la qualité de l'air confirme l'opinion courante, selon laquelle les polluants de l'air peuvent avoir des effets nocifs sur la santé même en très basses concentrations. Par ailleurs, les résultats d'études de cohorte comme SAPALDIA, dans lesquelles de grands échantillons de population ont été observés pendant de nombreuses années à intervalles réguliers, montrent que des améliorations durables de la qualité de l'air ont – à long terme - un effet positif sur la santé. Par conséquent, chaque nouvelle réduction de la concentration de polluants atmosphériques en Suisse apportera un bénéfice supplémentaire à la population en termes de santé.

Au contraire des poussières fines, on n'a observé que des améliorations minimes dans les dernières années en ce qui concerne certains polluants de l'air liés au trafic, tels que le NO_2. Toutefois, justement pour le NO_2, on a trouvé une corrélation relativement forte avec le taux journalier de mortalité.
La politique sur la protection de l'air devrait donc continuer à concentrer ses efforts, dans les prochaines années, sur les émissions dues à la combustion, et en particulier au trafic routier et de plus en plus aussi aux chauffages au bois.

Kurzfassung der Studie über die Kurzzeiteffekte von PM10 auf die täglichen Zahlen der notfallmässigen Spitaleinweisungen und der Todesfälle in 13 Regionen der Schweiz

Die vorliegende Studie entstand im Auftrag der Umweltämter von 21 Schweizer Kantonen. Das Amt für Abfall, Wasser, Energie und Luft des Kantons Zürich koordinierte die Studie.
Ziel war es, Kurzzeiteffekte von PM10 und NO_2 auf die tägliche Zahl der Todesfälle zu untersuchen. Weiter untersuchte die Studie den Einfluss von PM10 auf die tägliche Zahl der notfallmässigen Spitaleinweisungen aufgrund medizinischer Ursachen. Eine Vorgängerstudie hatte sich bereits mit Kurzzeiteffekten von PM10 auf notfallmässige medizinische Spitaleinweisungen in den Jahren 2001 – 2005 befasst.

Die neue Studie stützte sich auf Mortalitätsdaten der Periode 1995 – 2010 und auf Spitaleinweisungsdaten der Periode 2001 - 2010 aus 13 Regionen der Schweiz. Die Auswertungen betrafen medizinische Ursachen allgemein sowie die beiden Untergruppen der Herz-Kreislauf- und der Atemwegserkrankungen. Neben den umfassenden Auswertungen, welche alle Altersgruppen einschlossen, zielten spezifische Auswertungen auch auf die Altersgruppen der 15 bis 65-jährigen, der über 65-jährigen und der über 75-jährigen Personen ab. Alle Auswertungen wurden zuerst nach Regionen getrennt durchgeführt. Anschliessend wurden die regionsspezifischen Resultate zusammengefasst.

Trotz der generellen Abnahme der PM10-Belastung während der Untersuchungsperiode blieben die in der Vorgängerstudie beobachteten Zusammenhänge zwischen täglichen medizinischen Notfalleinweisungen und PM10-Konzentrationen bestehen. So war auch bei den heute tieferen Konzentrationen ein Anstieg von 10 µg/m^3 im Zweitagesmittelwert der PM10-Konzentration mit einem durchschnittlichen Anstieg der Zahl der medizinischen Notfälle um 0.17% (95%-Vertrauensintervall: 0.01 – 0.33%) verbunden (Gesamtdaten). Extrapoliert auf die ganze Schweiz entspricht dies 1 bis 2 zusätzlichen medizinischen Notfällen pro Tag. Der entsprechende Anstieg bei den Herz-Kreislaufnotfällen betrug 0.43% (95%-VI: 0.12 – 0.73%). Bei den respiratorischen Notfällen war ein Anstieg von 10 µg/m^3 im Viertagesmittelwert der PM10-Konzentration mit einer Zunahme um 0.22% (95%-VI: -0.43 – 0.87%) verbunden. Die entsprechenden Resultate für die Altersgruppe der 15 bis 65-Jährigen waren von ähnlicher Grössenordnung. Am deutlichsten waren die Resultate in der Altersgruppe der über 75-jährigen. In dieser Altersgruppe war ein Anstieg von 10 µg/m^3 im Viertagesmittelwert der PM10-Konzentration mit einem Anstieg der respiratorischen Notfalleinweisungen um 1.11% (95%-VI: 0 – 2.23%) verbunden. Diese Zusammenhänge veränderten sich im Laufe der Zeit wenig. Somit wurden die Resultate der Vorgängerstudie weitgehend bestätigt.

Vergleichbare Zusammenhänge wurden für die täglichen Todesfälle gefunden. Die Resultate unterschieden sich zudem nicht wesentlich, wenn NO_2 an Stelle von PM10 als Indikator der Luftschadstoffbelastung betrachtet wurde. Hingegen unterschieden sich die beobachteten Effekte auf die täglichen Zahlen der Todesfälle und der Notfalleinweisungen in Bezug auf die Latenzzeit.
Bei den medizinischen Notfällen insgesamt und den Herz-Kreislauf-Notfalleinweisungen im Besonderen waren Auswirkungen erhöhter PM10-Konzentrationen innerhalb von ein bis zwei Tagen sichtbar, bei den entsprechenden Todesfällen hingegen erst mit einer zeitlichen Verzögerung von mindestens zwei Tagen. Bei den respiratorischen Not- und Todesfällen war die Situation gerade umgekehrt. Hier reagierte die Zahl der Todesfälle schneller auf Erhöhungen der PM10-Konzentrationen als die Zahl der Notfalleinweisungen.

Diese Befunde legen den Schluss nahe, dass sich die Toxizität der Luftverschmutzung in der Schweiz in den letzten 10 bis 15 Jahren nicht wesentlich verändert hat, obwohl in diesem Zeitraum ein beträchtlicher Wandel in der Fahrzeugflotte und der Motorentechnik stattgefunden hat und die Belastungen tendenziell zurück gingen. Dass die Zusammenhänge zwischen den täglichen Schwankungen in der Zahl der Notfalleinweisungen und in der Luftschadstoffbelastung trotz weithin verbesserter Luftqualität nicht abgenommen haben, bestätigt die vorherrschende Auffassung, dass Luftschadstoffe sogar bei sehr geringen Konzentrationen gesundheitliche Auswirkungen haben können. Andererseits zeigen Resultate aus Kohortenstudien wie SAPALDIA, in denen grosse Stichproben von Personen über viele Jahre beobachtet und in regelmässigen Abständen untersucht werden, dass nachhaltige Verbesserungen der Luftqualität sich langfristig günstig auf die Gesundheit auswirken. Somit wird auch jede weitere Senkung der Luftschadstoffbelastung in der Schweiz der Gesundheit der Bevölkerung zusätzlichen Nutzen bringen.

Anders als beim Feinstaub wurden bei gewissen verkehrsnahen Luftschadstoffen wie NO_2 in den letzten Jahren kaum mehr Verbesserungen beobachtet. Gerade bei NO_2 konnten wir aber relativ starke Zusammenhänge mit der täglichen Mortalität beobachten. Daher sollte sich die Luftreinhaltepolitik auch in den nächsten Jahren auf Emissionen aus Verbrennungsprozessen konzentrieren. Im Zentrum stehen der Strassenverkehr sowie zunehmend auch Holzfeuerungen.

2 Extended Summary

Introduction

The health effects of air pollution are now well recognized. On days following an increase in air pollution there is an increase in mortality, in urgent hospitalizations or in asthma symptoms, as an example. While those are referred as short-term effects, there is also evidence that living a major part of one's life in areas with higher air pollution has consequences for health also on the longer-term, such as reduction of life expectancy, the average time left to live.

While the pathophysiological pathways by which this happens are only partly elucidated, it is clear that the day to day short-term insults of air pollution to health certainly contribute in part to the long-term effects. In many countries and urban areas, great efforts have been conducted to reduce peaks of high air pollution levels, but also, as in Switzerland, to reduce overall pollution level and emissions. Understanding how population exposure changes and how this may affect the association between air pollution and health effects is of relevance for national and regional administrations in charge to control and mitigate air pollution.

In a previous study mandated by 16 cantons and co-ordinated by the Office of Waste, Water, Energy and Air (WWEA/AWEL) of the canton of Zurich, we investigated the association between short-term exposure to air pollution and emergency hospital admissions across 12 geographical regions which included 70% of the Swiss population. This past study covered the time period between 2001 and 2005 and PM10 (Particulate Matter with diameters up to 10 µm) was used as the marker of air pollution. We found that on average and across regions cardiovascular emergency admissions increased by 0.6% (95%-CI: 0.1 to 1.1%) and respiratory admissions by 0.5% (95%-CI: -0.4% to 1.5%) for a 10 µg/m^3 increment in the two and four day mean[1] of PM10, respectively. These results were very similar to those found in other short-term time-series studies conducted in urban areas in Europe.

Since 2005, Switzerland has pursued and reinforced its efforts to further improve air quality. It was timely to evaluate if this has resulted in changes in the short-term health effects of air pollution across Switzerland. The main aim of this newly mandated study by a consortium of 21 Swiss Cantons and coordinated by WWEA was to update the previous analyses and to evaluate if the short term effects of air pollution on the various outcomes changed or remained the same when covering a longer time period (2001-2010). The study was also extended to include analysis on short term effects of air pollution on mortality which were not assessed in the previous

[1] The two-day mean is defined as the average level of the pollutant over the day of the event and the day before the event and the four day mean as the average level of the pollutant over the day of the event and the three days preceding the event.

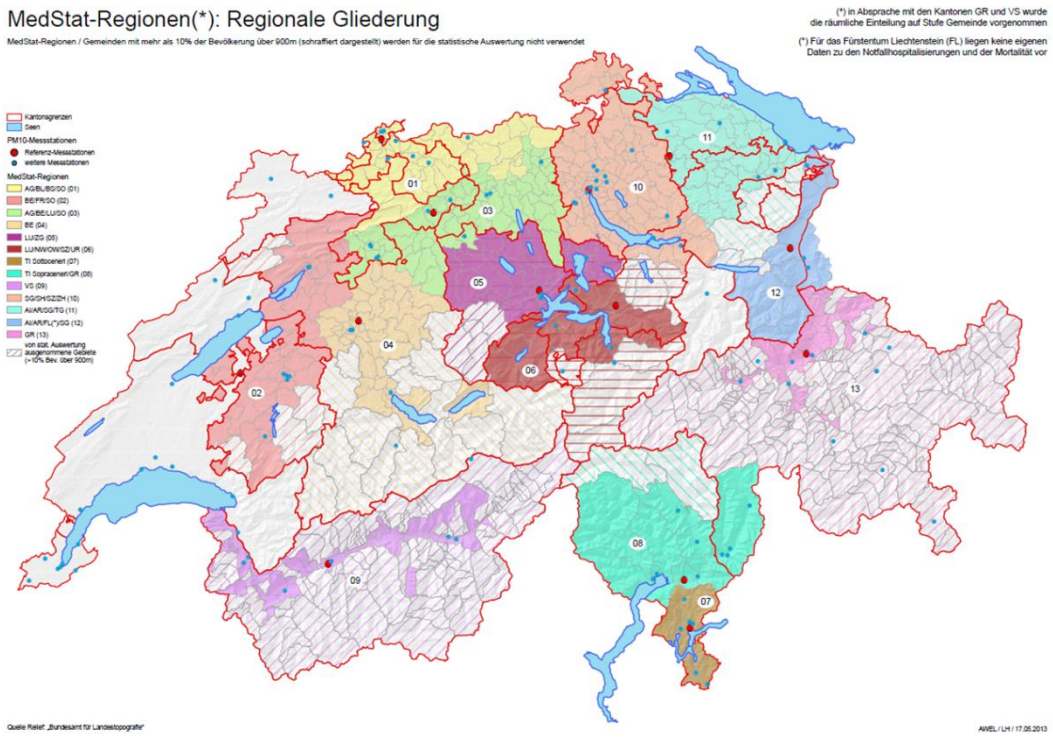
study. We also translated these new findings into the prevention potential that could have been achieved with two hypothetical but realistic abatement scenarios across the 13 regions that would have reduced air pollution to lower levels than those observed during the study period.

Methods

Study population

The study was conducted over 13 geographical regions (figure 1) accounting for a total of 5'943'575 inhabitants (2010 census) and covering a total of 21 cantons. As in the previous study, the regions were aggregated over MedStat regions (the smallest geographical region for which anonymized hospitalization data can be provided in Switzerland) with similar day-to-day variations in air pollution levels. As in the precedent study, populations living in MedStat regions more than 900 metres above sea level (msl) were excluded from the analysis. Therefore, data from the cantons of Valais and Grisons were provided at the community level.

Figure 1. The 13 analysis regions and their reference air pollutant measuring stations



Outcomes

The outcomes evaluated in the analysis included the daily number of emergency hospital admissions and daily mortality from any medical causes (ICD-10 codes C to E and G to R, excluding specific infectious and parasitic and all psychiatric diseases), cardiovascular causes (ICD-10

codes I00-I99 [excluding I67.3, I68.0, I88, I97.8, I97.9, I98.0], G45 [excluding G45.3], G46, M30, M31 und R58), and respiratory causes (ICD-codes: J00 to J98).

Pollutant indicator and selection of lag effect

As in the past study we conducted our main analysis using PM10 as main pollution indicator. Evidence shows that pollutants resulting from primary combustion processes may specifically be related to the toxicity of air pollution. For mortality, we repeated the analysis with NO_2, because of its availability for the years prior to 2000 and also for its property as an indicator of combustion-related pollution. For each region, the daily levels of pollutants were obtained from the most representative federal or cantonal monitoring station. Daily PM10 levels were available for the period 2001 to 2010 while NO_2 data were additionally available for the years 1995 to 2000.

It has been shown that the health effects due to increased levels of air pollution may not be immediate but may take a few days to develop and that these time patterns may depend on the cause and type of the event.

Based on the current literature and past results, we used as representative exposure the 2-day mean of PM10-concentration (i.e. the average of the 24hr-means of PM10 on of on the day of the event and on the day before the event) for any medical cause and cardiovascular events but a 4-day mean for respiratory outcomes (i.e., the average of the 24hr-means of PM10 on the day of the event and on the three days prior to the event).

Data sources

Anonymised individual emergency hospital admission data and mortality data with information on sex and age group were provided by the Federal Office of Statistics (FSO/BFS) and by the Statistical Offices of the cantons of Valais and Grisons. The air pollutant data were provided by the Federal Office for the Environment (FOEN/BAFU) and by the cantons, the meteorological data by the Federal Office of Meteorology and Climatology (MeteoSwiss) and the weekly data on influenza incidence by the Federal Office of Public Health (FOPH/BAG).

Statistical analysis

Short term effects of air pollution on daily counts of deaths or emergency admissions were analysed using statistical models referred as “Poisson regression models”. These models predict daily number of events as a function of air pollution levels and other predictor variables. The predictor variables considered in our analyses were temperature, humidity, barometric pressure, day of the week, season, and the presence of an influenza epidemic. The inclusion of such variables is important for increasing statistical precision and for obtaining valid estimates of the independent effects of air pollution which can then no longer be explained by these other factors.

The analyses were conducted at the region level. Separate models for all ages, ages between 15 and 65 years, ages above 65 years, and ages above 75 years were developed. Region-specific estimates by age and event category were then summarized into a single overall estimate using so called “meta-analytic” techniques. In this study only the summary results across all areas are reported. Differences in risk estimates across regions are at least in part due to random variations and should only be interpreted with caution.

Additional analysis

To refine our results we conducted a series of additional analyses that included (1) expanding the window of exposure from 2 days to up to 28 days prior to the event, (2) differentiate effects according to their latency period[2] (“polynomial lag models”), (3) evaluate whether the health effects of PM10 or NO_2 might have changed over the years, and (4) develop models with more than one pollutant (i.e. NO_2 added to PM10 models) to disentangle potential effects of different components of air pollution.

Assessment of the health impacts of PM10 and NO_2 under realistic abatement scenarios

To assess the prevention potential for hospitalizations and mortality that could have resulted from lower air pollution levels during the study period across the 13 regions, the risk estimates were used to predict the number of events under two different pollution abatement scenarios. These abatement scenarios were selected to represent realistic (i.e., achievable) goals across the study period and included (1) a reduction of daily levels of pollutants down to the daily maximum levels recommended by World Health Organization (WHO) and (2) a reduction of daily levels of pollutants by 20% on any day. Impact estimations were done, separately for each pollutant type, for mortality and hospitalization and for the entire and elderly population (i.e., persons aged 75 years or more).

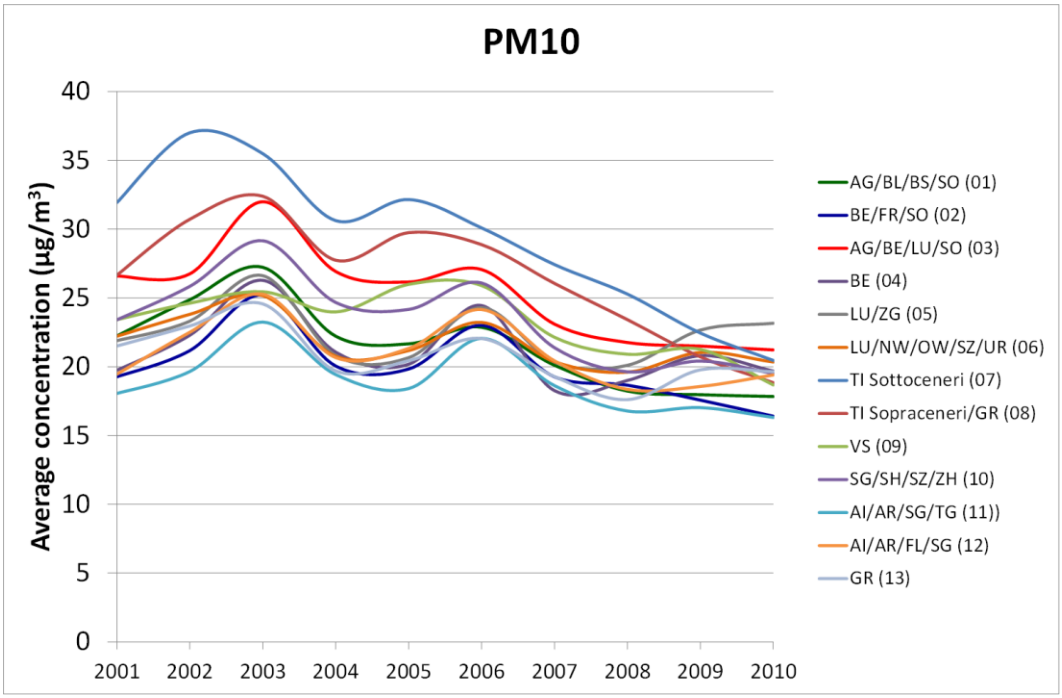
Results

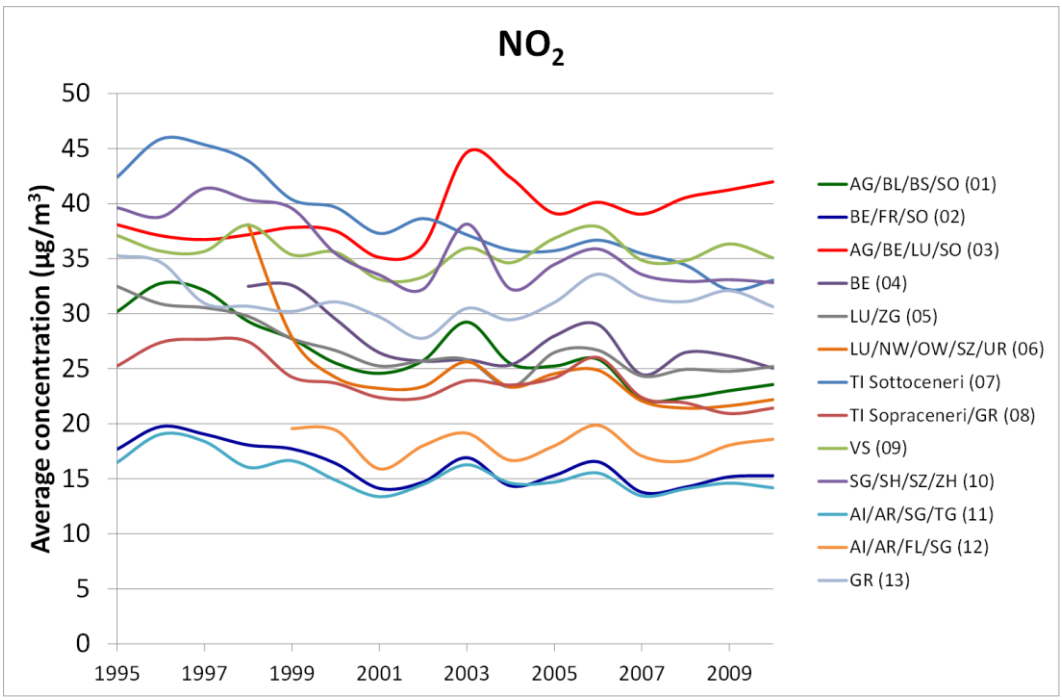
Changes in PM10 and NO_2 concentrations through time

Across all regions, a general decline in PM10 concentration with time (figure 2) was observed. In contrast, no decline was apparent across all regions or in any given region for NO_2.

Figure 2. Average yearly concentrations of PM10 and NO_2 through the study period and by study region

[2] The total observable effect of exposure on a given day is generally spread out over several consecutive days. Effects which are observable only after x days are said to have a latency period of x days.





Associations of daily emergency hospital admissions with PM10

There was a 0.17% (95%-CI: 0.01 to 0.33%) increase in the number of emergency hospitalizations from any medical cause for a 10 µg/m^3-increment in the two day mean of PM10[3]. The daily

[3] This result must be understood in the following way: If any two Mondays, Tuesdays, etc. are selected within a period of weeks and the two days differ by "x" µg/m^3 in their two day mean of PM10 while being indistinguishable with respect to meteorological and other conditions, then the numbers of emergency admissions from any medical cause will on average differ by (x/10)*0.17% on these two days according to this model. Thus, for x = 5 µg/m^3, the percentage difference in the number of events would be 0.085% and for x = 20 µg/m^3 it would be 0.34%.

number of cardiovascular emergency admissions increased by 0.43% (95%-CI: 0.12 to 0.73%) for the same increment in PM10. The daily number of respiratory emergency admissions increased by 0.22% (95%-CI: -0.43 to 0.87%) for a 10 µg/m^3-increment in the four-day mean of PM10 (table 1). While effects of PM10 on cardiovascular admissions did not show any delays, the corresponding effects on respiratory admissions showed a latency period of two days. Therefore, the four-day and not the two-day mean of PM10 was considered as primary exposure measure for the latter category of admissions.

The strongest effects were observed in the oldest population for all three outcomes, but effects were also quite strong among persons between 15 and 65 years. Statistically significant effects for respiratory hospitalizations were only seen in the older group. Estimating the effects of PM10 adjusted by levels of NO_2 in the same model led to an increase in the effects of PM10. This confirms that PM10 and NO_2 capture, at least in part, different aspects of the health relevant mixture of air pollution. Overall, there was little evidence for any time trends in short term effects of PM10 on emergency admissions over the examined 10 years, suggesting that the acute effects of PM10 are persisting over time despite decreases in PM10. This is an important observation given the changes in car fleet, engine technology and heating sources having occurred during this period. Apparently, these changes did not reduce the acute toxicity of the air pollution mixture. When looking at estimates by region, we observed effects of PM10 on respiratory emergency admissions to be particularly strong in the two study regions south of the Alps.

Table 1. Association between daily PM10 and daily emergency hospitalizations. Results are expressed as percentage change in daily hospitalization for each 10 µg/m^3 increase in the respective PM10 exposure measure

Age group	Daily emergency hospitalizations					
	Any medical cause (2-day average)		Cardiovascular causes (2-day average)		Respiratory causes (4-day average)	
	% change in number of cases (with 95% CI)		% change in number of cases (with 95% CI)		% change in number of cases (with 95% CI)	
All ages*	0.17	(0.01 to 0.33)	0.43	(0.12 to 0.73)	0.22	(-0.43 to 0.87)
15 to 64	0.27	(0.06 to 0.49)	0.46	(-0.12 to 1.04)	0.74	(-0.02 to 1.51)
≥ 65	0.20	(-0.01 to 0.42)	0.43	(0.07 to 0.79)	0.73	(-0.17 to 1.64)
≥ 75	0.33	(0.07 to 0.59)	0.64	(0.20 to 1.08)	1.11	(0.00 to 2.23)

* Effect estimates for all ages are smaller than those for the three specific age groups because of the inclusion of children below age 15. However, this does not explain the large difference for respiratory hospitalizations for which the effects of PM10 may not be well captured in a model encompassing all age groups.

Associations of daily mortality with PM10 and NO_2

For consistency reasons, the same primary time windows of exposure were used to estimate short term effects of air pollution on mortality and emergency admissions, i.e., a two-day mean for events from any medical causes and for cardiovascular events and a four-day mean for events from respiratory causes. There was a 0.2% (95%-CI: 0.1 to 0.6%) increase in the daily number of deaths from any medical cause for a 10 µg/m^3-increment in the two day mean of PM10. The daily number of cardiovascular deaths increased by 0.3% (95%-CI: -0.2 to 0.8%) for the same increment in PM10. The daily number of respiratory mortality increased by 2.7% (95%-CI: 0.2 to 3.3%) for a 10 µg/m^3-increment in the four-day mean of PM10 (table 2). Effects were similar across age groups. When repeating the analysis using NO_2 as marker of pollution, results were slightly higher for deaths for all medical causes and cardiovascular causes but were notably lower for respiratory causes. Estimating the effects of PM10 and NO_2 in the same model led to a decrease in both pollutant estimates, although estimates for NO_2 remained stronger than the ones for PM10. The analysis of trends showed that short term effects of PM10 on mortality had somewhat increased over time while effects of NO_2 had become slightly smaller. However, these trends were not statistically significant overall and should therefore not be over-interpreted. To substantiate these trends, a longer time series of 20 to 25 years will be necessary. While results for natural and for cardiovascular mortality were quite comparable across study regions, effects of PM10 on respiratory mortality were particularly strong in the two study regions south of the Alps.

Table 2. Association between daily PM10 and daily mortality. Results are expressed as percentage change in daily mortality for each 10 µg/m^3 increase in the respective PM10 exposure measure

Pollutant	Age group	Daily mortality					
		Any medical cause (2-day average)		Cardiovascular causes (2-day average)		Respiratory causes (4-day average)	
		% change in number of cases (with 95% CI)		% change in number of cases (with 95% CI)		% change in number of cases (with 95% CI)	
PM10	all	0.2	(0.1 to 0.6)	0.3	(-0.2 to 0.8)	2.7	(0.2 to 3.3)
	≥65	0.2	(-0.2 to 0.5)	0.1	(0.4 to 0.6)	2.8	(-0.1 to 3.5)
	≥75	0.4	(-0.1 to 0.8)	0.3	(0.3 to 0.9)	2.6	(0.1 to 3.6)
NO_2	all	0.7	(0.1 to 1.3)	0.4	(-0.1 to 0.8)	1.7	(0.5 to 5.0)
	≥65	0.6	(0.0 to 1.3)	0.3	(0.2 to 0.8)	1.7	(0.7 to 4.9)
	≥75	0.6	(0.0 to 1.2)	0.3	(0.3 to 0.8)	1.9	(0.4 to 4.8)

Assessment of the health impacts of PM10 and NO_2 under realistic abatement scenarios

There is considerable evidence that ratios between changes in event rates and changes in air pollutant levels are smaller over short periods of a few days than over long periods of several years. Therefore, the proportion of deaths and hospitalizations attributable to PM10-exposure should have decreased from 2001 to 2010 along with the concurrent average decrease in PM10 by 3.5 µg/m^3. In fact, using a recently developed risk function based on a thorough literature review of all studies on long-term associations between exposure to PM10 (rescaled from $PM_{2.5}$) and mortality, we can estimate that medical mortality would have been about 1% to 2% higher in 2010 without the decrease in PM10 observed between 2001 and 2010

However according to our estimates, about 700 hospitalizations for medical causes could have been additionally avoided if PM10 levels had been further abated to those hypothesized under scenario 1 (meeting WHO recommended daily levels). For scenario 2 (reducing air pollution by 20% on any given day) the corresponding number would have been about 3000 (table 3). This represents 0.03% and 0.15% of total hospitalizations, respectively. Similarly, the number of avoidable premature cardiovascular deaths among older ages was largest for scenario 2, with 760 or 0.32% of all deaths. Estimated numbers of preventable premature deaths were still higher when using NO_2 as marker of pollution, especially for scenario 2.

Table 3. Number of preventable hospitalizations and deaths achieved under different abatement scenarios for PM10 (for 7 day exposure window) during the study period 2001-2010

Cause	Age Group	Emergency hospitalizations		Deaths	
		Preventable number (with 95% CI)	% preventable (with 95% CI)	Preventable number (with 95% CI)	% preventable (with 95% CI)
Scenario 1: no daily concentration above 50 µg/m^3					
Any medical	All	735 (385 to 1085)	0.03% (0.02 to 0.05)	284 (133 to 435)	0.04% (0.02 to 0.06)
	≥ 75	401 (224 to 578)	0.06% (0.03 to 0.09)	309 (180 to 437)	0.06% (0.04 to 0.09)
Cardiovascular	All	118 (-30 to 266)	0.03% (-0.01 to 0.06)	174 (131 to 217)	0.06% (0.04 to 0.07)
	≥ 75	88 (-14 to 191)	0.04% (-0.01 to 0.09)	166 (127 to 204)	0.07% (0.05 to 0.09)
Respiratory	All	159 (25 to 292)	0.07% (0.01 to 0.12)	56 (-43 to 154)	0.12% (-0.09 to 0.34)
	≥ 75	177 (98 to 255)	0.24% (0.13 to 0.34)	67 (-28 to 162)	0.19% (-0.08 to 0.46)
Scenario 2: all daily concentrations are reduced by 20%					
Any medical	All	3269 (1390 to 5149)	0.15% (0.06 to 0.23)	1493 (731 to 2251)	0.21% (0.10 to 0.32)
	≥ 75	2003 (1085 to 2922)	0.31% (0.17 to 0.45)	1465 (831 to 2095)	0.31% (0.17 to 0.44)
Cardiovascular	All	624 (-142 to 1390)	0.14% (-0.03 to 0.31)	854 (371 to 1335)	0.29% (0.13 to 0.45)
	≥ 75	581 (60 to 1102)	0.27% (0.03 to 0.51)	760 (326 to 1192)	0.32% (0.14 to 0.51)
Respiratory	All	398 (-182 to 979)	0.17% (-0.08 to 0.41)	200 (15 to 385)	0.44% (0.03 to 0.85)
	≥ 75	573 (256 to 890)	0.76% (0.34 to 1.19)	226 (50 to 402)	0.64% (0.14 to 1.14)

Main conclusions

We updated and extended a previous analysis to evaluate if the short term effects of air pollution on emergency hospital admissions changed or remained the same when covering a time period between 2001 and 2010 instead of 2001 to 2005 and how effects on daily mortality compared to the effects on emergency admission. The main conclusions of this study are:

- While a decline in PM10 through time was observed across all the study regions, we still observed short term effects of PM10 on emergency hospital admissions and deaths for any medical, cardiovascular and respiratory causes. Thus, more people still die or must be hospitalized during periods of days with increased air pollution.
- Estimated short term effects of PM10 on mortality and emergency hospitalizations from any medical and from cardiovascular causes were of similar magnitude when expressed on a percentage scale. On the other hand, corresponding effects on respiratory mortality were considerably larger than those on respiratory emergency hospitalizations. Although cardiovascular diseases are more frequent in absolute numbers, one should not overlook the group of persons with underlying respiratory diseases because they are particularly susceptible to air pollution. As has been shown in other studies, we also found older populations to be at higher risk of hospitalization if air pollution increases.
- The risk estimates for the association between emergency hospitalizations and PM10 over the period 2001-2010 obtained in this updated analysis were similar to the ones previously obtained for the period 2001-2005. Yet, they are not directly comparable because the regions of analysis of the two studies were not identical.
- Overall, no significant changes in short term effects over the last decade were observed. Thus, the average percentage increase in emergency admissions after a given short term increase in PM10 or NO_2 has remained comparable. This suggests that the acute toxicity of air pollution has remained similar over time, despite changes in car fleet, engine and combustion technology.
- As in the analysis of the precursor study, effects of PM10 on respiratory emergency admissions were found to be particularly strong in the two study regions south of the Alps. And interestingly, we also found higher effects on respiratory mortality in these two regions.
- Short term effects of PM10 on mortality and hospital admissions showed different latency periods for cardiovascular and respiratory events. They were immediate for cardiovascular emergency admissions but showed a latency period of about two days for respiratory admissions. Thus, exacerbations of respiratory diseases may take a few days to develop while the cardiovascular system may react immediately. On the other hand, short term effects of PM10 on cardiovascular deaths also showed a latency period

of about two days. It is unclear how this different response of cardiovascular deaths and emergencies to short term changes in PM10 can be explained.

- When conducting mortality analyses combining PM10 and NO_2 in the same model, associations were slightly stronger for NO_2 than for PM10. This might point to a special role of traffic related pollution in these effects.
- The fact that the magnitude of acute effects did not decrease despite some overall improvements in air quality supports the concept that there is no “safe level of air pollution” or “threshold of no effect”.
- While short term increases in air pollution over few days may still have the same short term effects as 10 or 15 years ago, the gradual decreases of pollutant levels over time are likely to have led to a reduction in chronic effects, as findings from SAPALDIA and other cohort studies suggest.

In conclusion, considerable decreases in PM10 levels have been observed across 13 regions in Switzerland during the period 2001 to 2010. Despite these improvements, the short term effects of PM10 on hospitalizations and mortality remained unchanged and are of a magnitude seen in other urban areas with higher pollution levels. This indicates that the acute toxicity of air pollution did not decrease. Results from cohort studies- such as SAPALDIA conducted over 8 cities in Switzerland- that follow a population over time and measure mortality rates at the end of the period show that sustainable improvements in air quality have beneficial effects on health on the long-term.

It can thus be expected that efforts to further reduce air pollution will result in further short-term and long-term health benefits across all regions of Switzerland. In particular, traffic-related air pollution ought to be the target of future policies as no further improvements in NO_2 were observed during the last 10 years and the effects of NO_2 on mortality were seen to be quite strong in the present study.

3 Introduction

Studies on the relationship between air pollution and health are classified into short- and long-term studies.

Long-term studies (such as SAPALDIA[1-4]) monitor a relatively small study population (a cohort) over several years to assess potential long-term effects of air pollution on health outcomes. Long-term epidemiological studies are complex and often beyond the scope and money resources of local environmental agencies.

Short-term studies investigate effects of short term changes in air pollutant concentrations on health outcomes. These outcomes usually include daily death or emergency hospital admission counts and the observed effects are expressed as relative changes in daily mortality or emergency admission rates. Short-term effects are usually studied using time series analyses. A large study of this type was the Europen APHEA-project having included data from over 30 European cities[5, 6]. Switzerland contributed mortality but not emergency admission data from the three largest urban areas (Zurich, Geneva and Basel). Therefore, published results concerning Swiss data include only the effects of air pollution on mortality.

In a precursor study [7] of the present project, short term effects of PM10 on emergency admissions were studied across 12 regions of Switzerland for the period from 2001 to 2005. The results of these analyses have been summarized in a long and in a short report in 2009.

The aim of the current study was to extend the previous analyses as follows:

1) To increase the previous study time period for the association between PM10 and emergency hospital admissions from 2001-2005 to 2001-2010.
2) To enlarge the population under study by including additional geographic regions.
3) To include, in addition, mortality as an outcome and examine its association not only with PM10 but also with NO_2. For PM10, the respective study period was 2001-2010 and for NO_2 1995-2010.
4) To investigate whether the acute effects of air pollution on the outcomes changed or remained rather stable over the 10 or 15 year periods studied.
5) To determine the public health benefits which might have been achieved under different air pollution abatement scenarios.

The present study included two new regions, Grisons and Fribourg, whereas the the greater area of the lower Lac Leman basin did not participate in this study. Some of the existing regions were enlarged.

While the previous project had also considered subcategories of respiratory and cardiovascular emergency admissions, the present project has now focused on the main categories “all medical”, “cardiovascular” and “respiratory” causes. On the other hand, separate analyses have newly been performed for the age group of persons 15 to 64 years old.

Based on the results of the precursor study, the primary exposure window for PM10 and NO_2 extended over two days for all medical and for cardiovascular outcomes and over four days for respiratory outcomes, giving rise to the calculation of mean concentrations over the day of the event and the day before (referred to as 2-day mean) and over the day of the event and the three preceding days (referred to as 4-day mean). However, 7-day means and 28-day means were also considered. Our observation of respiratory events being associated more strongly with the 4-day than with the 2-day mean of PM10 or NO_2 may reflect longer latency periods between exposure and clinical manifestations in the respiratory as compared to the cardiovascular system. To substantiate these claims, the lag structure of effects over 7 days was explored for all three categories of events. This was done using the method of polynomial lag models.

As in the precursor study, models with simultaneous inclusion of PM10 and NO_2 were also computed to assess the degree of independence of the effects of the two pollutants.

As cited above, time-series analyses are an efficient and an economical way to evaluate the short-term effects of an exposure on health in a given city or region without having to interpret or extrapolate findings from other settings and different contexts [8]. It is possible to extend these analyses by translating their epidemiological information into the prevention potential expressed as the number of cases that would result from the change in exposure observed or hypothesized during the time-series study period. This can additionally support policy makers, decision makers and the general public to better understand the public health dimension of air pollution and the possible benefits of different clean air policy choices [9].
In the last part of the study, we estimated the short-term prevention potential for hospitalizations and mortality that would have resulted from lower daily PM10 and NO_2 levels between 2001 to 2010 and 1995 and 2010, respectively, in 13 regions in Switzerland, under two realistic air pollution abatement scenarios assuming strict respectation of daily concentration limits (scenario 1) or a general decrease of daily pollutant levels by 20% (scenario 2). We build on the well-known method of population attributable fraction (PAF) which consists in estimating the number of cases in a population that are attributable to an exposure or to a change in exposure [10]. To better take into account events which would have occurred a few days later anyway also without increased air pollution exposure, we considered longer exposure windows of 7 and 28 days,

respectively, and used the Poisson regression models directly for the estimation of the prevention potential across the 13 study regions associated with the two abatement scenarios.

4 Methods

4.1 Methods of population exposure assessment

4.1.1 Basic framework and general concepts

The present study aims to assess the short term effects of exposure to ambient air pollutants on morbidity and mortality.

Daily counts of emergency hospital admissions and deaths were used, respectively, as indicators of daily morbidity and mortality. These counts were calculated for different age groups and cause categories. Data were provided by the Federal Office of Statistics at the level of individual persons in anonymised form. Emergency admission data included the age of the person, the diagnosis at admission and the so-called MedStat region of residence[4]. For the present study, only MedStat regions with reliable daily air pollutant exposure estimates could be considered. These estimates had to be obtained from a fixed monitoring station within the study region or in its surroundings. Since the MedStat regions are the building blocks of the study regions, care had to be taken that only MedStat regions with similar short term profiles of air pollutant exposure were combined into a given study region. It was not required that all MedStat regions within a study region had the same average exposure levels, but day-to-day changes in pollutant levels had to be similar across all of them. By the same token, the reference monitoring station of a given study region did not have to reflect the average exposure level of the region but had to represent well the regional average of the day-to-day changes of pollutant levels.

4.1.2 MedStat Regions

The definition of study regions must be based on the smallest geographic units defined by the Federal Office of Statistics for the hospital admission data. While information on residence is provided at the community level in mortality records, it is provided in wider geographic categories, so-called MedStat-regions, in hospital admission records due to data protection reasons. The places of residence of the population of Switzerland are divided into 706 MedStat regions, each combining several zip code areas. For two of the study regions, Grisons and Valais, hospital admission data were provided at the community level by the respective Cantonal Offices of Statistics. Therefore, the study regions of these two cantons could be defined in a more refined way. This was necessary because one of the requirements for the inclusion of a MedStat region was that more than 90% of its population live at an altitude of less than 900 m asl. In the two afore mentioned cantons, this would have led to the exclusion of most MedStat regions.

[4] Individual hospitalisation data collected by the Federal Office of Statistics are geographically categorized into 706 regions of residence referred to as MedStat regions.

4.1.3 Characteristics of PM10-exposure

In densely populated areas of Switzerland, the spatial distribution of annual mean concentrations of PM10 is quite homogeneous when compared to that of NO_2. This is true for modelled and measured data. When excluding data from monitoring stations over 900 m asl, the ratio between the highest and the lowest annual means measured between 2001 and 2010 was about 2:1. In contrast, daily exposure levels show a much stronger variation. Maximal daily concentration levels generally exceed annual average levels by a factor of 5 to 8. Nevertheless, day-to-day variations in PM10-levels show good correlations across many of the monitoring stations within and in proximity of the 13 study regions, with 40% of correlations reaching R2-values of 0.7 and higher. A closer look to nine regions, excluding the region of Tessin and mountain areas, shows that 70% of the correlations reach that level. When considering correlations across NABEL stations, whose measurements are characterised by highly standardised technology, R2-values of pairwise comparisons are above 0.7 (excluding the stations of Lugano, Magadino, Rigi and Chaumont).

Among the factors responsible for temporal variation in air pollutant levels, emissions only account for a small fraction of this variation. The major part of the variation is explained by meteorological factors. Inversion situations, rain and wind force, and to a lesser extent also wind direction, are strong determinants of daily PM10-levels. These factors are generally quite homogeneous across the central plateau while conditions may be quite different in alpine valleys due to the special topography. Here, local wind systems including föhn may have a strong influence on daily PM10-levels.

With regard to short term effects of air pollution on health, inversion situations are of particular importance:

- As a consequence of the blocked vertical exchange of air masses during inversion situations, PM10 concentrations may quickly rise to high levels below the inversion layer if such situations last several days. In contrast, pollutant levels above the inversion layer decrease during such phases.
- As long as the majority of the population of a MedStat region lives below the inversion layer, its exposure during inversion situations is well represented by a local monitoring station located below the inversion layer as well. The same would hold true also if the majority of the population lived above the inversion layer and a monitoring station located above the inversion layer were used to measure its exposure. However, if considerable fractions of the population of a MedStat region are living on both sides of an inversion layer, their exposure cannot be well represented by one monitoring station only. Based on balloon measurements

by MeteoSchweiz in Payerne, an average inversion layer altitude of 900 m asl was determined.

4.1.4 PM10-measurements

4.1.4.1 Measuring methods

In practice, PM10-data are obtained using two different procedures, automatised measurements and manual processing of samples.

The manual gravimetric method (e.g., HiVol) consists in weighing of filters before and after sampling of the PM10 fraction in a conditioned environment. The conditioning and weighing procedure requires several days and makes it impossible to provide real-time information to the public.

In contrast, automatised measurements (e.g., TEOM, Betameter) provide continuous real time measurements of PM10 which are immediately available for information to the public. However, since the measurement principles of the automatized procedures differ from the reference method, these data may need to be post-processed, especially regarding peak concentrations (see below).

4.1.4.2 Reference methods

The European standard EN 12341 for PM10 measurements defines a manual gravimetric assessment as reference procedure. Switzerland has adopted this standard. The recommendations for the measurement of ambient air pollutant levels, issued by the Federal Office for the Environment (FOEN/BAFU) in January 2004 include instructions for the correct measurement of PM10.

If methods deviating from the reference procedure are used, the respective responsible agency must prove that these methods provide results that are equivalent to the reference procedure. In addition long-term experience with automatic monitors has shown that even after a successful equivalence test periodic parallel measurements with the gravimetric reference methods are necessary because the relations between the automatic system and the reference method can vary with time and season. It is, therefore, not possible to use a fixed correction factor over a longer time period.

Without periodic parallel measurements, adjustments of measurement data obtained with automatic monitors with the purpose of making them consistent with data from gravimetric procedures are of limited validity.

4.1.4.3 Comparability of measurements from different techniques

In practice, data obtained from different measurement procedures may show considerable differences, in particular at the daily level. The differences and ratios between monitors and the

reference method are often not constant over time (see above) and may also be different for instruments of the same type.

Moreover, since 2004, particle mass need to be expressed related to actual conditions (temperature, barometric pressure) whereas concentrations of gaseous pollutants still relate to standard conditions (e.g., 20°C/1013hPa). Unfortunately, not all of the monitoring agencies have retrospectively adjusted their PM10 data collected before 2004, therefore comparability of PM10 data for the period 2001 – 2003 is lower than for the period after 2003. However, the effect of this inconsistency is usually quite small (< 2%).

The uncertainties associated with the different measuring procedures rather favor the use of data from the NABEL-stations. First of all, these stations guarantee complete coverage of the entire study period, and secondly they use the reference procedure in a completely standardised way.

The following hierarchical list, starting with the highest preference, was developed in collaboration with the Swiss Federal Laboratories for Materials Science and Technology (Empa).

- Gravimetric measurements according to reference method (e.g., HiVol)
- TEOM or Betameter measurements with corrections based on parallel measurements with the reference procedure (NABEL-Method)
- TEOM FDMS measurements (only since 2004)
- TEOM or Betameter measurements corrected using models (e.g. energy model, period model, linear model or model with a quadratic correction factor).

4.1.5 Definition of statistical analysis regions

4.1.5.1 Requirements on the analysis regions

As outlined before, the variations of daily air pollutant concentrations must be estimable for all MedStat regions.

The limited number of monitoring stations and statistical constraints imply that MedStat regions with similar temporal patterns of PM10-variation are combined into larger regions, each represented by one reference monitoring station. These regions are referred to as analysis regions because data are analysed separately for each of them.

Analysis regions must satisfy the following requirements:

1. Day-to-day variations in air pollutant exposure should be as homogeneous as possible across the entire region. Thus, some differences in average levels are allowed as long as day-to-day differences are similar.
2. For statistical reasons, the average daily counts of deaths and emergency admissions in a given analysis region must not be too small.

3. There must exist a suitable monitoring station within the analysis region or in its proximity which represents well the day-to-day changes in the ambient PM10-exposure of the respective population.

4.1.5.2 Procedures used to define the analysis regions

A first coarse division of the total area of all participating cantons into analysis regions was based on the topography and on the available monitoring stations. If possible, boundaries of regions were drawn along cantonal borders. In a second step, MedStat regions with more than 10% of the population living 900 meters or more asl were excluded (cf. 4.1.3).

From the point of view of representativeness of the reference stations, analysis regions should ideally be rather small, while statistical considerations require them to be of sufficient size. This makes compromises inevitable. The validation of requirement 1) of 4.1.5.1 was done by comparing the time series of daily PM10-measurements across different monitoring stations within or in proximity of the respective analysis region. The similarity of the temporal variation patterns of two measurement series was characterized by their R2-value and by the standard deviation of the differences between their daily means.

4.1.5.3 Characterisation of population exposure within an analysis region

Reference stations for the different analyses regions were selected according to the following criteria which aimed to guarantee at best the representativeness of the daily changes in PM10 exposure experienced by the respective populations.

- Availability of data
- Measurement procedure
- Plausibility of the course of annual mean levels of PM10
- Correlations with other stations
- Representativeness of the site of the reference station
- Proportion of the population of the analysis region living within a perimeter of 5 km of the reference station
- Standard deviation of the differences of the daily means of PM10-concentration between the reference station and other monitoring stations in the same region or in its proximity

Small gaps in the time series of daily PM10-measurements were filled by an imputation algorithm using data from other monitoring stations in sufficient proximity. If measurements from stations using different procedures than the reference station were necessary, they were adjusted to the reference station method accordingly.

4.1.5.4 Analysis regions and their reference monitoring stations

Region 1: BS/BL (including SO and AG northern Jura)

Reference station: Basel Binningen (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter; since 2009: TEOM 8500 FDMS / Microbalance

Region 2: FR+ BE lake and Jura regions

Reference station: Station Payerne (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter; since 2009: TEOM 8500 FDMS / Microbalance

Region 3: SO + AG + BE (northern region)+ Wiggertal (partly of LU), excluding northern Jura region of SO and AG

Reference station: Härkingen (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter; since 2008: TEOM 8500 FDMS / Microbalance

Region 4: BE (Excluding northern and northwestern regions)

Reference station: Bern Ittingen (Cantonal station) - Thermo ESM Andersen FH 62-IR / Betameter; since 2009: TEOM 8500 FDMS / Microbalance

Region 5: Z_CH_Nord (Luzern, Zug)

Reference station: Ebikon Sedel (Cantonal station) - until 2007: TEOM 1400AB SES; since 2007: TEOM 1400AB FDMS

Region 6: Z_CH_Sued (NW, OW, UR, SZ excluding SZ March)

Reference station: Schwyz (Cantonal station) – until 2004: TEOM 1400AB SES; since 2004: TEOM 1400 AB FDMS

Region 7: TI Sottoceneri

Reference station: Station Lugano (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter; since 2009: TEOM 8500 FDMS / Microbalance

Region 8: TI Sopraceneri + Valle Mesolcina (GR)

Reference station: Standort Magadino (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter; since 2010: TEOM 8500 FDMS / Microbalance

Region 9: VS

Reference station: - Sion (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter

Region 10: ZH + SH + SG March and SZ March

Reference station: Zürich (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter; since 2008: TEOM 8500 FDMS / Microbalance

Region 11: TG, AI, AR and SG, excluding Toggenburg, March, Sarganserland and Rheintal

Reference station: Tänikon (NABEL) - Thermo ESM Andersen FH 62-IR / Betameter; since 2010: TEOM 8500 FDMS / Microbalance

Region 12: SG Rheintal, Sarganserland, AI, AR and Liechtenstein

Reference station: Grabs (Cantonal station) - until 2009: Digitel DHA-80; 2009: Thermo TEOM1400 / FDMS / TEOM

Region 13: Graubünden (excluding Valle Mesolcina / Valle Calanca)

Reference station: Chur (Cantonal station) - Digitel HVS; 2003: Eberline FH62; 2010: TEOM FDMS / TEOM

4.2 Mortality, hospital admission and influenza data

Every hospital of Switzerland is required to keep records of all individual hospitalisations and to provide these data in anonymised form to the Cantonal Statistical Offices and to the Federal Office of Statistics. These data include socio-demographic (sex, age, region of residence), administrative (insurance status) and medical (cause of admission, treatments) patient information. As outlined before, residential information is provided in relatively broad geographic categories, so-called MedStat regions. For most of the analysis regions, hospital admission data were provided by the Federal Office of Statistics, but for two regions (i.e., Valais and Grisons), the data was provided by the respective cantonal offices at the level of the community of residence. Without this refined residential information, large fractions of the populations of these two regions would have had to be excluded because many of their most populated MedStat regions violate the criterion of less than 10% of their inhabitants living 900 m or more above sea level.

Mortality is reported to the Federal Office of Statistics by the communal authorities. Data include socio-demographic, medical and residential information. The postal code of the place of residence at the time of death was provided.

Data on influenza incidence at the cantonal level are collected by the Swiss sentinel network of the Federal Office of Health. Participating physicians from all parts of Switzerland report weekly numbers of patient contacts in different diagnostic categories.

4.3 Data sources and data bases

Air pollutant data were provided by the Federal Office for the Environment (FOEN / BAFU) and by the cantons. Daily mean values of PM10, NO_2 and O_3, and daily maxima of hourly O_3 concentrations of all regional reference stations were provided for the period 2001 - 2010. In addition, daily means of NO_2 were also provided for the period 1995 – 2000.

Meteorological data, daily mean values of temperature, relative humidity and barometric pressure, were provided by the national weather service of Switzerland (MeteoSwiss).

Emergency hospital admissions data including the date of admission, sex, age group, MedStat region of residence and cause of admission, were provided by the Federal Office of Statistics (FSO/BFS) for the period 2001 – 2010 at the level of individual events. For the two regions of Valais and Grison, the respective data were provided by the Cantonal Offices of Statistics.

Individual mortality data were available from the Federal Office of Statistics for the years 1995 to 2010. Data included date of birth, date of death, sex, postal code of residence and underlying cause of death. Weekly data on influenza incidence, number of doctor consultations related to influenza per 1000 doctor consultations, at the cantonal level were provided by the Federal Office of Public Health (FOPH / BAG).

4.4 Statistical analyses

4.4.1 Hospital admission data

The following hospital admission variables, defined at the level of analysis regions, were considered:

1. The daily number of emergency hospital admissions from the majority of medical causes (ICD-10 codes C to E and G to R, excluding specific infectious and parasitic and all psychiatric diseases).
2. The daily number of emergency hospital admissions from cardiovascular causes (ICD-10 codes I00-I99 (excluding I67.3, I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31 and R58).
3. The daily number of emergency hospital admissions from respiratory causes (ICD-codes: J00 to J98).

Separate analyses for the following age groups were conducted:

a) All ages.
b) Ages below 15 years.
c) Ages between 15 and 65 years.
d) Ages above 65 years.
e) Ages above 75 years.

Due to the small number of events in the youngest age group of children between 0 and 14 years, only descriptive but no time series analyses were performed for this age group.

4.4.2 Mortality data

The following mortality variables, defined at the level of analysis regions, were considered:

4. The daily number deaths from medical causes (ICD-10 codes C to E and G to R, excluding specific infectious and parasitic diseases and all psychiatric diseases).
5. The daily number of deaths from cardiovascular causes (ICD-10 codes I00-I99 (excluding I67.3, I68.0, I88, I97.8, I97.9, I98.0), G45 (excluding G45.3), G46, M30, M31 und R58).
6. The daily number deaths from respiratory causes (ICD-codes: J00 to J98).

Separate analyses for the following age groups were conducted:

f) All ages.
g) Ages above 65 years.
h) Ages above 75 years.

4.4.3 Meteorological variables

Meteorological influences on daily counts of emergency admissions and deaths were modelled using the 24-hr means of temperature, relative humidity and barometric pressure of the event day and the two days preceding the event.

4.4.4 Influenza epidemics

Influenza epidemics lead to an increase in the numbers of daily deaths and medical emergency admissions. Therefore, these effects need to be taken into account when studying short term effects of air pollution on these daily counts. In the present study the daily intensity of an influenza epidemic is estimated by the proportion of physician-patient contacts relating to influenza obtained from the Swiss sentinel network. Since these proportions are available at the level of cantons and weeks, they were smoothed using a seven day moving average for each canton. Moreover, population-weighted means of cantonal proportions were derived for analyses regions belonging to more than one canton.

4.4.5 Statistical model

Short term effects of air pollution on daily counts of deaths or emergency admissions are generally analysed using Poisson regression models. These models describe the natural logarithm of the expected daily event count of interest as a function f of values of the predictor variables on the event day and days preceding the event. In the simplest case, this function is a linear combination of predictor values, but generally, the function is more complex. In our models, these variables include the index of the event day in the chronological order of days, the 24 hr means

of temperature (T_t, T_{t-1}, T_{t-2}) relative humidity (RH_t, RH_{t-1}, RH_{t-2}) and barometric pressure (P_t, P_{t-1}, P_{t-2}) on the day of the event t and the two preceding days t-1 and t-2, the proportion of physician-patient contacts relating to influenza INF_t, indicator variables for the different days of the week, MO_t, …., SA_t, and an indicator variable for holidays, HO_t, in addition to the variable(s) representing air pollution exposure. Formally, the function f can be described as follows:

$$
\begin{aligned}
f(t) = \alpha + \beta_1 MO_t + \beta_2 TU_t + \beta_3 WE_t + \beta_4 TH_t + \beta_5 FR_t + \beta_6 SA_t + \beta_7 HO_t \\
+ f_1(t) \\
+ f_2(INF_t) \\
+ f_3(T_t, T_{t-1}, T_{t-2}; RH_t, RH_{t-1}, RH_{t-2}; P_t, P_{t-1}, P_{t-2}) \\
+ \gamma\, PM10_t
\end{aligned}
$$

For instance, the variable WE_t is defined as follows: if day t is a Wednesday, then $WE_t = 1$ and $MO_t = TU_t = TH_t = FR_t = SA_t = 0$. The variable HO_t equals 1 if the respective day t is a holiday and 0 on all other days.

The function $f_1(t)$ was modelled as a cubic spline, i.e., a function consisting of a sequence of locally defined cubic polynomials with seamless and smooth transitions between each other. This function describes longer term time trends and seasonal variations in the natural logarithm of daily hospital admission counts. The function f_2 (INF_t) describes the influence of influenza frequency on the natural logarithm of daily hospital admission counts. It was modelled as a cubic polynomial of INF_t.

Meteorological influences were modelled using a polynomial function of degree 2 of the variables T_t, T_{t-1}, T_{t-2}, RH_t, RH_{t-1}, RH_{t-2}, P_t, P_{t-1} and P_{t-2} , additionally including the squares of these variables as well as the pairwise products T_tRH_t, $T_{t-1}RH_{t-1}$, $T_{t-2}RH_{t-2}$, T_tP_t, $T_{t-1}P_{t-1}$, $T_{t-2}P_{t-2}$, P_tRH_t, $P_{t-1}RH_{t-1}$, $P_{t-2}RH_{t-2}$, This function thus involved 27 parameters.

In concordance with the European APHEA-study, the primary PM10-variable was defined as the mean of $PM10_t$ and $PM10_{t-1}$. However, for respiratory emergency admissions and deaths, the four day mean of PM10, i.e., the mean of $PM10_t$, $PM10_{t-1}$, $PM10_{t-2}$ and $PM10_{t-3}$ was found to be a better predictor than the two day mean in the precursor study.

Following the APHEA2-protocol, the number of local polynomials defining f_1 was determined based on the requirement that correlations between residuals be minimised. This is a natural criterion for a good model fit. A predominance of positive correlations would indicate an insufficient fit and a predominance of negative correlations an overfit. If it was not possible to get rid of significant positive correlations among residuals of neighboring days without creating a pre-

dominance of negative correlations at longer lags, one or more autoregressive terms[5] were additionally included in the model.

In some regions, a marked increase in hospital admissions between 2001 and 2002 was observed, Moreover, there was a marked increase in hospital admissions in analysis region 3 from 2009 to 2010. These changes were modelled using indicator variables for the periods after the change.

The function $E(Y_t) = \exp(f(t))$ provides a prediction of the daily number of emergency hospital admissions based on the values of the predictor variables for the respective day t. However, this prediction is correct only on average. If the daily number of cases Y_t truly followed a Poisson distribution with mean $E(Y_t)$, then the variance of $Y_t - E(Y_t)$ (i.e., the residual or the prediction error) would be equal to $E(Y_t)$. However, the variance of the prediction error tends to be larger than $E(Y_t)$, a phenomenon referred to as over-dispersion. Such over-dispersion leads to biased standard errors, p-values and confidence intervals and therefore requires suitable posterior adjustments.

All analyses were first stratified by analysis region. Then, the region-specific estimates were summarized into an overall estimate using meta-analysis. This was done in two ways, once without and once upon taking into consideration potential heterogeneity of estimates across regions. In statistics, heterogeneity refers to a situation where observed differences are statistically significant. In meta-analysis, the influence of an individual result on the summary result is positively related to its statistical precision and thus to the inverse of its standard error. However, this relation is attenuated in the presence of heterogeneity. I the case of strong heterogeneity, all individual results will have similar influences on the summary result.

At last, the region-specific estimates were corrected toward the meta-analytic summary estimate using empirical Bayes methodology. In contrast to the original estimates which were derived without taking into account information from other analysis regions, empirical Bayes estimates incorporate all available information. Therefore, they are more robust than the original estimates. Notice, however, that the forest plots contain the uncorrected regional estimates.

[5] Model residuals of one or more days preceding the event. Residuals are defined as differences between observed and predicted daily counts.

Analyses were performed using the following statistical programs: SAS (Version 9.3, 2010, SAS Institute Inc., Cary NC, USA), R (Version 3.0.0, 2014, The R foundation for Statistical Computing, Vienna, Austria) and STATA (Version 12.1, 2011, Stata Corp. LP., College Station TX, USA).

4.4.6 Statistical significance and confidence intervals

Associations with a p-value < 0.05 were considered statistically significant.

The p-value is computed under the so-called null-hypothesis that the observed association reflects sampling error only in the absence of any true underlying association. The p-value equals the probability with which an association of at least the same magnitude would have had to be expected under the null-hypothesis. The lower the p-value, the stronger the evidence against the null-hypothesis and in favour of the alternative hypothesis asserting that at least part of the observed association reflects a true underlying pattern. The statistical precision of an effect estimate is expressed by its 95%-confidence interval, which includes the effect estimate and has the property that the true underlying effect is covered in 95% of all studies.

4.4.7 Refined analyses involving longer exposure periods

Based on experiences from the precursor project, PM10- and NO_2-exposure was primarily represented using the two day or the four day mean. The two-day mean is the average of the 24hr concentration means of the respective pollutant on the event day (lag 0) and the day before (lag 1). This exposure measure was found to be a good predictor of medical and of cardiovascular emergency hospital admissions whereas the four day mean, additionally involving the 24hr concentration means at lags 2 and 3, appeared to be a better predictor of respiratory emergency admissions. The two day mean was used as the standard exposure measure in the APHEA2 study. In addition, we conducted analyses with the 7-day mean (involving lags 0 to 6) and the 28-day mean (involving lags 0 to 27). Analyses with the 28-day mean were done in view of subsequent health impact assessments.

In addition, polynomial distributed lag models were computed and graphically represented. Here, the total effect of PM10 (or NO_2)-exposure observable on day t was modelled in the form

$$\text{effect} = p(0) \cdot PM10(t) + p(1) \cdot PM10(t-1) + p(2) \cdot PM10(t-2) + \ldots + p(L) \cdot PM10(t-L)$$

with p(l) denoting a polynomial of third degree, i.e.,

$$p(l) = \beta_0 + \beta_1 \cdot l + \beta_2 \cdot l^2 + \beta_3 \cdot l^3 \qquad (l = 0, 1, 2, \ldots, L)$$

and L = 6 or 27.

The parameters β_0, β_1, β_2 and β_3 were estimated along with all other parameters of the model.

The coefficient p(l) is the estimated effect per unit increase in PM10(t-l) which is observable on day t and thus with a latency period of l days.

Such models enable assessing the relative importance of increased exposure levels on different preceding days. The meta-analysis of the polynomial lag models was done in two ways:

a) by meta-analyzing regional estimates of p(l) separately for each of the lags 0, 1, …, L
b) by meta-analyzing the vector of parameter estimates $(\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, \hat{\beta}_3)$ across analysis regions

Method a) was used in the analysis of mortality data and method b) in the analysis of hospital admission data.

4.4.8 Models of combined influence of PM10, NO_2 and ozone.

To some extent, the parallel inclusion of PM10 and NO_2-exposure in the same model enables disentangling effects of different components of air pollution. In particular, NO_2 is more strongly associated with traffic sources than PM10. This will be addressed in the discussion. For consistency reasons, all two-pollutant models included the same type of PM10- and NO_2- variable (i.e., the two day mean for medical and cardiovascular events and the four day mean for respiratory events). In the case of emergency hospital admissions, an additional analysis consisted in estimating parallel polynomial distributed lag models for PM10 and NO_2.

Parallel effects of NO_2 and ozone were investigated for mortality only. This was because of the strong focus on NO_2 in the mortality time series analyses where air pollution exposure could only be represented by NO_2 for the years before 2001.

4.4.9 Analysis of time trends

To address the question whether short term effects of PM10 or NO_2 might have changed over the 10 or 16 years studied, an interaction term between the respective pollutant variable and the calendar time variable t was additionally introduced into the model. Thus, the effect of the respective pollutant X was modelled as follows:

$$\text{effect}(X(t)) = \gamma_0 \cdot X(t) + \gamma_1 \cdot X(t) \cdot t$$

Depending on the sign of γ_1, the effect increases ($\gamma_1 > 0$) or decreases ($\gamma_1 < 0$) over time.

Meta-analysis of the regional estimates of γ_1 showed whether there was a significant overall trend or not. By meta-analyzing the estimates of effect(X(t)) for 1000 values of t in the respective time interval (i.e., of 16 years for NO_2 and of 10 years for PM10), and plotting the resulting summary estimates against calendar time t, the change in effect(X(t)) over time could be graphically represented. To assess potential non-linearities of such time trends, we additionally

included a term $\gamma_2 \cdot X(t) \cdot t^2$ into the model. In case of significant time trends, separate time trend analyses were conducted for the summer and the winter season (i.e., for the periods May to October and November to April, respectively). Analyses were not stratified by season for this purpose. Instead, a model with the following terms was considered

$$\begin{aligned} \text{effect}(X(t)) = {} & \gamma_{01} \cdot X(t) \cdot \text{SUMMER}(t) + \gamma_{02} \cdot X(t) \cdot \text{WINTER}(t) \\ & + \gamma_{11} \cdot X(t) \cdot t \cdot \text{SUMMER}(t) + \gamma_{12} \cdot X(t) \cdot t \cdot \text{WINTER}(t), \end{aligned}$$

with SUMMER(t) = 1 if t is in the summer season and 0 otherwise, and
WINTER(t) = 1 – SUMMER(t).

4.5 Assessment of the health impacts of PM10 and NO_2: Prevention of daily hospitalizations and deaths under realistic air pollution abatement scenarios.

4.5.1 Outcomes

We estimated the prevention potential that would have resulted from lower daily PM10 levels for hospitalizations and mortality between 2001 to 2010 and from lower daily NO_2-levels for mortality between 1995 and 2010 in Switzerland. For both pollutants, estimates were developed separately for medical, cardiovascular and respiratory outcomes and for all ages and ages above 75 years.

4.5.2 Abatement scenarios

We estimated the prevention potential for two realistic air pollution abatement scenarios to reflect different approaches of air quality mitigation in Switzerland:

1) daily levels of pollutants are reduced to daily maximum levels recommended by World Health Organization (WHO) [11]
2) daily levels of pollutants are reduced by 20% on any day

4.5.3 Development of risk functions

Following the statistical approach used in other sections of this report, a Poisson regression model was developed for each region to derive the risk estimates of the association between PM10 and the daily number of hospitalizations and between PM10 or NO_2 and the daily number of deaths for three different cause categories. As previously, the model was fitted with spline functions of calendar time, polynomial functions of meteorological variables and influenza frequency, and indicator variables for different days of the week and holidays. In this part of the analysis, the model was developed for a 7-day and a 28-day window of exposure, including separate effect estimates for all 7 and 28 lags, respectively. This choice was made to account

for potential longer latency periods between exposure and effect on the one hand, and for potential anticipations of events by only a few days (7-day window) or weeks (28-day window), on the other hand. Separate models were derived for PM10 and NO_2, for different age groups and for the three different outcome categories.

4.5.4 Derivation of attributable cases

Once the models were derived, daily cases were predicted for each of the two abatement scenarios by replacing the daily pollutant values actually observed by the ones which would have been implied by the respective abatement scenario. The numbers of preventable daily cases were then obtained by subtracting the daily numbers predicted under the respective abatement scenario from the actual daily numbers observed. Finally, these differences were summed over the entire study period and all regions to obtain the total prevention potential of the respective abatement scenario during the study period in question across the 13 regions.

5 Results

To simplify the terminology, we will often speak of “effects of air pollution” rather than of “associations with air pollution” in the following sections, although the causality of the statistical associations cannot be proven.

All tables and figures presenting the main results are included in the appendix and those showing additional information are included in the annex. The numbering of tables and figures in the annex is preceded by the letter A.

5.1 Analysis regions

Figure 1 shows the 13 analysis regions and the corresponding reference air pollution measurement stations. This figure outlines the cantons participating in the study and shows which of their areas could be included and whichhad to be excluded due to restrictions mentioned in the methods. All other available measurement stations are also shown. Table 1 shows the population of the different analysis regions and the proportion of the population considered in the analyses. Table A1 shows similar information for each of the participating cantons. Overall, the study covered 78.7% of the Swiss population. An example of the incidence of emergency hospital admissions and of mortality is given for 2010 in tables 3a and 3b respectively. Tables 1, A1, 2 and 3 were calculated based on the census of 2010.

5.2 Geographic and temporal differences in PM10 and NO_2-exposure

A statistical summary of the measures of PM10 and NO_2 and of other variables considered in the analysis is given in table A2. Figures 2 and 3 show the distribution of the daily mean of PM10 and NO_2 during the study years for each analysis region. The regional means of daily PM10 exposure over the period 2001 - 2010 varied between 19.0 µg/m^3 in region 11 and 29.3 µg/m^3 in region 7. Median values of daily PM10 measurements were consistently smaller than the arithmetic means due to the positively skewed distribution of these daily levels. Median values of daily PM10 measurements varied between 15.7 µg/m^3 in region 11 and 25.1 µg/m^3 in region 7.

The temporal pattern of daily PM10 values revealed a similar order of the regions. The smallest interquartile range of daily PM10 values was found in region 13 (12.6 µg/m^3) while the largest one occurred in region 8 (22.3 µg/m^3). The range (maximum – minimum) of daily PM10 values varied from 118.6 µg/m^3 in region 1 to 194.5 µg/m^3 in region 8.

The regional means of daily NO_2 exposure over the period 1995 - 2010 varied between 15.4 µg/m^3 in region 11 and 39.0 µg/m^3 in region 3. Median values of daily NO_2 exposures ranged between 12.7 µg/m^3 in region 11 and 38.1 µg/m^3 in region 3.

The smallest interquartile range of daily NO_2 values was found in region 11 (10.7 µg/m^3) while the largest one occurred in region 7 (24.5 µg/m^3). The range (maximum – minimum) of daily NO_2 values varied from 67.1 µg/m^3 in region 6 to 124.5 µg/m^3 in region 10.

Table A2 also shows the summary statistics for meteorological and other variables used in the analysis.

5.3 Basic associations of daily emergency hospital admissions with PM10

Table A3 gives the summary statistics for the daily numbers of emergency hospital admissions by region, cause and age groups. Association analyses for the age group 0 to 14 years were not feasible because of the low numbers of events This group is nevertheless included in the 'all ages' group.

5.3.1 Associations of daily medical emergency admissions with PM10

The course of the daily number of emergency hospital admissions due to medical causes over time for each of the regions is shown in figures A1 to A13. Hospital admissions followed the expected pattern, being higher in the winter and lower in the summer. Similarly to mortality, hospital admissions seem to correlate with cases of influenza.

In these figures, one can observe a rather abrupt change from the year 2001 to 2002 in some analyses regions and from 2009 to 2010 in region 3. As described in the statistical methods, these changes were considered in the analytic models by introduction of indicator variables for the respective years. The number of daily hospitalizations seems to increase with the course of time through the whole considered period. This time trend is taken into account by the spline function of calendar time contained in each of the models.

The mean number of daily hospitalizations due to medical causes varied from 10.8 for region 13 to 170.9 for region 10 for all age groups, from 4.6 to 68.3 for the age group ≥ 65 years and from 3.1 to 44.8 for the age group ≥75 years (table A3).

The estimated effect of the two-day mean of PM10 (i.e., the mean concentration of PM10 over the day of the event and the day before) on the daily number of medical emergency hospitalizations, expressed for an increase in this mean by 10 µg/m^3, varied considerably across regions and was in general not statistically significant at the regional level (figure 4). The meta-analytic estimate over all 13 regions resulted in an increase in the number of medical emergency hospitalizations by 0.2% for all ages, by 0.3% for the 15 to 64 year olds and for the ≥65 years olds and by 0.3% for the ≥75 years old (table 4). These % changes correspond to relative risks of 1.002 and 1.003.

The meta-analytic estimate is labelled as 'combined' in figure 4.

5.3.2 Associations of daily cardiovascular emergency admissions with PM10

Cardiovascular events can be classified into two groups, with one group including the events of the heart itself (referred to as cardiac events) and the other one including the events of the circulatory system outside the heart.

The overall daily mean number of emergency hospital admissions due to cardiovascular causes varied from 2.1 cases in region 13 to 32.4 cases in region 10. The respective range was 0.7 to 10.0 cases for the 15 to 64 year olds, 2.1 to 22.4 cases for the ≥ 65 year olds and 1.3 to 15.3 cases for the ≥ 75 year olds (table A3).

Figure 5 shows the estimated effect of the two day mean of PM10 on the daily number of cardiovascular emergency hospitalizations, expressed for an increase in this mean by 10 µg/m^3, for the different regions and the meta-analytic estimate for all regions by age groups. The meta-analytic relative risk over all 13 regions was 1.004 for all ages, for the 15 to 64 year olds and for the ≥65 year olds, and 1.006 for the ≥75 year olds. These risks correspond to changes of 0.4% and 0.6%, respectively, in the number of daily admissions. The effects were statistically significant for all ages and for the age groups ≥65 years and ≥75 years (table 5).

5.3.3 Associations of daily respiratory emergency admissions with PM10

The overall daily mean number of emergency hospital admissions due to respiratory causes varied from 1.5 cases in region 13 to 16.2 cases in region 10. The respective range was 0.5 to 5.6 cases for the 15 to 64 year olds in the same regions. For the ≥65 year olds, the mean number run from 0.6 in region 12 to 7.4 in region 10 and for the ≥75 year olds from 0.4 in region 12 to 4.9 in region 10 (table A3).

Figure 6 shows the estimated effect of the four day mean of PM10 (i.e., the mean concentration of PM10 over the day of the event and three days preceding the event) on the daily number of respiratory emergency hospitalizations, expressed for an increase in this mean by 10 µg/m^3, for the different regions and the meta-analytic estimate for all regions by age groups. The meta-analytic relative risk was 1.002 for all ages, 1.007 for the 15 to 64 year olds, 1.007 for the ≥65 year olds, and1.011 for the ≥75 year olds. These risks correspond to changes of 0.2%, 0.7%, and 1.1%, respectively in the number of daily admissions. The association was statistically significant for all ages and for the ≥75 year olds. These results are illustrated in Figure 6. In contrast, the corresponding effect estimates are considerably lower for the two day mean of PM10, with relative risks of 0.999, 1.004, 1.002 and 1.006, respectively.. The importance of considering different time windows of the PM10 exposure is discussed in section 6.3.1.

5.4 Basic associations of daily mortality with PM10 and NO_2

5.4.1 Associations of daily mortality from medical causes with PM10 and NO_2

Mortality followed a well-known seasonal pattern in all regions with higher numbers of deaths during the winter and lower values during the summer (figures A14 to A26). Moreover, mortality correlates strongly with frequency of influenza cases.

The average daily numbers of deaths due to medical causes for all ages ranged from 1.9 in region 13 to 30.5 in region 10 (table A2). The corresponding values for people aged ≥65 years ranged between 1.6 in region 13 and 25.5 in region 10. For people aged ≥75 years the values ranged between 1.3 in region 13 and 20.7 in region 10.

The region-specific relative risks of daily mortality from medical causes across all ages for an increase in the two day mean of PM10 by 10 µg/m^3 ranged from 0.996 in region 3 to 1.023 in region 8 (figure 7). The meta-analytic summary estimate was 1.002 (95%-CI: 0.999 to 1.006). This means that, for an increase in the two day mean of PM10 by 10 µg/m^3, the daily mortality from medical causes increased by 0.2%. However, since the confidence interval includes the value 1, this overall association was not statistically significant. There was little evidence for heterogeneity between the regions (p=0.28) which means that the differences between the relative risks among the regions could be explained by sampling chance alone. The summary estimates for people aged ≥65 years and ≥75 were 1.002 and 1.004, respectively (table 7).

The region-specific relative risks of daily mortality from medical causes across all ages for an increase in the two day mean of NO_2 by 10 µg/m^3 ranged from 0.997 in region 3 to 1.057 in region 8 (Figure 10). The meta-analytic summary estimate was 1.007 (95%-CI: 1.001 to 1.013). This association was statistically significant. This means that, for an increase in the two day mean of NO_2 by 10 µg/m^3, the daily mortality from medical causes increased by 0.7%. There was evidence for heterogeneity of the effects between the regions (p = 0.002). The summary estimates for people aged ≥65 years and ≥75 were 1.006 and 1.006, respectively (table 7).

5.4.2 Associations of daily mortality from cardiovascular causes with PM10 and NO_2

The average daily numbers of deaths due to cardiovascular causes for all ages ranged from 0.7 in region 13 to 12.7 in region 10 (table A2). The corresponding values for people aged ≥65 ranged between 0.7 in region 13 and 11.7 in region 10. For people aged ≥75 the values ranged between 0.6 in region 13 and 10.2 in region 10.

The region-specific relative risks of daily mortality from cardiovascular causes across all ages for an increase in the two day mean of PM10 by 10 µg/m^3 , ranged from 0.992 in region 3 to 1.027 in regions 8 and 12 (figure 8). The meta-analytic summary estimate was 1.003 (95%-CI: 0.998 to 1.008). This means that, for an increase of the two day mean of PM10 by 10 µg/m^3 , the daily mortality from cardiovascular causes increased by 0.3%. However, this association

was not statistically significant. There was little evidence for heterogeneity between the regions (p=0.35). The summary estimates for people aged ≥65 years and ≥75 years were 1.001 and 1.003, respectively (table 8).

The region-specific relative risks of daily mortality from cardiovascular causes across all ages for an increase in the two day mean of NO_2 by 10 µg/m^3 ranged from 0.984 in region 6 to 1.037 in region 8 (figure 11). The meta-analytic summary estimate was 1.004 (95%-CI: 0.999 to 1.008). This means that for an increase in the two day mean of NO_2 by 10 µg/m^3, the daily mortality from cardiovascular causes increased by 0.4%. Again, this association was not statistically significant. There was little evidence for heterogeneity of the effects between the regions (p = 0.64). The summary estimates for people aged ≥65 years and ≥75 were 1.003 and 1.003, respectively (table 8).

5.4.3 Associations of daily mortality from respiratory causes with PM10 and NO_2

The average daily numbers of deaths due to respiratory causes for all ages ranged from 0.15 in region 13 to 1.7 in region 10 (table A2). The corresponding values for people aged ≥65 ranged between 0.1 in region 13 and 1.6 in region 10. For people aged ≥75 the values ranged between 0.1 in region 13 and 1.3 in region 10.

The region-specific relative risks of overall daily mortality from respiratory causes for an increase in the four day mean of PM10 by 10 µg/m^3 ranged from 0.963 in region 6 to 1.092 in region 13 (figure 9). The meta-analytic summary estimate was 1.017 (95%-CI: 1.002 to 1.033). This means that for an increase in the four day mean of PM10 by 10 µg/m^3 the daily mortality from respiratory causes increased by 1.7%. This association was statistically significant. There was some evidence for heterogeneity between the regions (p=0.1) which means that sampling chance alone might not explain all differences between the regional risk estimates. In particular, the association was very strong in the region of Sottoceneri. The summary estimates for people aged ≥65 years and ≥75 years were 1.017 and 1.019, respectively (table 9).

The region-specific relative risks of overall daily mortality from respiratory causes for an increase in the four day mean of NO_2 by 10 µg/m^3 ranged from 0.948 in region 6 to 1.127 in region 8 (figure 12). The meta-analytic summary estimate was 1.027 (95%-CI: 1.005 to 1.050). This means that for an increase in the four day mean of NO_2 by 10 µg/m^3, the daily mortality from respiratory causes increased by 2.7%. This association was statistically significant. There was strong evidence for heterogeneity of the effects between the regions (p = 0.005). Again, the association was very strong in the region of Sottoceneri but it reached statistical significance also in other regions. The summary estimates for people aged ≥65 years and ≥75 years were 1.028 and 1.026, respectively (table 9).

5.5 Importance of different time windows of PM10- and NO_2-exposure

5.5.1 Importance of different time windows of PM10 exposure for emergency hospital admissions

Associations between emergency hospital admissions and PM10 were also examined separately for the levels of PM10 on the day of the event and on each of the three days preceding the event, as well as for the three, four and seven day means of PM10 (i.e., the means of PM10 over the day of the event and the two, three and six preceding days, respectively).

Tables 4, 5, and 6 show, respectively, the estimated effects of these PM10 exposure measures on hospitalizations due to medical, cardiovascular and respiratory causes. The number of cardiovascular hospitalizations was most strongly associated with exposure to PM10 on the day of the event. A 10 µg/m^3 increment in the level of PM10 on the day of the event was associated with an increase of about 0.6% in the number of cardiovascular emergency hospitalizations across all age groups. Exposures on previous days showed weaker associations. Hospitalizations due to respiratory causes showed quite different associations to these exposure measures. The same increment in the concentration of PM10 three days before the event was associated with an increase by 0.8% in the 15 to 64 year olds and in the ≥65 year olds, and by 1% in the ≥75 year olds. Mean concentrations over several days showed similar associations with daily numbers of respiratory emergency admissions. However, exposure to increased levels of PM10 over additional days further increased the risk of respiratory emergency admissions. An increment in the seven day mean of PM10 by 10 µg/m^3 was associated with an increase in respiratory admissions by 1.9% in the ≥75 year olds and by 1.4% in the ≥65 year olds.

In addition, the parallel effects of exposure to PM10 on the day of the event and on the six days before were examined. How effects with different latency periods are disentangled despite the high correlations of the pollutant levels on consecutive days is explained in section 4.4.7. Figures 13, 14 and 15 illustrate these effects. The figures in the left column are relevant for this section. Figure 14 shows that exposure on the hospitalization day and the day before were associated with an increase in the number of cardiovascular admissions while effect estimates for previous days of exposure were even slightly negative. Respiratory emergency admissions showed a different pattern (figure 15), no effect was observed for the exposure to PM10 on the day of the event but the effect increased with the length of the latency period (i.e., the time interval between exposure and event). For medical emergency hospitalizations the latency pattern of effects varied between the different age groups (figure 13). Tables A4, A5 and A6 in the annex show these effects also as relative risks.

5.5.2 Importance of different time windows of PM10- and NO_2-exposure for mortality

The polynomial lag models revealed that positive effects from PM10 on mortality from medical causes for all age groups were still present even after 7 days (figure 16). The effects of PM10 on mortality from all medical causes were actually increasing with the length of the latency period, with no evidence of an immediate effect within 24 hours. The effects of PM10 on mortality from respiratory causes were positive over 7 days across all age groups (figure 18). Confidence intervals were wide, though, and mostly included the neutral relative risk of 1. The effect of PM10 on daily mortality from cardiovascular causes showed a similar pattern as the effect on all medical causes (figure 17). Thus, we found evidence that effects of PM10 on daily mortality may be detectable even after 7 days.

Effects of NO_2 on daily mortality from all medical causes were also clearly visible after 7 days (figure 19). This was true for all age groups. Effects became significant after 2 days indicating delayed effects of NO_2 on mortality from medical causes. The effect of NO_2 on mortality from respiratory causes was positive over the whole 7 day period considered for all age groups (figure 21). As for mortality from medical causes, the effect of NO_2 on mortality from cardiovascular causes increased with increasing lag and reached statistical significance at lag 2, indicating delayed effects on mortality from cardiovascular causes as well (figure 20).

5.6 Summer and winter difference in associations of emergency hospital admissions with PM10

Associations between emergency hospital admissions and PM10 were also examined separately for the summer (May to October) and winter (November to April) semesters by using semester-specific terms of the respective PM10-variable.

The results are given, as usual, per 10 $\mu g/m^3$ increment in the respective PM10-variable. By default, the two day mean of PM10 is considered for emergency hospitalizations from medical causes in general and from cardiovascular causes in particular and the four day mean of PM10 for emergency hospitalizations from respiratory causes. The effects of PM10 during the summer and winter semesters are illustrated in figure 22, and described more in detail in the next sections.

5.6.1 Summer and winter associations for medical emergency admissions

In general the % change in the number of daily emergency hospitalizations due to medical causes was higher in the summer (ranging from 0.2% to 0.6%) than in the winter (ranging from 0.1% to 0.3%) across all ages, and in the 15 to 64 year old and the ≥65 year old groups (tables A7 to A10).

In the oldest age group of persons aged ≥75 years, the effects were larger in the winter than in the summer (table A10). For the winter semester, the % change in the number of daily hospital

admissions ranged from 0.3% to 0.8%, increasing with the length of the exposure window considered. The change in summer was around 0.2%.

With the exception of results for the seven day mean of PM10 in persons aged ≥75 years, these seasonal differences were, however, not statistically significant.

5.6.2 Summer and winter associations for cardiovascular emergency admissions

Stronger effects of PM10 on the day of the event were observed during summer than during winter for cardiovascular emergency admissions for all ages, and the 15 to 64 year and ≥65 year old groups (0.8%, 1.2% and 0.8% change, respectively), all three associations were statistically significant (tables A11 to A13). The effect decreased when looking at the exposure on previous days, and it reached its maximum with the two day mean of PM10 (0.6% change across all ages, 1.0% among the 15 to 64 years olds and 0.5% among the ≥65 year olds).

The effect of PM10 exposure on cardiovascular hospitalizations was lower in the winter than in the summer for the younger group, as already mentioned. In the ≥65 year olds, the effect in winter remained almost constant for the 2, 3, 4 and 7 day means, at about 0.5% change (statistically significant). In the ≥75 year olds, the effect of exposure to PM10 was higher in winter than in summer, across all exposure time windows considered (table A14). These effects were higher for exposure to PM10 on the day of the event (0.7%) than for exposures on the three preceding days (for which effects were around 0.5%), but they were almost identical for the two, three, four and seven day means (with a statistically significant change of about 0.8% in the number of cardiovascular emergency hospitalizations).

Although the effects in summer and winter differ, a statistically significant difference was observed only for the ≥65 and ≥75 year olds when the exposure measure was the 7 day mean of PM10.

5.6.3 Summer and winter associations for respiratory emergency admissions

With respect to emergency hospital admissions due to respiratory causes, a different pattern to that of admissions due to cardiovascular causes was observed across all ages and among the 15 to 64 year olds. For these age groups, effects of all PM10 exposure measures were higher in summer than in winter and effects increased with the length of the exposure window (tables A15 to A16). Effects were bigger than for admissions due to medical or cardiovascular causes (with changes of 1% or higher as compared to 0.2%-0.3% for medical and 0.5%-0.8% for cardiovascular causes).

Unlike for the two other categories of emergency admissions, the effects on respiratory emergency admissions were generally higher in the summer semester than in the winter semester also in the older age groups (tables A17 and A18).

5.7 Time trends

5.7.1 Time trends in associations of emergency hospital admissions with PM10

Figures 23, 24, and 25 show the estimated time trends in the effects of PM10 on daily emergency hospital admissions due to medical, cardiovascular and respiratory causes.. Effects reported always relate to a 10 µg/m^3 increment in the two day mean of PM10 for emergency hospital admissions for medical causes in general and for cardiovascular causes in particular and to a 10 µg/m^3 increment in the four day mean of PM10 for emergency hospital admissions from respiratory causes.

As described in the methods section (4.4.9), a linear trend of the effect was calculated first and then a non-linear trend (as a quadratic function) was examined.

The observed change in medical emergency admissions per 10 µg/m^3 increment in the two day mean of PM10 showed a slight increase from 0.1% to 0.3% between 2001 and 2010 across all ages and among the ≥65 year olds and ≥75 year olds (figure 23). These increasing trends were not statistically significant, however. A slightly higher and borderline significant increase was observed for the 15 to 64 year olds (from 0% to 0.6%; p-value=0.09).

The time trends were heterogeneous for hospitalizations due to cardiovascular reasons (figure 24). The observed effects increased when combining all ages and in the age group of the 15 to 64 year olds, while it slightly decreased in the two older age groups. The increase was almost statistically significant in the younger age group where the change increased from -0.5% to 1.5% between 2001 and 2010 (p = 0.054).

For emergency hospital admissions due to respiratory causes, the change increased from -0.5% to 1% between 2001 and 2010 when combining all ages (p = 0.04) and from -0.2% to 2% in the group of the 15 to 65 year olds (p = 0.06). The effect also slightly increased with time among the ≥65 year olds but it remained almost constant in the ≥75 year olds (figure 25).

There was no evidence of any non-linearities in these time trends.

5.7.2 Time trends in associations of natural mortality with PM10 and NO_2

Results of time trend analyses are summarized in table A19 and illustrated in figures 26 to 31. There was no evidence of any non-linearities in the observed time trends. Effects of NO_2 on daily mortality from medical and respiratory causes slightly decreased between 1995 and 2010 in people aged ≥65 years (figure 29 and figure 31, respectively). In contrast, the effects of PM10 slightly increased between 2001 and 2010. However, most of these time trends failed to reach statistical significance. Thus, overall, there was little evidence for relevant changes in the effects of NO_2 or PM10 on daily mortality since 1995 and 2001, respectively.

As part of the sensitivity analyses, we also estimated separate trends for summer and winter. Generally, effects of PM10 and NO_2 were higher in summer compared to winter. This was true

for all causes of mortality (medical, respiratory, cardiovascular). On the other hand, there was little evidence for any time trends in the effects of PM10 and NO_2 during the summer semester, while time trends observed for the winter semester resembled those observed in the main analyses.

5.8 Parallel effects of PM10, NO_2 and O_3

Table 10 shows the temporal correlations between daily measurements of PM10 and NO_2. These correlations were quite high in all regions and the correlation coefficients ranged from 0.51 in region 3 to 0.77 in region 12. During the summer semester, correlations of O_3 with PM10 were small across all regions while correlations with NO_2 were consistently negative, with correlation coefficients ranging from -0.20 in region 13 to -0.59 in region 4.

5.8.1 Parallel effects of PM10 and NO_2 on daily emergency hospital admissions

Although, the magnitude of the observed effects of PM10 on emergency hospital admissions did not change much when NO_2 was included in the model, the following observations were made: Inclusion of NO_2 reduced the association with the level of PM10 on the day of the event for all categories of emergency admissions and either increased associations with the levels of PM10 on the two days preceding the event (all medical admissions) or left them unchanged.

For medical admissions, inclusion of NO_2 in the model led to a reduction in the effect of PM10 on the day of the event (from 0.2% to -0.1% for all ages combined and from 0.3% to -0.1% for the other three ages groups). On the other hand, the change in emergency admissions from medical causes per 10 µg/m^3 increment in the two day mean of PM10increased from 0.2% to 0.8% across all age groups, and from 0.3% to 1.1% among the 15 to 65 year olds. (table 11). Increases were also observed in the two older age groups.

Similar changes were observed for cardiovascular admissions. The PM10 effect of the day of the event was decreased by the introduction of NO_2 and almost vanished. Effects of the two day mean of PM10 increased in all four age groups while those of the seven day mean decreased. Increases and decreases were observed for the three and the four day means of PM10, depending on the age group considered.

When NO_2 was included in the model, the effects of PM10 on hospital admissions from respiratory causes also slightly increased for the two day mean and remained similar for the three, four and seven day means across all ages combined. While the effects of all these means slightly increased in the oldest age group, they completely collapsed in the youngest age group (table 13).

The latency pattern of effects of PM10 over a period of seven days was also examined in a combined polynomial lag model for PM10 and NO_2. Figures 13 to 15 illustrate the estimated

effects. The first column in the figures gives the results for PM10 in the one pollutant model, the second one for PM10 in the two pollutant model and the third one for NO_2 in the two pollutant model. It can be observed in figures 13 and 14, that the effect from PM10 on the day of the event on admissions of medical and cardiovascular character is always positive in the one pollutant model but negative or close to 0 in the two pollutant model. It can also be observed that the acute effect is attributed to NO_2 in the two pollutant model (third column) The acute effect of NO_2 lies between 0.5% and 1% for medical and between 1% and 1.5% for cardiovascular admissions. The effects of PM10 and NO_2 tend to show opposite signs for the same latency period. These patterns are similar across the 4 age groups examined.
For emergency hospital admissions due to respiratory causes, the acute effect of PM10 is close to 0 or slightly negative in the one and two pollutant model, but remains positive in the two pollutant model for latency periods of one to three days across all ages combined and in the two older age groups. In the youngest age group, it stays positive for latency periods of three to five days. The acute effect of NO_2 ranges from 0.5% to 1.2% across the 4 age groups. Latent effects of NO_2 are negative for latency periods of one to three days but again positive for latency periods of four to five days across all ages combined and in the two older age groups. (figure 15).

5.8.2 Parallel effects of PM10, NO_2 and O_3 on daily natural mortality

High correlations between PM10 and NO_2 could have led to confounding of the estimated effects of PM10. When NO_2 was included in the models together with PM10, meta-analytic risk estimates for PM10 and NO_2 generally decreased compared to the ones of the respective single pollutant models (table 12). Moreover, due to the collinearity of PM10 and NO_2, all confidence intervals became wider. Therefore, none of these estimates reached statistical significance any more. However, almost all variables of daily mortality (i.e., across the three age groups and the three cause categories) showed stronger associations with NO_2 than with PM10 in the two pollutant models combining PM10 and NO_2.

As described in table 10, the correlations between PM10 and O_3 were small across all regions. Thus, major confounding of PM10–effects by O_3 was not to be expected. However, when ozone was included in the models together with PM10, all meta-analytic relative risks were increased and the p-values decreased compared to the one-pollutant models (table 14). For persons aged ≥65 years, the association between the four day mean of PM10 and daily mortality due to respiratory causes newly reached statistical significance.

The negative correlations between NO_2 and O_3, might have led to confounding of the estimated effects of NO_2 by O_3. When O_3 was included in the models together with NO_2, all meta-analytic relative risk estimates for NO_2 increased and all but two p-values decreased (table 14). For per-

sons aged ≥75 years, the association between the two day mean of NO_2 and daily mortality due to medical causes newly reached statistical significance.

5.9 Assessment of the health impacts of PM10 and NO_2: Prevention of daily hospitalizations and deaths under realistic air pollution abatement scenarios.

5.9.1 Change in exposure

The change in annual PM10 and NO_2 observed between the first and last year of the study period are presented in table 15. Across the 13 regions, an average decrease of 3.5 µg/m^3 was observed for PM10 between 2001 and 2010 while NO_2 increased by 0.4 µg/m^3 between 1995 and 2010. Table 15 also presents the change in exposure as it would have resulted from each of the two abatement scenarios. For both pollutants, scenario 1 (mitigating peak events only, by a reduction of daily levels of pollutants down to the daily maximum recommended by the WHO) has limited additional reduction benefit compared to the natural decline observed. The assumption of a general 20% reduction in all daily levels (scenario 2), represents a larger average reduction in exposure to both, PM10 and NO_2.

5.9.2 Relative risk for Lag7 and Lag28

The relative risk estimates (in percentage) derived and used for this part of the analysis are presented in table 16 for PM10 and hospitalization outcomes and in table 17 for both, PM10 and NO_2, and mortality outcomes.

Consistent positive associations between PM10 and cardiovascular and respiratory emergency hospitalizations among older ages (above 65 and above 75 years) were observed (table 16), when using as relevant exposure measure the average pollutant level over the day of the event and the 6 days before the event (Lag 7). For the population above 75 years, there was a 0.5% (not statistically significant) and 1.85% (95% confidence interval: 0.44% to 3.29%) increase in cardiovascular and respiratory hospitalizations, respectively, per 10 µg/m^3 increase in the respective PM10 exposure measure. Risk estimates were positive but not statistically significant when considering individuals of all ages. For respiratory emergency hospitalizations, but among older age groups only, we found larger risk estimates with an exposure window of 28 days, i.e., when taking the average level of PM10 over the day of the event and the 27 days before the event as the relevant exposure measure. The increase in the number of respiratory emergency hospitalizations for a 10 µg/m^3 increment in the 28-day mean of PM10 reached 2.9% compared to 1.85% for a 10 µg/m^3 increment in the 7-day mean of PM10.

The increased risks (in percent) per 10 µg/m^3 increase in the 7-day mean of PM10 were 1.99% (95% confidence interval: 0.59% to 3.41%) for respiratory mortality and 0.90% (95% confidence

interval: 0.24% to 1.56%) for cardiovascular mortality across all ages (table 17). For the population above 75 years, the respective risks increased to 2.43% and 11.06%. The risk estimates were about twice as high for respiratory outcomes when using the models with 28 lags. The corresponding effect estimates for NO_2 and respiratory admissions were slightly higher and showed a similar rise from the 7-day to the 28-day mean, with an estimated percent increase in respiratory emergency admissions among the oldest age group by 11.60% for a 10 µg/m^3 increment in the 28-day mean of NO_2.

5.9.3 Preventable cases

The estimated numbers of preventable emergency hospital admissions under the two different abatement scenarios are presented in table 18 for PM10. According to these estimates, 735 and 3269 hospitalizations from medical causes could have been avoided over the study period 2001-2010 under scenario 1 and scenario 2, respectively, representing 0.03% and 0.15% of those hospitalizations. The largest benefits were estimated for the elderly population of persons aged 75 years or more under scenario 2, with 3 cardiovascular and 3 respiratory cases avoided per year and 100,000 persons, representing 0.27% and 0.76%, respectively, of the respective numbers of hospitalizations during the study period. Table 19 presents results for preventable premature deaths under the two abatement scenarios for PM10. According to these estimates, 284 and 1493 deaths for medical causes could have been avoided under scenario 1 and scenario 2, respectively, over the study period 2001-2010, representing 0.04% and 0.21% of all corresponding deaths. The largest benefits were again estimated for the elderly population under scenario 2 with 11 cardiovascular and 3 respiratory deaths avoided per year and 100,000 persons , representing 0.32% and 0.64% of all respective deaths during the study period. When using NO_2 as indicator the estimated numbers of avoidable premature deaths were even larger, especially under scenario 2 (table 20).

The differences in the estimated numbers of preventable hospitalizations and avoidable premature deaths over the study period that result when using a 28 versus a 7 day exposure window are further presented in figure 32 for respiratory and cardiovascular outcomes. The largest differences were seen for mortality, especially for cardiovascular deaths.

6 Discussion of results

To simplify terminology, we will repeatedly use the term “effect” instead of “association” to describe the relationship between PM10 or NO_2 on one hand and emergency hospital admissions or mortality on the other. This is not meant to imply that the respective relationships be causal. As in the previous, sections, the term “two day mean” of PM10 or NO_2 is used for the average level of PM10 or NO_2 over the day of the event and the day preceding the event, while the term “L-day mean” is used for the average level of PM10 or NO_2 over the day of the event and the L-1 days preceding the event.

6.1 Effects of PM10 and NO_2 on daily emergency hospital admissions

There are relatively few results on short-term effects of air pollution on emergency admissions for general medical causes reported in the literature. In general, such studies focus on hospitalizations as a result of respiratory or cardiovascular complications [12]. In the present study, the estimated effects of the two day mean of PM10 on admissions due to medical causes across the different age groups are comparable to the corresponding results from the previous study [7], and reached statistical significance. Among persons aged 65 years or more we observed about a 0.2% increase in the number of cases for a 10 µg/m^3 increase in the two day mean of PM10 . Taking into consideration that the cardiovascular and respiratory emergencies account for only about a quarter of all medical emergencies and assuming that there is no correlation between PM10 and emergencies due to other medical reasons, the effect of PM10 on the cardiovascular or respiratory admissions would have to amount to an increase of about 0.8% for the same increment in PM10. In fact, our estimates for these two subgroups were lower. This suggests a weak association of PM10 with other medical emergencies, which is consistent with the results given by Dominici et al. [12].

The association of the two day mean of PM10 and the hospital admissions due to cardiovascular causes showed a 0.4% increase in the number of admissions for a 10 µg/m^3 increase in PM10 for the overall population and the ≥65 year olds and a 0.6% increase for the ≥75 year olds. These estimates were 0.2% higher in the previous study. The European APHEA2 study[6] published similar results some years ago. These results were based on data from all of the Netherlands and from 7 major European cities (London, Birmingham, Paris, Milan, Rome, Barcelona and Stockholm). The mean increase in cardiac emergency admissions was 0.5% per 10 µg/m^3 in the two day mean of PM10 for the overall population and 0.7% for subjects older than 65 years.

Contrary to our expectations and as in the earlier study, the observed associations between the two day mean of PM10 and respiratory emergency admissions were overall considerably lower than the corresponding associations with cardiovascular emergencies. In the APHEA2 study, the estimated percent change in the number of respiratory emergency admissions per 10 µg/m^3 increment in the two day mean of PM10 was 0.9% and thus higher than the corresponding estimate for the de cardiovascular emergency admissions [5].

As air pollutants primarily affect the lung epithelium and must penetrate it to get into the internal system, one would expect a higher effect of the pollutants on admissions due to respiratory causes. On the other hand, inflammatory reactions in the lung release cytokines which, by stimulating the autonomic nervous system, may directly affect the cardiovascular system [13]. This could explain why life-threatening crises associated with short term increases in air pollutant levels occur more often in the cardiovascular than in the respiratory system. It could also be that the effects on the lungs occur with some delay. This hypothesis would be supported by our own observation that respiratory emergency admissions were more strongly associated with the four day mean of PM10 than with the two day mean. Results of a previous evaluation of hospital admission data in three Swiss cities could point in this direction [14]. In this study, respiratory emergency admissions showed the strongest relationship with the TSP or NO_2 levels two to three days earlier.

Two other European studies did not find a clear relationship between particle concentrations and respiratory emergency admissions [15, 16]. In both studies, however, pollutants strongly associated with traffic, showed a statistically significant association with respiratory emergency admissions (NO_2 and CO in the study of Rome and NO_2 and benzene in the study from Drammen, Norway).

In the present study, there were considerable differences in the estimated effects of PM10 on respiratory emergencies among regions. In both regions of the Ticino, the empirical Bayes corrected estimates of the effect of the four day mean of PM10 were around of 0.5% per 10 µg/m^3 for the older group. On the other hand, negative associations were found in certain regions.

An Australian study in four cities (Brisbane, Melbourne, Perth and Sydney) had observed considerable heterogeneity in its estimated effects of $PM_{2.5}$ on the respiratory emergency admissions [17]. In this study, the effect of $PM_{2.5}$ was significantly attenuated when the simultaneously influence of NO_2 was taken into account. These findings may give rise to a presumption that the strength of the association between suspended particulates and respiratory emergency admissions depends on the correlation between the suspended particulates and the emissions of motorized transport in the region of concern.

6.2 Effects of PM10 and NO_2 on daily mortality

There is overwhelming evidence from many studies all over the world that there is a positive relationship between exposure to PM10 and NO_2 and daily mortality [18]. But most of these studies were conducted in urban regions with considerably higher pollutant levels than those encountered in Switzerland. Nevertheless, our estimates of the effects of PM10 and NO_2 on mortality are comparable to those found in many other studies and they are actually comparatively high for respiratory mortality. We found that increased exposure to PM10 and NO_2 increased the rate of daily mortality from all medical and respiratory causes (table 4). For example, an increase of 10 µg/m^3 in the two day mean of PM10 increased the number of daily deaths from medical causes by 0.2% and of daily deaths from respiratory causes by 1.7%. These effects were stronger among the elderly (≥75 years), where the corresponding increases in the numbers of daily deaths were 0.4% for medical causes and 1.9% for respiratory causes. Among subjects aged 65 years or more, the effect estimates were identical to the overall estimates for both categories of mortality. The corresponding estimates from a meta-analysis by Anderson et al. published in 2004 were 0.6% per 10 µg/m^3 of PM10 for overall mortality from medical causes and 1.3% for overall mortality from respiratory causes [18]. Thus our estimates are slightly higher for respiratory mortality but lower for mortality from medical causes. On the other hand, a re-analysis of the large data set of the American NMMAPS-study provided an estimate for mortality from medical causes of 0.2% per 10 µg/m^3 of PM10 as well [18].

We also found a consistent relationship between NO_2 and daily mortality from medical and respiratory causes across all age groups (table 4). For an increase in the two day mean of NO_2 by 10 µg/m^3, daily numbers of deaths from medical causes increased by 0.7% and daily numbers of respiratory deaths by 2.7%. The corresponding effect on the daily number of deaths from cardiovascular causes was 0.4% The observed effect of NO_2 on the daily number of deaths from medical causes was consistent across all age groups and was around 0.6% per 10 µg/m^3. The effect of NO_2 on the daily number of respiratory deaths was even higher for people aged ≥65 years (2.8% per 10 µg/m^3). A study in Italy had observed an increase in the daily number of deaths from medical causes by 2.1% for a 10 µg/m^3-increment in the 6-day mean of NO_2, an increase in the daily number of deaths from respiratory causes by 3.5% for a 10 µg/m^3-increment in the mean of NO_2 over the period of 1 to 5 days preceding the event and an increase in the daily number of deaths from cardiovascular causes by 2.6% for a 10 µg/m^3-increment in the 6-day mean of NO_2 [19]. These estimates are slightly higher than the ones we can infer from the results of the polynomial lag models (cf. 5.5).

Even though all meta-analytical estimates of the effects of PM10 and NO_2 on daily mortality from cardiovascular causes were positive, none of them reached statistical significance. The

effect estimate for a 10 µg/m^3 increase in the two day mean of PM10 was 0.3% for all cardiovascular deaths. Thus, compared to the corresponding meta-analytic estimate by Anderson et al.[18] of 0.9%, our estimate is low. On the other hand, the re-analysis of the data set of the NMMAPS-study also provided an estimate of 0.3% per 10 µg/m^3 of PM10.

6.3 Importance of different time windows of PM10- and NO_2-exposure

6.3.1 Importance of different time windows of PM10-exposure for emergency hospital admissions

Health effects of pollutants can be characterized among other things in terms of their acuteness or delay. Even with short-term effects, such as those examined in the present and in past studies, differences in latencies of effects can be observed.

Effects of PM10 on cardiovascular hospitalizations seem to occur, on average, with minimal delay. Already for a latency period of only two days, almost no effect of PM10 on cardiovascular emergency admissions could be observed any more and associations for longer latency periods even got negative. This could indicate harvesting, which refers to the temporal advancement of adverse events by a few days among the most frail part of the population where these events were imminent anyway. Such harvesting typically leads to fewer events than expected in the days following increased exposure. However, most studies having looked at harvesting found that the sum of effects over different latency periods was generally positive implying that some of the effects were not just advanced by a few days.

For respiratory admissions, the situation seems to be quite different. In our analysis, the effects become apparent only after two or more days. This difference does not seem implausible, especially since the development of severe respiratory infections may take some time. In fact, similar delays for the effects of air pollutant on respiratory hospital admissions have been reported previously [20-22].

6.3.2 Importance of different time windows of PM10- and NO_2-exposure for mortality

Results of polynomial lag models showed that the effects of PM10 and NO_2 on mortality from all medical causes increased with increasing latency time indicating that exposure to PM10 and NO_2 may have delayed effects. In particular, exposure on the event day and the day before had almost no effect. The effects of PM10 and NO_2 on mortality from cardiovascular causes showed the same pattern indicating delayed effects again. This may explain why the associations between mortality from cardiovascular causes and the two day means of PM10 and NO_2 were weak in our study. For respiratory deaths, effects of PM10 and NO_2 were positive over the whole 7 day period considered. This suggests that PM10 and NO_2 may have both immediate and delayed effects on respiratory mortality. The fact that we did not find negative effects for longer

latency periods indicates that the positive effects cannot be explained by a displacement of death among frail people by a few days only but involved deaths having been anticipated by more than one week. Our results are quite consistent with findings by [19]. Based on the results of our polynomial lag models, we can infer the following effects for the longer term means of NO_2 considered in the study by Chiusolo et al.[19]: an increase by about 1% in the daily number of deaths for a 10 µg/m^3 -increment in the 6-day mean of NO_2 (compared to a 2.1%-increase in their study), an increase by at least 2% in the daily number of deaths from respiratory causes for a 10 µg/m^3 -increment in the mean of NO_2 over the 5 days preceding the event (compared to a 3.5%-increase in their study), and an increase by about 2% in the daily number of deaths from cardiovascular causes (compared to a 2.6%-increase in cardiac deaths in their study).

6.4 Time trends

6.4.1 Time trends in associations of emergency hospital admissions with PM10

The associations between PM10 and emergency hospital admissions due to medical and respiratory causes tended to increase between 2001 and 2010. The observed change in the number of medical admissions for a 10 $\propto\gamma$/m^3-increment in the two day mean of PM10 across all age groups increased from 0.1% in 2001 to 0.3% in 2010 but did not reach statistical significance. The corresponding change in the number of respiratory admissions increased from -0.5% in 2001 to 1.5% in 2010, this increase was statistically significant. The increase was smaller in the population over 65 years and there was no apparent change in the population over 75 years.

The association of PM10 with emergency admissions due to cardiovascular causes slightly increased between 2001 and 2010 in the entire population and among persons aged 15 to 65 years. However, it slightly decreased in the two older age groups.

To our knowledge, there are no published results on changes in short term effects of air pollution on hospital admissions over the last one or two decades. However, some publications, which are cited in the next section, looked at time trends in short term effects of PM10 and NO_2 on daily mortality.

6.4.2 Time trends in associations of natural mortality with PM10 and NO_2

We found little evidence for an upward or downward trend in the effects of PM10 or NO_2 on mortality over the observed periods of 2001 – 2010 and 1995 – 2010, respectively. The effects of PM10 seemed to increase over the years while the effects of NO_2 seemed to decrease (table 5). Most of the meta-analytic trend estimates were not statistically significant, however. In addition, there was little evidence for heterogeneity of linear trend estimates across the regions. When analysing mortality data from the Netherlands over the period 1992 to 2006, Fischer et al [23] had also found increasing trends for PM10-effects on deaths from medical and from respiratory

causes, respectively, and a decreasing trend for effects of NO_2 on deaths from pneumonia. On the other hand, Shin et al [24] had found increasing effects of NO_2 on mortality in Canada. If daily mortality were more strongly associated with NOx than with NO_2 then the decrease in the ratio of NO_2 to NO_x having occurred in the last decade might provide an explanation why the association between daily mortality and NO_2 decreased over time. But this remains speculative.

6.5 Parallel effects of PM10 and NO_2

6.5.1 Parallel effects of PM10 and NO_2 on emergency hospital admissions

When the effects of PM10 and NO_2 are simultaneously considered in a prediction model, the observed effect of each of the two pollutants relates to its specific part which is not correlated with the other pollutant. One may therefore hypothesize that the independent effects of PM10 mainly represent effects from pollutants which are not directly related to emissions from local traffic.

In general, the estimated effects of PM10 did not change much when the parallel effects of NO_2 were considered in the analysis. However, when the parallel daily effects of the two pollutants were examined over an entire week, differences in the latency patterns were observed. The effects of NO_2 seemed to be rather short term in nature and subside after 2 days, while the effects of PM10 were observed with a time lag of at least 2 days. Effects of the two pollutants thus showed a complementary pattern. This contrast was less pronounced in the cardiovascular emergency admissions, which may indicate that short term effects of air pollution on the cardiovascular system tend to have short latency periods. The stronger contrast observed in the case of respiratory emergency admissions might indicate that air pollutants from local motorized traffic exert more immediate effects on the lungs than pollutants originating mainly from other sources.

The estimated parallel effects of the two-day means of PM10 and NO_2 (figure 15) seem to contradict the patterns described above. Here, the effects of PM10 are consistently positive and the effects of NO_2 mostly negligible or even negative. The only explanation for this apparent contradiction lies in the high correlation of the daily levels of pollutants across consecutive days. Therefore, the two-day means do not only stand for exposures on the day of the event and the day before but also for exposures on previous days.

In the literature, there are so far no results from two pollutant models with a comparable degree of differentiation between immediate and delayed effects. Usually only pollutant levels of days very close to the event were considered. With respect to cardiovascular emergency admissions two studies found stronger and more consistent effects of NO_2 and CO, two pollutants which are associated with local motorized transport [25, 26]. In another study, however, a consistent relationship was observed rather with PM10 than with NO_2 [27]. Respiratory emergency admissions showed a similar picture. Two studies have found here a stronger association with traffic asso-

ciated than with PM10 [15, 28], but another study reported a stronger association with PM10 than with NO_2 and CO [25]. Interestingly, this latter study had found a much clearer link between cardiovascular emergency admissions and NO_2 and CO.

6.5.2 Parallel effects of PM10, NO_2 and O_3 on daily natural mortality

The effects of both PM10 and NO_2 decreased when the other pollutant was included in the model. This suggests that part of the observed effects of PM10 on mortality were due to NO_2 and vice versa. As NO_2 is a better indicator for air pollution from traffic than PM10 this suggests that the effects of NO_2 independent of PM10 reflect effects from traffic pollutants pollutants at least to some extent. In fact, the independent effects of NO_2 were stronger than the ones of PM10 although they did no longer reach statistical significance either (table 19). Effects of NO_2 on daily mortality that were independent of PM10 were also reported by Chiusolo et al [19]. This suggests that traffic pollution accounts for a considerable part of the observed effects on mortality. When we included ozone in the models, both the effects of PM10 and NO_2 increased compared to the respective one pollutant models.

6.6 Assessment of the health impacts of PM10 and NO_2: Prevention of daily hospitalizations and deaths under realistic air pollution abatement scenarios

6.6.1 Change in exposure

We estimated the short-term prevention potential for emergency hospitalizations and mortality that would have resulted if air pollution levels had been reduced in the 13 analysis regions of the present study. For both types of events, i.e., deaths and emergency hospitalizations, the prevention potential was highest in the oldest age group of persons aged 75 years or more. However, the two types of events differed with respect to the cause showing the highest prevention potential. While the prevention potential was higher for respiratory than for cardiovascular emergency admissions, it was higher for cardiovascular than for respiratory deaths.

6.6.2 Benefits of different policy scenarios

In Switzerland and elsewhere, peak events of pollution receive a lot of attention by media and policy-makers. Our results suggest that strategies aimed at reducing such peak events have only limited benefits even for outcomes that are clearly linked to large short-term fluctuations of air pollution, such as respiratory exacerbations. Reducing annual average levels instead does bring larger benefits even for these short-term outcomes [4, 29].

Based on the observed health and pollution data in the13 regions in Switzerland, we showed that the mitigation policies in the past could not materialize in large short-term reductions in hospitalizations and mortality because decrease in average annual levels have been moderate

for PM10 between 2001 and 2010 and inexistent for NO_2 between 1995 and 2010. To our knowledge very few studies have used time-series models to compare health benefits of observed and hypothesized air pollution mitigation policies.

6.6.3 Chronic versus short term impacts

We presented results for mortality for both PM10 and NO_2, but the preventable cases cannot be summed across pollutants because the sources of pollution overlap between these indicators. With comparable abatement scenarios, we found larger risk estimates and prevention potentials for NO_2 than for PM10. In accordance with other studies, our results suggest that NO_2 is a better indicator of the health-relevant components of air pollution than PM10, and they point to a special role of the mixture of primary pollutants emitted by combustion vehicles. The development of a regulated standard for an indicator that reflects this specific mixture and that would protect against its specific detrimental effects (e.g. black smoke, elemental carbon) is a current policy discussion in Switzerland and in Europe [30].

While we presented our main results based on a 7 day window of exposure, we showed that the risk estimates increased when considering a window of 28 days. This increase was quite important for cardiovascular mortality under scenario 2. Larger numbers of preventable cases when considering longer exposure windows indicate that lowering air pollution does not just postpone acute outcomes by a few days but leads to a cumulation of benefits. Evidence from epidemiological studies shows that air pollution does not only contribute to exacerbating underlying pathological conditions such as asthma, COPD, or CHD but also the development of these diseases [31-33]. It is known that individuals suffering from COPD and CHD have a reduced life span. The few existing cohort studies having followed adults over longer time periods have consistently found that those exposed to high levels of pollution during their lifetime had higher mortality rates than those exposed to lower levels. In these studies, relative risks associated with a 10 µg/m^3 difference in average PM10-exposure are of an average size of about 1.06 as compared to the relative risks of about 1.005 found in mortality time-series studies like ours [34, 35]. This large difference reflects the fact that long term exposure to increased levels of air pollution may lead to chronic changes of health while short term increases of air pollution trigger acute respiratory or cardiovascular events. This difference also propagates to the estimations of the total burden of air pollution. A seminal past analysis in Switzerland showed that the burden of air pollution contributed to approximately 3000 deaths per year, much larger than the preventable cases estimated in the present study [36]. The preventable numbers of cases estimated in our analysis are thus considerably smaller than if chronic effects had been considered as well. In fact, using a recently developed risk function based on a thorough literature review of all studies between long-term exposure to PM10 (rescaled from $PM_{2.5}$) and mortality [37], we can estimate

that mortality from natural causes would have been about 1% to 2% higher in 2010 without the decrease in PM10 observed between 2001 and 2010.

6.6.4 Limitations

Our analysis has some limitations. Since the magnitude of the risk estimates was robust across models and outcomes, we calculated preventable cases even when the associated risk estimates were not statistically significant. Preventable cases below zero should thus be interpreted as no benefits. Because risk estimates by region are subject to random variation, we provided estimates aggregated across the 13 regions. This may be less informative for local policy-makers. On the other hand, small numbers of preventable cases by region may also be more difficult to communicate to local stakeholders. We did not sum the preventable cases for hospitalizations and deaths as this would have introduced some double counting of individuals having died of their disease after hospitalization. Finally our approach assumes a direct causal relationship between air pollution reduction and decrease in daily deaths or emergency hospitalizations. Although we cannot prove this with our data, other evidence from Switzerland supports this assumption [29].

In conclusion our study suggests that the changes in PM10 and NO_2 levels in 13 regions of Switzerland between 2001 and 2010 and 1995 and 2010, respectively, only led to moderate decreases in the number of hospitalizations and deaths attributable to air pollution. Much larger benefits could be achieved in the future if air quality mitigation plans were more ambitious at reducing annual levels of pollutants rather than just focusing on the reduction of peak events.

7 Conclusions

We updated and extended a previous analysis to evaluate if the short term effects of air pollution on emergency hospital admissions changed or remained the same when covering a time period between 2001 and 2010 instead of 2001 to 2005 and how effects on daily mortality compared to the effects on emergency admission. The main conclusions of this study are:

- While a decline in PM10 through time was observed across all the study regions, we still observed short term effects of PM10 on emergency hospital admissions and deaths for any medical, cardiovascular and respiratory causes. Thus, more people still die or must be hospitalized during periods of days with increased air pollution.
- Estimated short term effects of PM10 on mortality and emergency hospitalizations from any medical and from cardiovascular causes were of similar magnitude when expressed on a percentage scale. On the other hand, corresponding effects on respiratory mortality were considerably larger than those on respiratory emergency hospitalizations. Although cardiovascular diseases are more frequent in absolute numbers, one should not overlook the group of persons with underlying respiratory diseases because they are particularly susceptible to air pollution. As has been shown in other studies, we also found older populations to be at higher risk of hospitalization if air pollution increases.
- The risk estimates for the association between emergency hospitalizations and PM10 over the period 2001-2010 obtained in this updated analysis were similar to the ones previously obtained for the period 2001-2005. Yet, they are not directly comparable because the regions of analysis of the two studies were not identical.
- Overall, no significant changes in short term effects over the last decade were observed. Thus, the average percentage increase in emergency admissions after a given short term increase in PM10 or NO_2 has remained comparable. This suggests that the acute toxicity of air pollution has remained similar over time, despite changes in car fleet, engine and combustion technology.
- As in the analysis of the precursor study, effects of PM10 on respiratory emergency admissions were found to be particularly strong in the two study regions south of the Alps. And interestingly, we also found higher effects on respiratory mortality in these two regions.
- Short term effects of PM10 on mortality and hospital admissions showed different latency periods for cardiovascular and respiratory events. They were immediate for cardiovascular emergency admissions but showed a latency period of about two days for respiratory admissions. Thus, exacerbations of respiratory diseases may take a few days to develop while the cardiovascular system may react immediately. On the other

hand, short term effects of PM10 on cardiovascular deaths also showed a latency period of about two days. It is unclear how this different response of cardiovascular deaths and emergencies to short term changes in PM10 can be explained.

- When conducting mortality analyses combining PM10 and NO_2 in the same model, associations were slightly stronger for NO_2 than for PM10. This might point to a special role of traffic related pollution in these effects.
- The fact that the magnitude of acute effects did not decrease despite some overall improvements in air quality supports the concept that there is no “safe level of air pollution” or “threshold of no effect”.
- While short term increases in air pollution over few days may still have the same short term effects as 10 or 15 years ago, the gradual decreases of pollutant levels over time are likely to have led to a reduction in chronic effects, as findings from SAPALDIA and other cohort studies suggest.

In conclusion, considerable decreases in PM10 levels have been observed across 13 regions in Switzerland during the period 2001 to 2010. Despite these improvements, the short term effects of PM10 on hospitalizations and mortality remained unchanged and are of a magnitude seen in other urban areas with higher pollution levels. This indicates that the acute toxicity of air pollution did not decrease. Results from cohort studies- such as SAPALDIA conducted over 8 cities in Switzerland- that follow a population over time and measure mortality rates at the end of the period show that sustainable improvements in air quality have beneficial effects on health on the long-term.

It can thus be expected that efforts to further reduce air pollution will result in further short-term and long-term health benefits across all regions of Switzerland. In particular, traffic-related air pollution ought to be the target of future policies as no further improvements in NO_2 were observed during the last 10 years and the effects of NO_2 on mortality were seen to be quite strong in the present study.

8 Glossary

Medstat region	Region defined by the Federal Office of Statistics for the geographical classification of hospital statistics

Air pollutants:

Fine particles:	very small subdivisions of solid or liquid matter suspended in the atmosphere. Sources of fine particles are among others traffic, fires and agricultural and construction activities (primary) and chemical reactions among pollutants (secondary)
PM10:	Fine particle with an aerodynamic diameter up to 10 µm. Particles under this diameter size penetrate the respiratory tract and can settle in the bronchi and alveoli causing health problems.

Causes of hospital admissions:

Cardiovascular:	Diseases concerning the heart or the circulatory system
Medical:	All non-infectious diseases excluding psychiatric disorders
Respiratory:	Diseases concerning the respiratory system

Statistical terms:

Lags:	Lag(0) refers to the day of the event Lag(1) refers to the day before the event Lag(2) refers to the day in the past separated from the day of the event by one day Lag(3) refers to the day in the past separated from the day of the event by two days etc... Lags are mainly used in the context of pollutant exposure, e.g. lag(2) of PM10 = 24hr-mean of PM10 two days before the event
K day average:	average of the 24hr-means of the respective pollutant on lag(0) through lag(K-1). For instance, the two day average of PM10 refers to the average of the 24hr-means of PM10 on the day of the event and the day before, while the four day average refers to the average of the 24hr-means of PM10 on the day of the event and the three preceding days. etc…

Polynomial distributed lag model: The effect of cumulative exposure over K days is written as a sum of contributions b(k)·x(k) where x(k) is the exposure level at lag(k) and b(k) is the effect of x(k). In the case of a polynomial distributed lag model, b(k) is modelled as a polynomial function.

Meta-analysis: Analysis summarizing results of different studies or from separate subsamples in an overall or combined result.

Meta-analytic estimate: Obtained as the result of a meta-analysis of study-specific estimates. Is also referred to as 'combined estimate' in this report.

Forest plot: Figure representing study-specific or stratum-specific estimates and their 95%-confidence intervals as parallel intervals along an axis. The estimates themselves are represented as dots within the intervals.

Relative risk: Ratio between a given risk among exposed persons and the corresponding risk among non-exposed persons.

% risk change[6]: Can be directly calculated from the relative risk as
(Relative Risk - 1) x 100

p-value: Probability with which an associationat least as strong as the one observed would have had to be expected a priori if no influence other than chance had been at work

Median: Value above and below which there are equal numbers of observations (syn. 50th percentile).

25th percentile: Value being larger than one quarter and smaller than 3 quarters of the data

75th percentile: Value being larger than 3 quarters and smaller than one quarter of the data.

[6] associated with a given exposure or change in exposure

9 Acknowledgments

We would like to thank the Federal Office of Statistics (FSO/BFS), the Statistical Offices of the cantons of Valais and Grisons, the Federal Office for the Environment (FOEN/BAFU), MeteoSwiss and the Federal Office of Public Health (FOPH/BAG) for providing the data for this study.

Furthermore, we would like to express our deep appreciation to Nino Künzli, Regula Rapp, Meltem Kultar Joss, Peter Straehl and Denise Felber for their professional advice and comments on this report.

10 References

1. Ackermann-Liebrich, U., et al., *Lung function and long term exposure to air pollutants in Switzerland. Study on Air Pollution and Lung Diseases in Adults (SAPALDIA) Team.* American Journal of Respiratory & Critical Care Medicine, 1997. **155**(1): p. 122-9.
2. Zemp, E., et al., *Long-term ambient air pollution and respiratory symptoms in adults (SAPALDIA study). The SAPALDIA Team.* American Journal of Respiratory & Critical Care Medicine, 1999. **159**(4 Pt 1): p. 1257-66.
3. Künzli, N., et al., *Clinically "small" effects of air pollution on FVC have a large public health impact. Swiss Study on Air Pollution and Lung Disease in Adults (SAPALDIA).* European Respiratory Journal, 2000. **15**(1): p. 131-6.
4. Downs, S.H., et al., *Reduced exposure to PM10 and attenuated age-related decline in lung function.* New England Journal of Medicine, 2007. **357**(23): p. 2338-47.
5. Atkinson, R.W., et al., *Acute effects of particulate air pollution on respiratory admissions: results from APHEA 2 project. Air Pollution and Health: a European Approach.* American Journal of Respiratory & Critical Care Medicine, 2001. **164**(10 Pt 1): p. 1860-6.
6. Le Tertre, A., et al., *Short-term effects of particulate air pollution on cardiovascular diseases in eight European cities.* Journal of Epidemiology & Community Health, 2002. **56**(10): p. 773-9.
7. Grize L, S.C., Schüpbach R, Alt GM, Gehrig R. , *Untersuchung des Einflusses der Feinstaubbelastung (PM10) auf die notfallmässigen Spitaleinweisungen in den Jahren 2001 bis 2006.* Schlussbericht. Basel/Zürich 2009. Bezugsquelle: http://www.feinstaub.ch/d_home_faq.cfm, 2009.
8. Katsouyanni, K., et al., *Short-term effects of air pollution on health: a European approach using epidemiological time-series data. The APHEA project: background, objectives, design.* Eur Respir J, 1995. **8**: p. 1030-38.
9. Kunzli, N. and L. Perez, *Evidence based public health - the example of air pollution.* Swiss Med Wkly, 2009. **139**(17-18): p. 242-50.
10. Perez, L. and N. Kunzli, *From measures of effects to measures of potential impact.* Int J Public Health, 2009. **54**(1): p. 45-8.
11. WHO, *World Health Organization. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment. WHO/SDE/PHE/OEH/06.02.*, 2005.
12. Dominici, F., et al., *Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases.* JAMA, 2006. **295**(10): p. 1127-34.
13. Nel, A., *Air pollution-related illness: Effects of particles.* Science, 2005. **308**: p. 804-806.
14. Mehta AJ, S.C., Perez L, Probst-Hensch N, Schwartz J, Brändl O, Karrer W, Tschopp JM, Rochat T, Künzli N; SAPALDIA Team., *Acute respiratory health effects of urban air pollutants in adults with different patterns underlying respiratory disease.* Swiss Medical Weekly, 2012. **142**: p. w13681.
15. Fusco, D., et al., *Air pollution and hospital admissions for respiratory conditions in Rome, Italy.* European Respiratory Journal, 2001. **17**(6): p. 1143-50.
16. Oftedal, B., et al., *Traffic related air pollution and acute hospital admission for respiratory diseases in Drammen, Norway 1995-2000.* European Journal of Epidemiology, 2003. **18**(7): p. 671-5.
17. Simpson, R., et al., *The short-term effects of air pollution on hospital admissions in four Australian cities.* Australian & New Zealand Journal of Public Health, 2005. **29**(3): p. 213-21.
18. Anderson, H.R., et al., *Meta-analysis of time series studies and panel studies of particulate matter (PM) and ozone (O3). Report of the WHO task group.*, 2004, WHO Regional Office for Europe: Copenhagen.
19. Chiusolo M, C.E., Stafoggia M, Galassi C, Berti G, Faustini A, Bisanti L, Vigotti MA, Dessì MP, Cernigliaro A, Mallone S, Pacelli B, Minerba S, Simonato L, Forastiere F.,

Short Term Effects of Nitrogen Dioxide on Mortality and Susceptibility Factors in Ten Italian Cities: the EpiAir Study., in *Environ Health Perspect*2011. p. [Epub ahead of print].
20. Wordley, J., S. Walters, and J.G. Ayres, *Short term variations in hospital admissions and mortality and particulate air pollution.* Occup Environ Med, 1997. **54**(2): p. 108-16.
21. Peel, J.L., et al., *Ambient air pollution and respiratory emergency department visits.* Epidemiology, 2005. **16**(2): p. 164-74.
22. Mehta, S.S., H.; Burnett,R.; North, T.; Cohen A.J.;, *Ambient particulate air pollution and acute lower respiratory infections: a systematic review and implications for estimating the global burden of disease.* Air Qual Atmos Health, 2013. **6**: p. 69-83.
23. Paul H.Fischer, M.M., Caroline B.Ameling, Nicole Janssen, Flemming R.Cassee, *Trends in relative riskestimates for the association between airpollution and mortality in The Netherlands,1992–2006.* Environmental Research, 2011. **111**: p. 94-100.
24. Shin H.H., S.D.M., Jessiman B., Goldberg M.S., Brion O., Brook J., Ramsay T., Burnett R.T. , *A temporal,multicity model to estimate the effects of short-term exposure to ambient air pollution on health.* Environ Health Perspect, 2008. **116**: p. 1147–1153.
25. Tolbert, P.E., et al., *Multipollutant modeling issues in a study of ambient air quality and emergency department visits in Atlanta.* Journal of Exposure Science & Environmental Epidemiology, 2007. **17 Suppl 2**: p. S29-35.
26. Moolgavkar, S.H., *Air pollution and hospital admissions for diseases of the circulatory system in three U.S. metropolitan areas.* J Air Waste Manag Assoc, 2000. **50**(7): p. 1199-206.
27. Ballester, F., et al., *Air pollution and cardiovascular admissions association in Spain: results within the EMECAS project.* Journal of Epidemiology & Community Health, 2006. **60**(4): p. 328-36.
28. Halonen, J.I., et al., *Urban air pollution, and asthma and COPD hospital emergency room visits.* Thorax, 2008. **63**(7): p. 635-41.
29. Schindler, C., et al., *Improvements in PM10 exposure and reduced rates of respiratory symptoms in a cohort of Swiss adults (SAPALDIA).* Am J Respir Crit Care Med, 2009. **179**(7): p. 579-87.
30. Brunekreef, B., et al., *Ten principles for clean air.* Eur Respir J, 2012. **39**(3): p. 525-8.
31. HEI, *HEI panel on the health effects of traffic-related air pollution. Traffic-related air pollution: a critical review o the literature on emissions, exposure, and health effects (preprint). HEI special report 17. Health Effects Institute. Boston, Mass. May. In press.*, 2009.
32. Kunzli, N., et al., *Investigating air pollution and atherosclerosis in humans: concepts and outlook.* Prog Cardiovasc Dis, 2011. **53**(5): p. 334-43.
33. Brook, R.D., *Cardiovascular effects of air pollution.* Clin Sci (Lond), 2008. **115**(6): p. 175-87.
34. Pope, C.A., 3rd and D.W. Dockery, *Health effects of fine particulate air pollution: lines that connect.* J Air Waste Manag Assoc, 2006. **56**(6): p. 709-42.
35. Pope, C.A., 3rd, M. Ezzati, and D.W. Dockery, *Fine-particulate air pollution and life expectancy in the United States.* N Engl J Med, 2009. **360**(4): p. 376-86.
36. Kunzli, N., et al., *Public-health impact of outdoor and traffic-related air pollution: a European assessment.* Lancet, 2000. **356**(9232): p. 795-801.
37. Hoek, G.K., RM; Beelen, R; Peters, A; Ostro, B; Brunekreef, B, *Long-term air pollution exposure and cardio- respiratory mortality: a review.* Environmental Health, 2013. **12**(43).

11 Appendix

11.1 Tables

Table 1. Population size of the different regions and their percentage taken into account in the analysis

Analysis Region	Total number of inhabitants in the region[§]	Number of inhabitants in the analysis region	% of inhabitants in a region integrated in the analysis
AG/BL/BS/SO (01)	659 192	659 192	100.0
BE/FR/SO (02)	527 776	484 235	91.8
AG/BE/LU/SO (03)	738 633	738 633	100.0
BE (04)	677 762	557 313	82.2
LU/ZG (05)	470 757	453 717	96.4
LU/NW/OW/SZ/UR (06)	201 997	156 976	77.7
TI Sottoceneri (07)	190 482	190 482	100.0
TI Sopraceneri/GR (08)	151 863	140 543	92.5
VS (09)*	314 478	186 550	59.3
SG/SH/SZ/ZH (10)	1 570 807	1 570 807	100.0
AI/AR/SG/TG (11)	578 366	523 349	90.5
AI/AR/FL/SG (12)	200 036	190 141	95.1
GR (13)*	186 533	91 637	49.1

*Based on communities instead of MedStat regions

[§]Population based on the 2010 Census

Table 2. Incidence of emergency hospital admissions in 2010 by cause and analysis region

Analysis Region	Number of inhabitants in the region[§]	Number of emergency hospital admissions in 2010			Incidence in 2010 Number of cases / 1000 inhabitants		
		All medical causes	Cardiovascular causes	Respiratory causes	All medical causes	Cardiovascular causes	Respiratory causes
AG/BL/BS/SO (01)	659 192	30 239	6 408	3 615	45.9	9.7	5.5
BE/FR/SO (02)	484 235	20 904	4 194	2 345	43.2	8.7	4.8
AG/BE/LU/SO (03)	738 633	27 598	6 127	3 157	37.4	8.3	4.3
BE (04)	557 313	23 891	5 420	2 831	42.9	9.7	5.1
LU/ZG (05)	453 717	16 645	3 535	1 755	36.7	7.8	3.9
LU/NW/OW/SZ/UR (06)	156 979	6 678	1 402	627	42.5	8.9	4.0
TI Sottoceneri (07)	190 482	10 678	2 608	1 205	56.1	13.7	6.3
TI Sopraceneri/GR (08)	140 543	8 413	1 810	1 088	59.9	12.9	7.7
VS (09)	186 550	7 135	1 288	716	38.2	6.9	3.8
SG/SH/SZ/ZH (10)	1 570 807	68 780	13 238	6 860	43.8	8.4	4.4
AI/AR/SG/TG (11)	523 349	22 711	4 539	2 296	43.4	8.7	4.4
AI/AR/FL/SG (12)	190 141	6 163	1 268	704	32.4	6.7	3.7
GR (13)	91 637	3 940	650	479	43.0	7.1	5.2

[§] Population based on the census of 2010

Table 3. Mortality in 2010 by cause and analysis region.

Analysis Region	Number of inhabitants in the region[§]	Number of deaths (2010)			Mortality rate (2010) Number of cases/1000 inhabitants		
		All medical causes	Respiratory causes	Cardiovascular causes	All medical causes	Respiratory causes	Cardiovascular causes
AG/BL/BS/SO (01)	659 192	5 525	355	1 973	8.4	0.5	3.0
BE/FR/SO (02)	484 235	3 536	256	1 326	7.3	0.5	2.7
AG/BE/LU/SO (03)	738 633	5 295	310	2 141	7.2	0.4	2.9
BE (04)	557 313	4 750	270	1 885	8.5	0.5	3.4
LU/ZG (05)	453 717	3 139	169	1 216	6.9	0.4	2.7
LU/NW/OW/SZ/UR (06)	156 979	1 027	65	423	6.5	0.4	2.7
TI Sottoceneri (07)	190 482	1 551	137	535	8.1	0.7	2.8
TI Sopraceneri/GR (08)	140 543	1 188	95	444	8.5	0.7	3.2
VS (09)	186 550	1 429	93	452	7.7	0.5	2.4
SG/SH/SZ/ZH (10)	1 570 807	10 988	581	4 072	7.0	0.4	2.6
AI/AR/SG/TG (11)	523 349	3 902	216	1 596	7.5	0.4	3.0
AI/AR/FL/SG (12)	190 141	1 124	82	466	5.9	0.4	2.5
GR (13)	91 637	695	51	253	7.6	0.6	2.8

[§] Population based on the census of 2010

Table 4. Meta-analytic relative risks of emergency hospital admissions due to medical causes for a 10 µg/m^3 increase in PM10 (by age groups and by PM10 exposure measures)

Age group	PM10 exposure	Regression coefficient	Relative risk	Relative risk 95% CI	p-value[§]	Heterogeneity test p-value[§#]	% change in number of cases	% change in number of cases 95% CI
All ages	Lag 0 days	0.00020	1.00196	1.00038 to 1.00354	0.015	0.268	0.19636	0.03851 to 0.35444
	Lag 1 days	0.00009	1.00088	0.99948 to 1.00227	0.216	0.430	0.08818	-0.0513 to 0.22790
	Lag 2 days	0.00020	1.00203	0.99998 to 1.00408	0.052	0.020	0.20313	-0.0017 to 0.40846
	Lag 3 days	0.00021	1.00214	1.00061 to 1.00367	0.006	0.164	0.21407	0.06107 to 0.36729
	2 days average	0.00017	1.00169	1.00011 to 1.00326	0.036	0.381	0.16901	0.01145 to 0.32681
	3 days average	0.00022	1.00221	1.00031 to 1.00410	0.022	0.218	0.22053	0.03133 to 0.41008
	4 days average	0.00027	1.00272	1.00054 to 1.00489	0.014	0.102	0.27173	0.05471 to 0.48920
	7 days average	0.00031	1.00312	1.00095 to 1.00529	0.005	0.189	0.31190	0.09501 to 0.52924
15 to 64	Lag 0 days	0.00025	1.00255	1.00052 to 1.00456	0.013	0.343	0.25464	0.05279 to 0.45688
	Lag 1 days	0.00020	1.00204	1.00010 to 1.00396	0.039	0.402	0.20356	0.01068 to 0.39681
	Lag 2 days	0.00028	1.00284	1.00046 to 1.00522	0.019	0.115	0.28412	0.04665 to 0.52214
	Lag 3 days	0.00024	1.00241	1.00078 to 1.00404	0.004	0.472	0.24131	0.07812 to 0.40477
	2 days average	0.00027	1.00271	1.00056 to 1.00485	0.013	0.375	0.27080	0.05695 to 0.48508
	3 days average	0.00032	1.00325	1.00077 to 1.00572	0.010	0.263	0.32462	0.07756 to 0.57229
	4 days average	0.00035	1.00354	1.00089 to 1.00619	0.009	0.214	0.35420	0.08964 to 0.61944
	7 days average	0.00030	1.00303	0.99998 to 1.00607	0.051	0.142	0.30274	-0.0014 to 0.60789
≥ 65	Lag 0 days	0.00027	1.00268	1.00070 to 1.00466	0.008	0.898	0.26837	0.07068 to 0.46643
	Lag 1 days	0.00007	1.00072	0.99872 to 1.00271	0.482	0.983	0.07164	-0.1278 to 0.27149
	Lag 2 days	0.00021	1.00207	1.00014 to 1.00400	0.035	0.522	0.20737	0.01470 to 0.40040
	Lag 3 days	0.00031	1.00309	1.00102 to 1.00515	0.003	0.253	0.30892	0.10289 to 0.51536
	2 days average	0.00020	1.00203	0.99987 to 1.00418	0.065	0.957	0.20272	-0.0128 to 0.41873
	3 days average	0.00025	1.00247	1.00020 to 1.00475	0.033	0.883	0.24733	0.02012 to 0.47504
	4 days average	0.00034	1.00336	1.00101 to 1.00570	0.005	0.712	0.33565	0.10173 to 0.57011
	7 days average	0.00047	1.00469	1.00215 to 1.00722	<0.001	0.892	0.46889	0.21557 to 0.72284
≥ 75	Lag 0 days	0.00034	1.00343	1.00103 to 1.00582	0.005	0.770	0.34278	0.10315 to 0.58298
	Lag 1 days	0.00022	1.00217	0.99975 to 1.00459	0.079	0.909	0.21708	-0.0247 to 0.45944
	Lag 2 days	0.00036	1.00359	1.00108 to 1.00609	0.005	0.364	0.35876	0.10862 to 0.60952
	Lag 3 days	0.00045	1.00454	1.00240 to 1.00668	<0.001	0.559	0.45412	0.24044 to 0.66824
	2 days average	0.00033	1.00331	1.00070 to 1.00593	0.013	0.878	0.33123	0.07000 to 0.59312
	3 days average	0.00042	1.00417	1.00141 to 1.00692	0.003	0.794	0.41655	0.14144 to 0.69241
	4 days average	0.00054	1.00539	1.00256 to 1.00822	<0.001	0.747	0.53913	0.25617 to 0.82287
	7 days average	0.00072	1.00726	1.00420 to 1.01033	<0.001	0.943	0.72646	0.42027 to 1.03358

[§]Statistical significance if p-value<0.05
[#] Chi^2-test of heterogeneity

.

Table 5. Meta-analytic relative risks of emergency hospital admissions due to cardiovascular causes for a 10 µg/m^3 increase in PM10 (by age groups and by PM10 exposure measures)

Age group	PM10 exposure	Regression coefficient	Relative risk	Relative risk 95% CI	p-value[§]	Heterogeneity test p-value[§#]	% change in number of cases	% change in number of cases 95% CI
All ages	Lag 0 days	0.00056	1.00559	1.00279 to 1.00839	<0.001	0.500	0.55939	0.27977 to 0.83977
	Lag 1 days	0.00016	1.00164	0.99882 to 1.00446	0.255	0.987	0.16388	-0.1178 to 0.44639
	Lag 2 days	0.00022	1.00222	0.99943 to 1.00500	0.119	0.419	0.22154	-0.0568 to 0.50068
	Lag 3 days	0.00007	1.00067	0.99818 to 1.00316	0.596	0.928	0.06735	-0.1811 to 0.31652
	2 days average	0.00043	1.00428	1.00123 to 1.00733	0.006	0.793	0.42811	0.12379 to 0.73334
	3 days average	0.00042	1.00422	1.00101 to 1.00742	0.010	0.670	0.42174	0.10170 to 0.74280
	4 days average	0.00036	1.00364	1.00035 to 1.00693	0.030	0.788	0.36404	0.03523 to 0.69392
	7 days average	0.00012	1.00118	0.99764 to 1.00474	0.513	0.967	0.11848	-0.2358 to 0.47407
15 to 64	Lag 0 days	0.00062	1.00618	1.00090 to 1.01148	0.022	0.511	0.61789	0.09017 to 1.14838
	Lag 1 days	0.00016	1.00158	0.99626 to 1.00692	0.560	0.636	0.15823	-0.3733 to 0.69262
	Lag 2 days	0.00019	1.00193	0.99654 to 1.00733	0.483	0.393	0.19256	-0.3455 to 0.73354
	Lag 3 days	-0.00010	0.99897	0.99428 to 1.00367	0.668	0.698	-0.10293	-0.5715 to 0.36789
	2 days average	0.00046	1.00458	0.99884 to 1.01035	0.118	0.482	0.45801	-0.1159 to 1.03522
	3 days average	0.00039	1.00394	0.99747 to 1.01044	0.233	0.373	0.39398	-0.2522 to 1.04439
	4 days average	0.00030	1.00297	0.99677 to 1.00920	0.348	0.458	0.29733	-0.3220 to 0.92057
	7 days average	-0.00014	0.99861	0.99195 to 1.00531	0.684	0.514	-0.13889	-0.8048 to 0.53150
≥ 65	Lag 0 days	0.00055	1.00551	1.00219 to 1.00883	0.001	0.841	0.55065	0.21921 to 0.88318
	Lag 1 days	0.00017	1.00174	0.99840 to 1.00509	0.307	0.973	0.17403	-0.1598 to 0.50902
	Lag 2 days	0.00024	1.00238	0.99916 to 1.00561	0.147	0.560	0.23815	-0.0837 to 0.56109
	Lag 3 days	0.00015	1.00151	0.99856 to 1.00446	0.315	0.626	0.15109	-0.1435 to 0.44661
	2 days average	0.00043	1.00429	1.00068 to 1.00790	0.020	0.940	0.42863	0.06801 to 0.79055
	3 days average	0.00043	1.00427	1.00047 to 1.00807	0.027	0.856	0.42692	0.04770 to 0.80756
	4 days average	0.00040	1.00405	1.00015 to 1.00795	0.042	0.750	0.40481	0.01525 to 0.79589
	7 days average	0.00025	1.00252	0.99831 to 1.00673	0.240	0.739	0.25175	-0.1681 to 0.67337
≥ 75	Lag 0 days	0.00063	1.00631	1.00229 to 1.01035	0.002	0.819	0.63148	0.22905 to 1.03552
	Lag 1 days	0.00045	1.00455	1.00049 to 1.00862	0.028	0.800	0.45519	0.04987 to 0.86215
	Lag 2 days	0.00047	1.00469	1.00077 to 1.00861	0.019	0.471	0.46876	0.07783 to 0.86121
	Lag 3 days	0.00030	1.00305	0.99946 to 1.00664	0.095	0.694	0.30497	-0.0530 to 0.66425
	2 days average	0.00064	1.00640	1.00202 to 1.01079	0.004	0.826	0.63993	0.20226 to 1.07950
	3 days average	0.00069	1.00689	1.00228 to 1.01151	0.003	0.767	0.68901	0.22881 to 1.15132
	4 days average	0.00068	1.00680	1.00206 to 1.01154	0.005	0.701	0.67973	0.20692 to 1.15477
	7 days average	0.00049	1.00492	0.99971 to 1.01015	0.064	0.423	0.49194	-0.0289 to 1.01557

[§]Statistical significance if p-value<0.05
[#] Chi^2-test of heterogeneity

.

Table 6. Meta-analytic relative risks of emergency hospital admissions due to respiratory causes for a 10 µg/m^3 increase in PM10 (by age groups and by PM10 exposure measures)

Age group	PM10 exposure	Regression coefficient	Relative risk	Relative risk 95% CI	p-value[§]	Heterogeneity test[§#] p-value	% change in number of cases	% change in number of cases 95% CI
All ages	Lag 0 days	-0.00010	0.99897	0.99520 to 1.00275	0.593	0.509	-0.10281	-0.4793 to 0.27516
	Lag 1 days	-0.00006	0.99937	0.99475 to 1.00399	0.788	0.209	-0.06328	-0.5240 to 0.39963
	Lag 2 days	0.00018	1.00182	0.99646 to 1.00719	0.507	0.044	0.18157	-0.3534 to 0.71950
	Lag 3 days	0.00039	1.00389	0.99898 to 1.00881	0.120	0.043	0.38898	-0.1010 to 0.88143
	2 days average	-0.00008	0.99919	0.99446 to 1.00393	0.736	0.279	-0.08141	-0.5538 to 0.39328
	3 days average	0.00003	1.00030	0.99448 to 1.00615	0.919	0.107	0.03037	-0.5510 to 0.61521
	4 days average	0.00022	1.00218	0.99567 to 1.00872	0.513	0.049	0.21762	-0.4329 to 0.87239
	7 days average	0.00050	1.00499	0.99611 to 1.01394	0.272	0.001	0.49875	-0.3886 to 1.39403
15 to 64	Lag 0 days	0.00036	1.00360	0.99623 to 1.01103	0.339	0.300	0.36047	-0.3766 to 1.10306
	Lag 1 days	0.00041	1.00412	0.99757 to 1.01070	0.218	0.889	0.41211	-0.2422 to 1.07077
	Lag 2 days	0.00052	1.00519	0.99886 to 1.01155	0.108	0.443	0.51901	-0.1132 to 1.15526
	Lag 3 days	0.00077	1.00773	1.00196 to 1.01352	0.009	0.864	0.77276	0.19617 to 1.35265
	2 days average	0.00040	1.00400	0.99693 to 1.01111	0.268	0.610	0.40019	-0.3063 to 1.11175
	3 days average	0.00052	1.00522	0.99780 to 1.01270	0.168	0.819	0.52248	-0.2196 to 1.27012
	4 days average	0.00074	1.00744	0.99982 to 1.01511	0.056	0.974	0.74398	-0.0178 to 1.51157
	7 days average	0.00100	1.01003	1.00182 to 1.01830	0.017	0.994	1.00288	0.18218 to 1.83029
≥ 65	Lag 0 days	0.00007	1.00070	0.99511 to 1.00631	0.807	0.405	0.06984	-0.4888 to 0.63170
	Lag 1 days	0.00032	1.00320	0.99776 to 1.00867	0.249	0.494	0.32028	-0.2236 to 0.86717
	Lag 2 days	0.00055	1.00549	0.99893 to 1.01207	0.101	0.182	0.54859	-0.1061 to 1.20761
	Lag 3 days	0.00081	1.00814	1.00174 to 1.01458	0.013	0.111	0.81449	0.17479 to 1.45827
	2 days average	0.00022	1.00222	0.99589 to 1.00859	0.492	0.363	0.22241	-0.4102 to 0.85911
	3 days average	0.00042	1.00421	0.99655 to 1.01191	0.282	0.198	0.42082	-0.3442 to 1.19176
	4 days average	0.00073	1.00731	0.99829 to 1.01639	0.112	0.070	0.73059	-0.1704 to 1.63979
	7 days average	0.00140	1.01410	1.00255 to 1.02577	0.017	0.008	1.40999	0.25557 to 2.57770
≥ 75	Lag 0 days	0.00052	1.00521	0.99798 to 1.01249	0.158	0.326	0.52134	-0.2015 to 1.24946
	Lag 1 days	0.00042	1.00420	0.99759 to 1.01084	0.214	0.512	0.41966	-0.2409 to 1.08464
	Lag 2 days	0.00078	1.00783	0.99955 to 1.01618	0.064	0.132	0.78321	-0.0448 to 1.61813
	Lag 3 days	0.00099	1.00992	1.00258 to 1.01731	0.008	0.165	0.99249	0.25885 to 1.73150
	2 days average	0.00055	1.00550	0.99751 to 1.01354	0.178	0.313	0.54974	-0.2482 to 1.35415
	3 days average	0.00078	1.00785	0.99809 to 1.01769	0.115	0.139	0.78489	-0.1901 to 1.76943
	4 days average	0.00111	1.01112	1.00003 to 1.02233	0.049	0.058	1.11239	0.00318 to 2.23389
	7 days average	0.00184	1.01852	1.00436 to 1.03287	0.010	0.006	1.85194	0.43642 to 3.28741

[§]Statistical significance if p-value<0.05
[#] Chi^2-test of heterogeneity

Table 7. Meta-analytic relative risks for mortality due to medical causes for a 10 µg/m^3 increase in pollutant (by age groups and by pollutant exposure measures)

Pollutant	Age group	PM10 exposure	Relative risk	95% CI (Relative risk)	p-value[§]	Heterogeneity test p-value[§#]
NO_2	all	2 days average	1.007	1.001 to 1.013	0.022	0.002
		4 days average	1.012	1.006 to 1.019	<0.001	0.003
		7 days average	1.018	1.010 to 1.026	<0.001	<0.001
	≥65	2 days average	1.006	1.000 to 1.013	0.042	0.007
		4 days average	1.013	1.005 to 1.019	0.001	0.005
		7 days average	1.020	1.011 to 1.028	<0.001	<0.001
	≥75	2 days average	1.006	1.000 to 1.012	0.053	0.036
		4 days average	1.012	1.006 to 1.018	<0.001	0.140
		7 days average	1.020	1.012 to 1.027	<0.001	0.038
PM10	all	2 days average	1.002	0.999 to 1.006	0.189	0.279
		4 days average	1.005	1.002 to 1.008	0.002	0.534
		7 days average	1.008	1.004 to 1.011	<0.001	0.345
	≥65	2 days average	1.002	0.998 to 1.005	0.311	0.355
		4 days average	1.006	1.002 to 1.010	0.003	0.312
		7 days average	1.009	1.005 to 1.014	<0.001	0.170
	≥75	2 days average	1.004	0.999 to 1.008	0.126	0.160
		4 days average	1.007	1.002 to 1.012	0.003	0.193
		7 days average	1.011	1.005 to 1.016	<0.001	0.139

[§]Statistical significance if p-value<0.05
[#] Chi^2-test of heterogeneity

Table 8. Meta-analytic relative risks for mortality due to cardiovascular causes for a 10 µg/m^3 increase in pollutant (by age groups and by pollutant exposure measures)

Pollutant	Age group	PM10 exposure	Relative risk	95% CI (Relative risk)	p-value[§]	Heterogeneity test p-value[§#]
NO_2	all	2 days average	1.004	0.999 to 1.008	0.139	0.643
		4 days average	1.012	1.005 to 1.019	0.001	0.211
		7 days average	1.019	1.011 to 1.027	0.000	0.168
	≥65	2 days average	1.003	0.998 to 1.008	0.208	0.74
		4 days average	1.012	1.005 to 1.018	0.001	0.273
		7 days average	1.019	1.011 to 1.027	0.000	0.171
	≥75	2 days average	1.003	0.997 to 1.008	0.316	0.771
		4 days average	1.011	1.005 to 1.018	0.001	0.358
		7 days average	1.020	1.012 to 1.029	0.000	0.170
PM10	all	2 days average	1.003	0.998 to 1.008	0.296	0.352
		4 days average	1.006	1.001 to 1.011	0.019	0.542
		7 days average	1.009	1.002 to 1.016	0.008	0.210
	≥65	2 days average	1.001	0.996 to 1.006	0.590	0.433
		4 days average	1.005	1.000 to 1.010	0.075	0.397
		7 days average	1.009	1.002 to 1.016	0.008	0.199
	≥75	2 days average	1.003	0.997 to 1.009	0.370	0.246
		4 days average	1.007	1.001 to 1.013	0.034	0.273
		7 days average	1.011	1.003 to 1.018	0.007	0.162

[§]Statistical significance if p-value<0.05
[#] Chi^2-test of heterogeneity

Table 9. Meta-analytic relative risks for mortality due to respiratory causes for a 10 µg/m^3 increase in pollutant (by age groups and by pollutant exposure measures)

Pollutant	Age group	PM10 exposure	Relative risk	95% CI (Relative risk)	p-value[§]	Heterogeneity test p-value[§#]
NO_2	all	2 days average	1.027	1.005 to 1.050	0.016	0.005
		4 days average	1.027	1.005 to 1.050	0.016	0.005
		7 days average	1.043	1.014 to 1.072	0.004	0.000
	≥65	2 days average	1.028	1.007 to 1.049	0.008	0.027
		4 days average	1.028	1.007 to 1.049	0.008	0.027
		7 days average	1.044	1.019 to 1.071	0.001	0.003
	≥75	2 days average	1.026	1.004 to 1.048	0.022	0.031
		4 days average	1.026	1.004 to 1.048	0.022	0.031
		7 days average	1.039	1.014 to 1.065	0.002	0.013
PM10	all	2 days average	1.017	1.002 to 1.033	0.029	0.097
		4 days average	1.017	1.002 to 1.033	0.029	0.097
		7 days average	1.020	1.006 to 1.034	0.005	0.323
	≥65	2 days average	1.017	0.999 to 1.035	0.058	0.029
		4 days average	1.017	0.999 to 1.035	0.058	0.029
		7 days average	1.022	1.008 to 1.035	0.001	0.474
	≥75	2 days average	1.019	1.001 to 1.036	0.036	0.077
		4 days average	1.019	1.001 to 1.036	0.036	0.077
		7 days average	1.024	1.010 to 1.039	<0.001	0.592

[§]Statistical significance if p-value<0.05
[#] Chi^2-test of heterogeneity

Table 10. Pearsons's correlation coefficients between the daily measurements* of PM10, NO_2 and summer O_3.

Analysis region	PM10 and NO_2			PM10 and $O_{3\ (summer)}$			NO_2 and $O_{3\ (summer)}$		
	N	Correlation coefficient	p-value	N	Correlation coefficient	p-value	N	Correlation coefficient	p-value
AG/BL/BS/SO (01))	3652	0.7703	<0.001	1840	0.0124	0.595	2944	-0.4480	<0.001
BE/FR/SO (02)	3652	0.7487	<0.001	1840	-0.0518	0.026	2944	-0.4368	<0.001
AG/BE/LU/SO (03)	3652	0.5092	<0.001	1840	-0.1262	<0.001	2944	-0.3643	<0.001
BE (04)	3652	0.5797	<0.001	1840	0.0777	<0.001	2392	-0.5940	<0.001
LU/ZG (05)	3652	0.6289	<0.001	1840	-0.0475	0.042	2944	-0.4024	<0.001
LU/NW/OW/SZ/UR (06)	3652	0.6319	<0.001	1840	-0.0167	0.474	2208	-0.4309	<0.001
TI Sottoceneri (07)	3652	0.6592	<0.001	1840	0.0573	0.014	2944	-0.5021	<0.001
TI Sopraceneri/GR (08)	3652	0.7454	<0.001	1840	0.0093	0.689	2944	-0.4461	<0.001
VS (09)	3652	0.7234	<0.001	1840	-0.0932	<0.001	2944	-0.3516	<0.001
SG/SH/SZ/ZH (10)	3652	0.7193	<0.001	1840	-0.1015	<0.001	2944	-0.3861	<0.001
AI/AR/SG/TG (11)	3652	0.7459	<0.001	1840	-0.0170	0.466	2944	-0.5141	<0.001
AI/AR/FL/SG (10)	3652	0.7707	<0.001	1840	-0.0059	0.800	2208	-0.5566	<0.001
GR (13)	3652	0.5612	<0.001	1840	0.2021	<0.001	2821	-0.2036	<0.001

*For the period 2001-2010

Table 11. One (PM10) and two pollutant (PM10 and NO_2) models: Meta-analytic relative risks of emergency hospital admissions due to medical causes for a 10 µg/m^3 increase in air pollutant (by age groups and by air pollutant exposure measures)

Age group	Air pollutant exposure	PM10 load (one pollutant model)			PM10 load (two pollutant model, PM10 and NO_2)			NO_2 load (two pollutant model, PM10 and NO_2)		
		Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]	Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]	Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]
All ages	Lag 0 days	1.00196	1.00038 to 1.00354	0.268	0.99851	0.99662 to 1.00039	0.329	1.00857	1.00593 to 1.01120	0.282
	Lag 1 days	1.00088	0.99948 to 1.00227	0.430	1.00316	1.00143 to 1.00489	0.884	0.99440	0.99154 to 0.99727	0.199
	Lag 2 days	1.00203	0.99998 to 1.00408	0.020	1.00354	1.00182 to 1.00524	0.496	0.99669	0.99450 to 0.99888	0.617
	Lag 3 days	1.00214	1.00061 to 1.00367	0.164	1.00172	0.99971 to 1.00373	0.179	1.00156	0.99881 to 1.00431	0.164
	2 days average	1.00169	1.00011 to 1.00326	0.381	1.00760	1.00415 to 1.01104	0.942	0.99267	0.98837 to 0.99698	0.411
	3 days average	1.00221	1.00031 to 1.00410	0.218	1.00242	1.00034 to 1.00450	0.843	0.99977	0.99692 to 1.00262	0.522
	4 days average	1.00272	1.00054 to 1.00489	0.102	1.00269	1.00048 to 1.00490	0.661	1.00060	0.99754 to 1.00365	0.538
	7 days average	1.00312	1.00095 to 1.00529	0.187	1.00321	1.00071 to 1.00570	0.947	1.00069	0.99717 to 1.00421	0.563
15 to 64	Lag 0 days	1.00255	1.00052 to 1.00456	0.343	0.99922	0.99680 to 1.00163	0.400	1.00783	1.00401 to 1.01165	0.205
	Lag 1 days	1.00204	1.00010 to 1.00396	0.402	1.00480	1.00246 to 1.00713	0.697	0.99248	0.98843 to 0.99654	0.147
	Lag 2 days	1.00284	1.00046 to 1.00522	0.115	1.00408	1.00178 to 1.00638	0.673	0.99685	0.99395 to 0.99974	0.762
	Lag 3 days	1.00241	1.00078 to 1.00404	0.472	1.00159	0.99882 to 1.00436	0.169	1.00141	0.99797 to 1.00485	0.243
	2 days average	1.00271	1.00056 to 1.00485	0.375	1.01105	1.00642 to 1.01568	0.732	0.98952	0.98404 to 0.99501	0.453
	3 days average	1.00325	1.00077 to 1.00572	0.263	1.00372	1.00093 to 1.00652	0.787	0.99852	0.99439 to 1.00266	0.366
	4 days average	1.00354	1.00089 to 1.00619	0.214	1.00380	1.00084 to 1.00675	0.491	0.99955	0.99553 to 1.00357	0.440
	7 days average	1.00303	0.99998 to 1.00607	0.142	1.00316	0.99979 to 1.00653	0.429	1.00030	0.99576 to 1.00484	0.584
≥ 65	Lag 0 days	1.00268	1.00070 to 1.00466	0.898	0.99854	0.99605 to 1.00102	0.577	1.01019	1.00593 to 1.01444	0.164
	Lag 1 days	1.00072	0.99872 to 1.00271	0.983	1.00224	0.99973 to 1.00475	0.972	0.99637	0.99271 to 1.00003	0.329
	Lag 2 days	1.00207	1.00014 to 1.00400	0.522	1.00306	1.00057 to 1.00553	0.720	0.99738	0.99421 to 1.00055	0.7247
	Lag 3 days	1.00309	1.00102 to 1.00515	0.253	1.00206	0.99913 to 1.00499	0.172	1.00244	0.99942 to 1.00546	0.578
	2 days average	1.00203	0.99987 to 1.00418	0.957	1.00478	0.99981 to 1.00976	0.948	0.99652	0.99052 to 1.00254	0.644
	3 days average	1.00247	1.00020 to 1.00475	0.883	1.00159	0.99859 to 1.00460	0.786	1.00196	0.99713 to 1.00680	0.289
	4 days average	1.00336	1.00101 to 1.00570	0.712	1.00206	0.99889 to 1.00524	0.681	1.00291	0.99805 to 1.00779	0.347
	7 days average	1.00469	1.00215 to 1.00722	0.892	1.00356	0.99998 to 1.00714	0.900	1.00295	0.99798 to 1.00793	0.758
≥ 75	Lag 0 days	1.00343	1.00103 to 1.00582	0.770	0.99869	0.99568 to 1.00170	0.599	1.01018	1.00635 to 1.01402	0.561
	Lag 1 days	1.00217	0.99975 to 1.00459	0.909	1.00257	0.99953 to 1.00560	0.997	0.99811	0.99233 to 1.00391	0.066
	Lag 2 days	1.00359	1.00108 to 1.00609	0.364	1.00422	1.00122 to 1.00722	0.811	0.99781	0.99326 to 1.00237	0.277
	Lag 3 days	1.00454	1.00240 to 1.00668	0.559	1.00348	1.00062 to 1.00633	0.667	1.00262	0.99899 to 1.00625	0.767
	2 days average	1.00331	1.00070 to 1.00593	0.878	1.00441	0.99842 to 1.01042	0.914	0.99897	0.99010 to 1.00791	0.233
	3 days average	1.00417	1.00141 to 1.00692	0.794	1.00211	0.99848 to 1.00574	0.914	1.00411	0.99778 to 1.01046	0.194
	4 days average	1.00539	1.00256 to 1.00822	0.747	1.00304	0.99921 to 1.00688	0.977	1.00477	0.99953 to 1.01002	0.470
	7 days average	1.00726	1.00420 to 1.01033	0.943	1.00612	1.00180 to 1.01044	0.993	1.00286	0.99694 to 1.00881	0.624

[§]Statistical significance if p-value<0.05
[#] Chi^2-test of heterogeneity

Table 12. One (PM10) and two pollutant (PM10 and NO_2) models: Meta-analytic relative risks of emergency hospital admissions due to cardiovascular causes for a 10 µg/m^3 increase in air pollutant (by age groups and by air pollutant exposure measures)

Age group	Air pollutant exposure	PM10 load (one pollutant model)			PM10 load (two pollutant model, PM10 and NO_2)			NO_2 load (two pollutant model, PM10 and NO_2)		
		Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]	Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]	Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]
All ages	Lag 0 days	1.00559	1.00279 to 1.00839	0.500	1.00149	0.99746 to 1.00553	0.270	1.00940	1.00498 to 1.01383	0.595
	Lag 1 days	1.00164	0.99882 to 1.00446	0.987	1.00359	1.00006 to 1.00712	0.935	0.99522	0.99077 to 0.99967	0.828
	Lag 2 days	1.00222	0.99943 to 1.00500	0.419	1.00456	1.00107 to 1.00806	0.690	0.99468	0.99030 to 0.99907	0.962
	Lag 3 days	1.00067	0.99818 to 1.00316	0.928	1.00068	0.99737 to 1.00400	0.712	0.99993	0.99575 to 1.00411	0.604
	2 days average	1.00428	1.00123 to 1.00733	0.793	1.00808	1.00112 to 1.01506	0.919	0.99623	0.98791 to 1.00462	0.946
	3 days average	1.00422	1.00101 to 1.00742	0.670	1.00423	1.00002 to 1.00845	0.526	1.00002	0.99441 to 1.00565	0.834
	4 days average	1.00364	1.00035 to 1.00693	0.788	1.00362	0.99918 to 1.00806	0.534	0.99991	0.99395 to 1.00589	0.647
	7 days average	1.00118	0.99764 to 1.00474	0.967	1.00019	0.99524 to 1.00514	0.688	1.00183	0.99512 to 1.00857	0.731
15 to 64	Lag 0 days	1.00618	1.00090 to 1.01148	0.511	1.00251	0.99547 to 1.00959	0.372	1.00783	0.99959 to 1.01611	0.829
	Lag 1 days	1.00158	0.99626 to 1.00692	0.636	1.00395	0.99578 to 1.01217	0.198	0.99136	0.98024 to 1.00259	0.176
	Lag 2 days	1.00193	0.99654 to 1.00733	0.393	1.00709	1.00050 to 1.01372	0.541	0.99138	0.98324 to 0.99958	0.827
	Lag 3 days	0.99897	0.99428 to 1.00367	0.698	1.00067	0.99442 to 1.00695	0.610	0.99742	0.98964 to 1.00526	0.900
	2 days average	1.00458	0.99884 to 1.01035	0.482	1.01075	0.99306 to 1.02875	0.115	0.99058	0.97157 to 1.00995	0.251
	3 days average	1.00394	0.99747 to 1.01044	0.373	1.00579	0.99589 to 1.01578	0.177	0.99522	0.98485 to 1.00568	0.635
	4 days average	1.00297	0.99677 to 1.00920	0.458	1.00476	0.99435 to 1.01528	0.177	0.99441	0.98343 to 1.00550	0.736
	7 days average	0.99861	0.99195 to 1.00531	0.514	0.99908	0.98749 to 1.01078	0.176	0.99586	0.98353 to 1.00832	0.803
≥ 65	Lag 0 days	1.00551	1.00219 to 1.00883	0.841	1.00167	0.99751 to 1.00583	0.786	1.00998	1.00402 to 1.01596	0.340
	Lag 1 days	1.00174	0.99840 to 1.00509	0.973	1.00310	0.99891 to 1.00730	0.999	0.99681	0.99153 to 1.00211	0.883
	Lag 2 days	1.00238	0.99916 to 1.00561	0.560	1.00371	0.99957 to 1.00786	0.869	0.99568	0.99048 to 1.00090	0.981
	Lag 3 days	1.00151	0.99856 to 1.00446	0.626	1.00095	0.99702 to 1.00490	0.515	1.00075	0.99579 to 1.00573	0.777
	2 days average	1.00429	1.00068 to 1.00790	0.940	1.00591	0.99767 to 1.01421	0.997	0.99889	0.98898 to 1.00888	0.936
	3 days average	1.00427	1.00047 to 1.00807	0.856	1.00361	0.99861 to 1.00861	0.985	1.00110	0.99445 to 1.00778	0.903
	4 days average	1.00405	1.00015 to 1.00795	0.750	1.00321	0.99795 to 1.00848	0.966	1.00117	0.99411 to 1.00826	0.928
	7 days average	1.00252	0.99831 to 1.00673	0.739	1.00083	0.99497 to 1.00671	0.829	1.00283	0.99490 to 1.01082	0.916
≥ 75	Lag 0 days	1.00631	1.00229 to 1.01035	0.819	1.00214	0.99710 to 1.00721	0.958	1.00999	1.00362 to 1.01639	0.606
	Lag 1 days	1.00455	1.00049 to 1.00862	0.800	1.00463	0.99955 to 1.00974	0.999	0.99863	0.99222 to 1.00507	0.730
	Lag 2 days	1.00469	1.00077 to 1.00861	0.471	1.00533	1.00030 to 1.01038	0.993	0.99655	0.99024 to 1.00289	0.660
	Lag 3 days	1.00305	0.99946 to 1.00664	0.694	1.00176	0.99697 to 1.00655	0.824	1.00230	0.99627 to 1.00836	0.882
	2 days average	1.00640	1.00202 to 1.01079	0.826	1.00769	0.99768 to 1.01780	0.996	0.99957	0.98755 to 1.01172	0.892
	3 days average	1.00689	1.00228 to 1.01151	0.767	1.00504	0.99898 to 1.01112	0.999	1.00282	0.99474 to 1.01095	0.790
	4 days average	1.00680	1.00206 to 1.01154	0.701	1.00465	0.99827 to 1.01106	0.999	1.00341	0.99483 to 1.01206	0.892
	7 days average	1.00492	0.99971 to 1.01015	0.423	1.00228	0.99517 to 1.00943	0.877	1.00441	0.99475 to 1.01415	0.962

[§]Statistical significance if p-value<0.05
[#] Ch^{i2}-test of heterogeneity

Table 13. One (PM10) and two pollutant (PM10 and NO_2) models: Meta-analytic relative risks of emergency hospital admissions due to respiratory causes for a 10 µg/m^3 increase in air pollutant (by age groups and by air pollutant exposure measures)

Age group	Air pollutant exposure	PM10 load (one pollutant model)			PM10 load (two pollutant model, PM10 and NO_2)			NO_2 load (two pollutant model, PM10 and NO_2)		
		Relative risk	95% CI (Relative risk)	Heterogeneity test[§#] p-value	Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]	Relative risk	95% CI (Relative risk)	Heterogeneity test p-value[§#]
All ages	Lag 0 days	0.99897	0.99520 to 1.00275	0.509	0.99636	0.99093 to 1.00181	0.285	1.00678	0.99686 to 1.01680	0.030
	Lag 1 days	0.99937	0.99475 to 1.00399	0.209	1.00074	0.99495 to 1.00654	0.210	0.99654	0.98721 to 1.00594	0.070
	Lag 2 days	1.00182	0.99646 to 1.00719	0.044	1.00300	0.99715 to 1.00888	0.181	0.99752	0.98827 to 1.00685	0.063
	Lag 3 days	1.00389	0.99898 to 1.00881	0.043	1.00399	0.99725 to 1.01076	0.030	1.00299	0.99233 to 1.01375	0.003
	2 days average	0.99919	0.99446 to 1.00393	0.279	1.00336	0.99258 to 1.01424	0.313	0.99331	0.97876 to 1.00807	0.211
	3 days average	1.00030	0.99448 to 1.00615	0.107	1.00048	0.99339 to 1.00762	0.189	1.00113	0.98682 to 1.01564	0.005
	4 days average	1.00218	0.99567 to 1.00872	0.049	1.00259	0.99451 to 1.01072	0.114	1.00271	0.98652 to 1.01917	0.002
	7 days average	1.00499	0.99611 to 1.01394	0.001	1.00384	0.99211 to 1.01570	0.005	1.00864	0.98643 to 1.03134	<0.001
15 to 64	Lag 0 days	1.00360	0.99623 to 1.01103	0.300	1.00002	0.99033 to 1.00980	0.236	1.00925	0.99820 to 1.02040	0.396
	Lag 1 days	1.00412	0.99757 to 1.01070	0.889	1.00071	0.99247 to 1.00901	0.636	1.00699	0.99299 to 1.02118	0.172
	Lag 2 days	1.00519	0.99886 to 1.01155	0.443	1.00054	0.99242 to 1.00872	0.574	1.00795	0.99714 to 1.01886	0.412
	Lag 3 days	1.00773	1.00196 to 1.01352	0.864	1.00468	0.99695 to 1.01247	0.582	1.00646	0.99508 to 1.01795	0.306
	2 days average	1.00400	0.99693 to 1.01111	0.610	0.99777	0.98152 to 1.01428	0.461	1.00798	0.98622 to 1.03020	0.365
	3 days average	1.00522	0.99780 to 1.01270	0.819	0.99845	0.98869 to 1.00830	0.537	1.01154	0.99358 to 1.02981	0.145
	4 days average	1.00744	0.99982 to 1.01511	0.974	0.99998	0.98972 to 1.01033	0.644	1.01248	0.99294 to 1.03239	0.113
	7 days average	1.01003	1.00182 to 1.01830	0.994	1.00032	0.98890 to 1.01185	0.666	1.01352	0.99094 to 1.03660	0.077
≥ 65	Lag 0 days	1.00070	0.99511 to 1.00631	0.405	0.99704	0.99020 to 1.00391	0.454	1.00519	0.99642 to 1.01403	0.563
	Lag 1 days	1.00320	0.99776 to 1.00867	0.494	1.00701	1.00010 to 1.01395	0.523	0.99133	0.97918 to 1.00361	0.139
	Lag 2 days	1.00549	0.99893 to 1.01207	0.182	1.00763	1.00082 to 1.01449	0.732	0.99743	0.98456 to 1.01046	0.080
	Lag 3 days	1.00814	1.00174 to 1.01458	0.111	1.00523	0.99637 to 1.01416	0.083	1.01074	0.99628 to 1.02540	0.009
	2 days average	1.00222	0.99589 to 1.00859	0.363	1.01481	1.00072 to 1.02909	0.427	0.98169	0.96169 to 1.00209	0.237
	3 days average	1.00421	0.99655 to 1.01191	0.198	1.00597	0.99765 to 1.01434	0.508	0.99745	0.98192 to 1.01321	0.138
	4 days average	1.00731	0.99829 to 1.01639	0.070	1.00778	0.99743 to 1.01824	0.242	1.00353	0.98438 to 1.02305	0.035
	7 days average	1.01410	1.00255 to 1.02577	0.008	1.01023	0.99266 to 1.02811	0.002	1.01650	0.98662 to 1.04727	<0.001
≥ 75	Lag 0 days	1.00521	0.99798 to 1.01249	0.326	1.00042	0.99124 to 1.00968	0.317	1.00587	0.99491 to 1.01695	0.425
	Lag 1 days	1.00420	0.99759 to 1.01084	0.512	1.00845	1.00006 to 1.01690	0.477	0.98853	0.97701 to 1.00017	0.389
	Lag 2 days	1.00783	0.99955 to 1.01618	0.132	1.00952	1.00124 to 1.01785	0.499	0.99594	0.98169 to 1.01039	0.154
	Lag 3 days	1.00992	1.00258 to 1.01731	0.165	1.00894	0.99946 to 1.01851	0.212	1.00849	0.99186 to 1.02539	0.018
	2 days average	1.00550	0.99751 to 1.01354	0.313	1.01597	0.99916 to 1.03306	0.553	0.98211	0.96223 to 1.00239	0.445
	3 days average	1.00785	0.99809 to 1.01769	0.139	1.00930	0.99832 to 1.02040	0.338	0.99559	0.97883 to 1.01262	0.255
	4 days average	1.01112	1.00003 to 1.02233	0.058	1.01210	0.99903 to 1.02532	0.191	1.00200	0.97934 to 1.02517	0.042
	7 days average	1.01852	1.00436 to 1.03287	0.006	1.01881	0.99894 to 1.03906	0.007	1.00801	0.97578 to 1.04130	0.001

[§]Statistical significance if p-value<0.05

[#] Chi^2-test of heterogeneity

Table 14. Parallel effects of pollutants on mortality by age groups and causes.

Pollutant	Age group	Cause of death*	Single-pollutant models				Two-pollutant models				
			Combined relative risk (for an increase of 10 µg/m^3)	95% confidence interval	p-value	p-value for heterogeneity	Combined relative risk (for an increase of 10 µg/m^3)	95% confidence interval	p-value	p-value for heterogeneity	***Second pollutant in the model***
NO_2	all	medical	1.007	1.001 to 1.013	0.022	0.002	1.005	0.998 to 1.012	0.193	0.083	PM10
		respiratory	1.027	1.005 to 1.050	0.016	0.005	1.019	0.984 to 1.055	0.293	0.017	PM10
		cardiovascular	1.004	0.999 to 1.008	0.139	0.643	1.003	0.996 to 1.011	0.418	0.464	PM10
	≥65	medical	1.006	1.000 to 1.013	0.042	0.007	1.005	0.998 to 1.011	0.144	0.313	PM10
		respiratory	1.028	1.007 to 1.049	0.008	0.027	1.019	0.986 to 1.054	0.259	0.054	PM10
		cardiovascular	1.003	0.998 to 1.008	0.208	0.74	1.000	0.992 to 1.008	0.986	0.676	PM10
	≥75	medical	1.006	1.000 to 1.012	0.053	0.036	1.006	0.997 to 1.014	0.183	0.131	PM10
		respiratory	1.026	1.004 to 1.048	0.022	0.031	1.017	0.992 to 1.042	0.196	0.637	PM10
		cardiovascular	1.003	0.997 to 1.008	0.316	0.771	1.003	0.994 to 1.011	0.556	0.607	PM10
NO_2	all	medical	1.007	1.001 to 1.013	0.022	0.002	1.011	1.003 to 1.018	0.006	<0.001	O_3
		respiratory	1.027	1.005 to 1.050	0.016	0.005	1.046	1.022 to 1.070	0.000	0.013	O_3
		cardiovascular	1.004	0.999 to 1.008	0.139	0.643	1.006	0.998 to 1.013	0.157	0.129	O_3
	≥65	medical	1.006	1.000 to 1.013	0.042	0.007	1.010	1.002 to 1.018	0.012	0.001	O_3
		respiratory	1.028	1.007 to 1.049	0.008	0.027	1.046	1.022 to 1.071	0.000	0.019	O_3
		cardiovascular	1.003	0.998 to 1.008	0.208	0.74	1.004	0.997 to 1.012	0.243	0.213	O_3
	≥75	medical	1.006	1.000 to 1.012	0.053	0.036	1.010	1.003 to 1.017	0.005	0.035	O_3
		respiratory	1.026	1.004 to 1.048	0.022	0.031	1.042	1.017 to 1.068	0.001	0.028	O_3
		cardiovascular	1.003	0.997 to 1.008	0.316	0.771	1.004	0.997 to 1.012	0.295	0.269	O_3

*The time window of exposure for medical and cardiovascular causes was the two day mean and for respiratory causes the four day mean

Table 14. Continuation.

Pollutant	Age group	Cause of death*	Single-pollutant models				Two-pollutant models				
			Combined relative risk (for an increase of 10 $\mu g/m^3$)	95% confidence interval	p-value	p-value for heterogeneity	Combined relative risk (for an increase of 10 $\mu g/m^3$)	95% confidence interval	p-value	p-value for heterogeneity	***Second pollutant in the model***
PM10	all	medical	1.002	0.999 to 1.006	0.189	0.279	1.001	0.997 to 1.005	0.665	0.518	NO_2
		respiratory	1.017	1.002 to 1.033	0.029	0.097	1.008	0.985 to 1.031	0.507	0.029	NO_2
		cardiovascular	1.003	0.998 to 1.008	0.296	0.352	1.002	0.995 to 1.009	0.577	0.229	NO_2
	≥65	medical	1.002	0.998 to 1.005	0.311	0.355	1.000	0.996 to 1.004	0.988	0.633	NO_2
		respiratory	1.017	0.999 to 1.035	0.058	0.029	1.007	0.982 to 1.032	0.591	0.016	NO_2
		cardiovascular	1.001	0.996 to 1.006	0.590	0.433	1.001	0.994 to 1.009	0.713	0.240	NO_2
	≥75	medical	1.004	0.999 to 1.008	0.126	0.16	1.002	0.996 to 1.007	0.495	0.229	NO_2
		respiratory	1.019	1.001 to 1.036	0.036	0.077	1.008	0.984 to 1.032	0.523	0.067	NO_2
		cardiovascular	1.003	0.997 to 1.009	0.370	0.246	1.003	0.994 to 1.011	0.538	0.174	NO_2
PM10	all	medical	1.002	0.999 to 1.006	0.189	0.279	1.003	1.000 to 1.007	0.062	0.344	O_3
		respiratory	1.017	1.002 to 1.033	0.029	0.097	1.021	1.005 to 1.037	0.011	0.093	O_3
		cardiovascular	1.003	0.998 to 1.008	0.296	0.352	1.003	0.998 to 1.009	0.233	0.326	O_3
	≥65	medical	1.002	0.998 to 1.005	0.311	0.355	1.002	0.999 to 1.006	0.184	0.400	O_3
		respiratory	1.017	0.999 to 1.035	0.058	0.029	1.021	1.002 to 1.039	0.026	0.030	O_3
		cardiovascular	1.001	0.996 to 1.006	0.590	0.433	1.002	0.997 to 1.008	0.437	0.387	O_3
	≥75	medical	1.004	0.999 to 1.008	0.126	0.16	1.004	1.000 to 1.009	0.058	0.191	O_3
		respiratory	1.019	1.001 to 1.036	0.036	0.077	1.023	1.005 to 1.041	0.014	0.085	O_3
		cardiovascular	1.003	0.997 to 1.009	0.370	0.246	1.003	0.997 to 1.010	0.303	0.214	O_3

*The time window of exposure for medical and cardiovascular causes was the two day mean and for respiratory causes the four day mean

Table 15. Description of changes in exposure under two hypothesized abatement scenarios during the study period, by regions

Region	PM10 (2001-2010)					NO_2 (1995-2010)				
	days in time-series	average in study perdiod (µg/m³)	average change between first year and last year of study period (µg/m³)	Hypothesized change in exposure during study period (in µg/m³)		days in time-series	average (µg/m³)	average change between first year and last year of study period (µg/m³)	Hypothesized change in exposure during study period (in µg/m³)	
				scenario 1: no day above 50 µg/m³	scenario 2: reduction by 20% of any daily level				scenario 1: no day above 80 µg/m³	scenario 2: reduction by 20% of any daily level
AG/BL/BS/SO (01)	3652	21.5	-4.4	-0.6	-4.3	5844	26.6	-1.0	0.0	-5.3
BE/FR/SO (02)	3652	20.0	-1.9	-0.5	-4.0	5844	16.2	1.2	0.0	-3.2
AG/BE/LU/SO (03)	3652	25.3	-11.5	-1.1	-5.1	5844	39.0	6.9	-0.1	-7.8
BE (04)	3652	21.2	-7.8	-0.7	-4.2	4748	27.5	-1.4	0.0	-5.5
LU/ZG (05)	3652	22.4	-4.7	-0.7	-4.5	5844	26.9	0.0	0.0	-5.4
LU/NW/OW/SZ/UR (06)	3652	21.8	-3.9	-0.4	-4.4	4392	23.7	-1.0	0.0	-4.7
TI Sottoceneri (07)	3652	29.3	-1.7	-2.3	-5.9	5844	38.4	-4.3	-0.1	-7.7
TI Sopraceneri/GR (08)	3652	26.5	-0.1	-1.7	-5.3	5844	24.0	-1.0	0.0	-4.8
VS (09)	3652	23.2	-1.9	-0.4	-4.6	5844	35.6	2.0	0.0	-7.1
SG/SH/SZ/ZH (10)	3652	23.4	-2.9	-0.8	-4.7	5844	35.9	-0.7	-0.1	-7.2
AI/AR/SG/TG (11)	3652	19.0	-5.4	-0.4	-3.8	5844	15.4	0.8	0.0	-3.1
AI/AR/FL/SG (12)	3652	21.0	-0.1	-0.6	-4.2	4383	18.1	2.7	0.0	-3.6
GR (13)	3652	20.8	1.3	-0.3	-4.2	5783	31.3	0.9	0.0	-6.3

Table 16. Meta-analytical estimates across the 13 regions of the percent change in daily hospitalizations per 10 µg/m^3 increase in the respective average level of PM10 (2001-2010)

		Average day 0-6*		Average day 0-27**	
Outcome	Age group	Mean % change (95% Confidence Interval)	p-value	Mean % change (95% Confidence Interval)	p-value
Medical	All ages	0.31% (0.10% to 0.53%)	0.005	0.39% (-0.02% to 0.79%)	0.059
hospitalization	0-14	0.24% (-0.94% to 1.43%)	0.694	1.52% (-0.49% to 3.58%)	0.140
	15-64	0.30% (0.00% to 0.61%)	0.051	0.09% (-0.41% to 0.59%)	0.732
	65 and more	0.47% (0.22% to 0.72%)	<0.001	0.85% (0.44% to 1.26%)	<0.001
	75 and more	0.73% (0.42% to 1.03%)	<0.001	1.38% (0.89% to 1.88%)	<0.001
Cardiovascular	All ages	0.12% (-0.24% to 0.47%)	0.513	-0.53% (-1.25% to 0.19%)	0.149
hospitalization	0-14	4.06% (-6.90% to 16.31%)	0.483	-3.38% (-19.79% to 16.38%)	0.717
	15-64	-0.14% (-0.80% to 0.53%)	0.684	-0.58% (-1.76% to 0.61%)	0.336
	65 and more	0.25% (-0.17% to 0.67%)	0.240	-0.46% (-1.34% to 0.43%)	0.310
	75 and more	0.49% (-0.03% to 1.02%)	0.064	0.16% (-0.78% to 1.10%)	0.746
Respiratory	All ages	0.50% (-0.39% to 1.39%)	0.272	0.27% (-0.64% to 1.19%)	0.562
hospitalization	0-14	-0.26% (-1.68% to 1.18%)	0.718	0.33% (-2.46% to 3.20%)	0.819
	15-64	1.00% (0.18% to 1.83%)	0.017	0.88% (-0.42% to 2.20%)	0.185
	65 and more	1.41% (0.26% to 2.58%)	0.017	2.51% (0.92% to 4.12%)	0.002
	75 and more	1.85% (0.44% to 3.29%)	0.010	2.90% (1.01% to 4.83%)	0.002

*Relevant exposure assumed as the average PM10 level over the day of the event and the 6 days before the event
** Relevant exposure assumed as the average PM10 level over the day of event and the 27 days before the event

Table 17. Meta-analytical estimates across the 13 regions of the percent change in daily mortality per 10 µg/m^3 increase the respective average level of of PM10 and NO_2

Mortality cause	Age group	Average level day 0-6* Mean % change (95% Confidence Interval)	Average day0-27** Mean % change (95% Confidence Interval)
NO_2 (study period 1995-2010)			
Natural mortality	All ages	1.77% (0.97% ; 2.57%)	3.35% (1.89% ; 4.82%)
	65 and more	1.98% (1.15% ; 2.81%)	3.61% (2.20% ; 5.03%)
	75 and more	1.95% (1.23% ; 2.68%)	3.91% (2.64% ; 5.19%)
Cardiovascular mortality	All ages	1.92% (1.14% ; 2.69%)	3.44% (2.17% ; 4.72%)
	65 and more	1.94% (1.13% ; 2.75%)	3.62% (2.40% ; 4.86%)
	75 and more	2.03% (1.17% ; 2.90%)	4.07% (2.74% ; 5.41%)
Respiratory mortality	All ages	4.26% (1.36% ; 7.24%)	10.87% (6.25% ; 15.69%)
	65 and more	4.43% (1.87% ; 7.06%)	11.21% (6.96% ; 15.62%)
	75 and more	3.89% (1.35% ; 6.48%)	11.60% (7.55% ; 15.79%)
PM10 (study period 2001-2010)			
Natural mortality	All ages	0.77% (0.39% ; 1.15%)	1.77% (1.02% ; 2.52%)
	65 and more	0.94% (0.47% ; 1.41%)	2.03% (1.26% ; 2.80%)
	75 and more	1.06% (0.52% ; 1.60%)	2.43% (1.76% ; 3.11%)
Cardiovascular mortality	All ages	0.90% (0.24% ; 1.56%)	1.92% (1.07% ; 2.78%)
	65 and more	9.72% (0.24% ; 1.63%)	2.19% (1.33% ; 3.07%)
	75 and more	11.06% (0.29% ; 1.82%)	2.74% (1.80% ; 3.68%)
Respiratory mortality	All ages	1.99% (0.59% ; 3.41%)	4.82% (2.14% ; 7.57%)
	65 and more	2.16% (0.83% ; 3.50%)	5.06% (2.23% ; 7.97%)
	75 and more	2.43% (1.01% ; 3.86%)	6.17% (3.28% ; 9.13%)

* Relevant exposure assumed as the average PM10 or NO_2- level over the day of the event and the 6 days before the event
** Relevant exposure assumed as the average PM10 or NO_2- level over the day of the event and the 27 days before the event

Table 18. Estimated numbers of preventable emergency hospital admissions under different abatement scenarios for PM10 (for a 7 day exposure window) during the study period 2001-2010

Hospitalization Cause	Age Group	Total number of hospitalizations in age group during study period	Total preventable cause specific and age specific hospitalizations during study period (95% Confidence interval)	Percentage of preventable cause and age specific hospitalizations during study period (95% Confidence interval)	Preventable cases per 100 000 and per year
Scenario 1: *no daily concentration above 50 µg/m^3*					
Medical	All ages	2 240 690	735 (385 to 1085)	0.03% (0.02% to 0.05%)	3.3
	75 and more	645 622	401 (224 to 578)	0.06% (0.03% to 0.09%)	1.8
Cardiovascular	All ages	453 540	118 (-30 to 266)	0.03% (-0.01% to 0.06%)	0.5
	75 and more	217 510	88 (-14 to 191)	0.04% (-0.01% to 0.09%)	0.4
Respiratory	All ages	236 412	159 (25 to 292)	0.07% (0.01% to 0.12%)	0.7
	75 and more	75 052	177 (98 to 255)	0.24% (0.13% to 0.34%)	0.8
Scenario 2: *all daily concentrations are reduced by 20%*					
Medical	All ages	2 240 690	3269 (1390 to 5149)	0.15% (0.06% to 0.23%)	15
	75 and more	645 622	2 003 (1085 to 2922)	0.31% (0.17% to 0.45%)	9
Cardiovascular	All ages	453 540	624 (-142 to 1390)	0.14% (-0.03% to 0.31%)	3
	75 and more	217 510	581 (60 to 1102)	0.27% (0.03% to 0.51%)	3
Respiratory	All ages	236 412	398 (-182 to 979)	0.17% (-0.08% to 0.41%)	2
	75 and more	75 052	573 (256 to 890)	0.76% (0.34% to 1.19%)	3

Table 19. Estimated numbers of preventable premature deaths under different abatement scenarios for PM10 (for a 7 day exposure window) during the study period 2001-2010

Mortality Cause	Age Group	Total number of deaths by age group during study period	Total preventable cause specific and age specific premature deaths during study period (95% Confidence interval)	Percentage of preventable cause and age specific premature deaths during study period (95% Confidence interval)	Avoidable premature deaths per 100 000 medical deaths and per year
Scenario 1: no daily concentration above 50 µg/m^3					
Medical	All ages	697 644	284 (133 to 435)	0.04% (0.02% to 0.06%)	4.1
	75 and more	477 295	309 (180 to 437)	0.06% (0.04% to 0.09%)	4.4
Cardiovascular	All ages	293 694	174 (131 to 217)	0.06% (0.04% to 0.07%)	2.5
	75 and more	234 193	166 (127 to 204)	0.07% (0.05% to 0.09%)	2.4
Respiratory	All ages	45 480	56 (-43 to 154)	0.12% (-0.09% to 0.34%)	0.8
	75 and more	35 240	67 (-28 to 162)	0.19% (-0.08% to 0.46%)	1.0
Scenario 2: all daily concentrations are reduced by 20%					
Medical	All ages	697 644	1 493 (731 to 2251)	0.21% (0.10% to 0.32%)	21.4
	75 and more	477 295	1 465 (831 to 2095)	0.31% (0.17% to 0.44%)	21.0
Cardiovascular	All ages	293 694	854 (371 to 1335)	0.29% (0.13% to 0.45%)	12.2
	75 and more	234 193	760 (326 to 1192)	0.32% (0.14% to 0.51%)	10.9
Respiratory	All ages	45 480	200 (15 to 385)	0.44% (0.03% to 0.85%)	2.9
	75 and more	35 240	226 (50 to 402)	0.64% (0.14% to 1.14%)	3.2

Table 20. Estimated numbers of preventable premature deaths under different abatement scenarios for NO_2 (for a 7 day exposure window) during the study period 1995-2010

Mortality Cause	Age Group	Total number of deaths by age group during study period	Total preventable cause specific and age specific premature deaths during study period (95% Confidence interval)	Percentage of preventable cause and age specific premature deaths during study period (95% Confidence interval)	Avoidable premature deaths per 100 000 medical deaths and per year
Scenario 1: *no daily concentration above 80 µg/m^3*					
medical	all	697644	19 (7 to 31)	0.003% (0.001% to 0.004%)	0.2
	75	477295	19 (8 to 30)	0.004% (0.002% to 0.006%)	0.2
cardiovascular	all	293694	19 (13 to 26)	0.007% (0.004% to 0.009%)	0.2
	75	234193	30 (24 to 36)	0.013% (0.010% to 0.015%)	0.3
respiratory	all	45480	5 (-14 to 23)	0.011% (-0.030% to 0.051%)	0.0
	75	35240	7 (-11 to 24)	0.019% (-0.030% to 0.068%)	0.1
Scenario 2: *all daily concentrations are reduced by 20%*					
medical	all	697644	2536 (1515 to 3552)	0.36% (0.22% to 0.51%)	24
	75	477295	2119 (1203 to 3030)	0.44% (0.25% to 0.63%)	20
cardiovascular	all	293694	4418 (2794 to 6035)	1.50% (0.95% to 2.05%)	42
	75	234193	4109 (2782 to 5429)	1.75% (1.19% to 2.32%)	39
respiratory	all	45480	578 (164 to 990)	1.27% (0.36% to 2.18%)	6
	75	35240	684 (292 to 1074)	1.94% (0.83% to 3.05%)	7

11.2 Figures

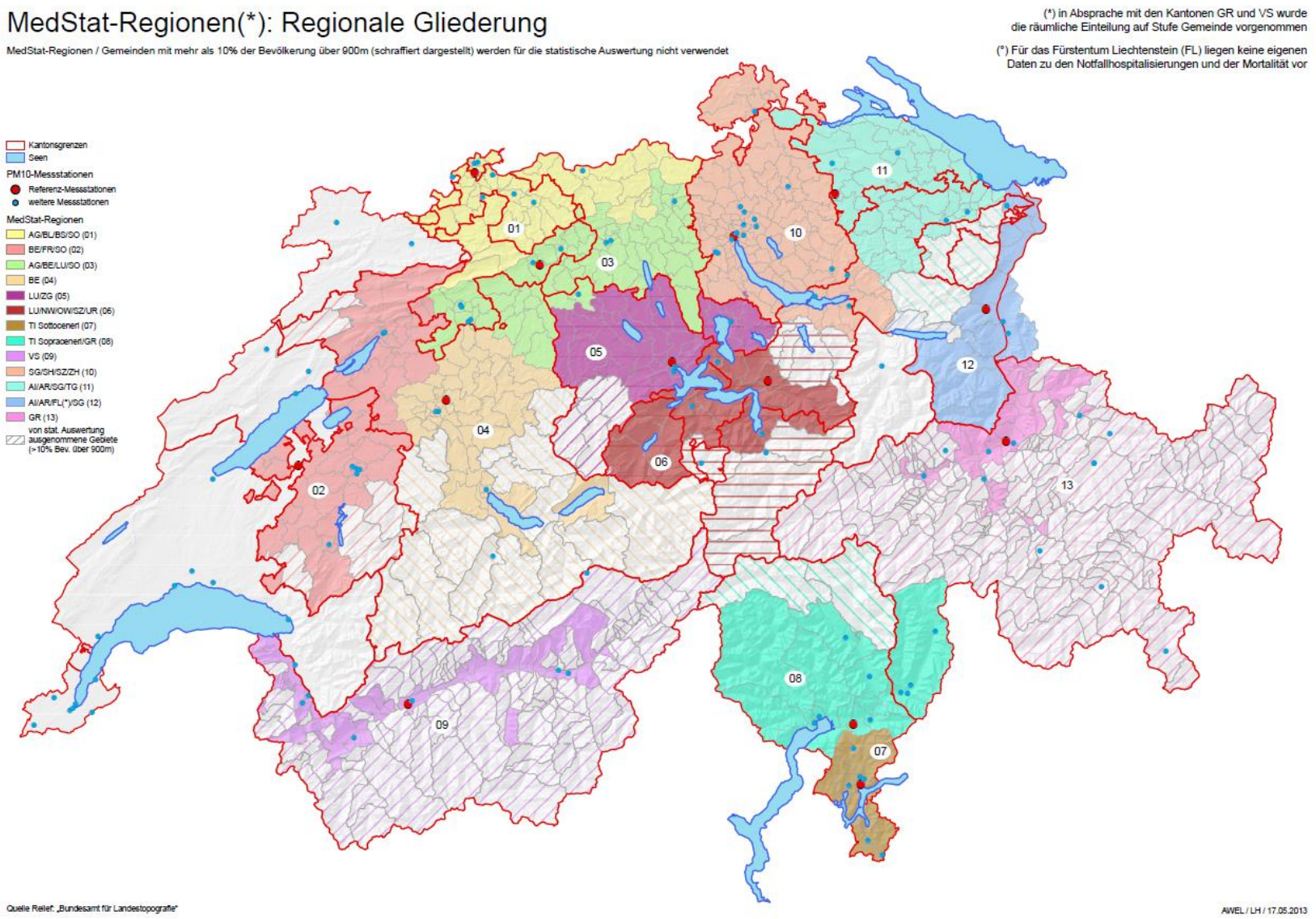


Figure 1. The 13 analysis regions and their reference air pollutant measuring stations.

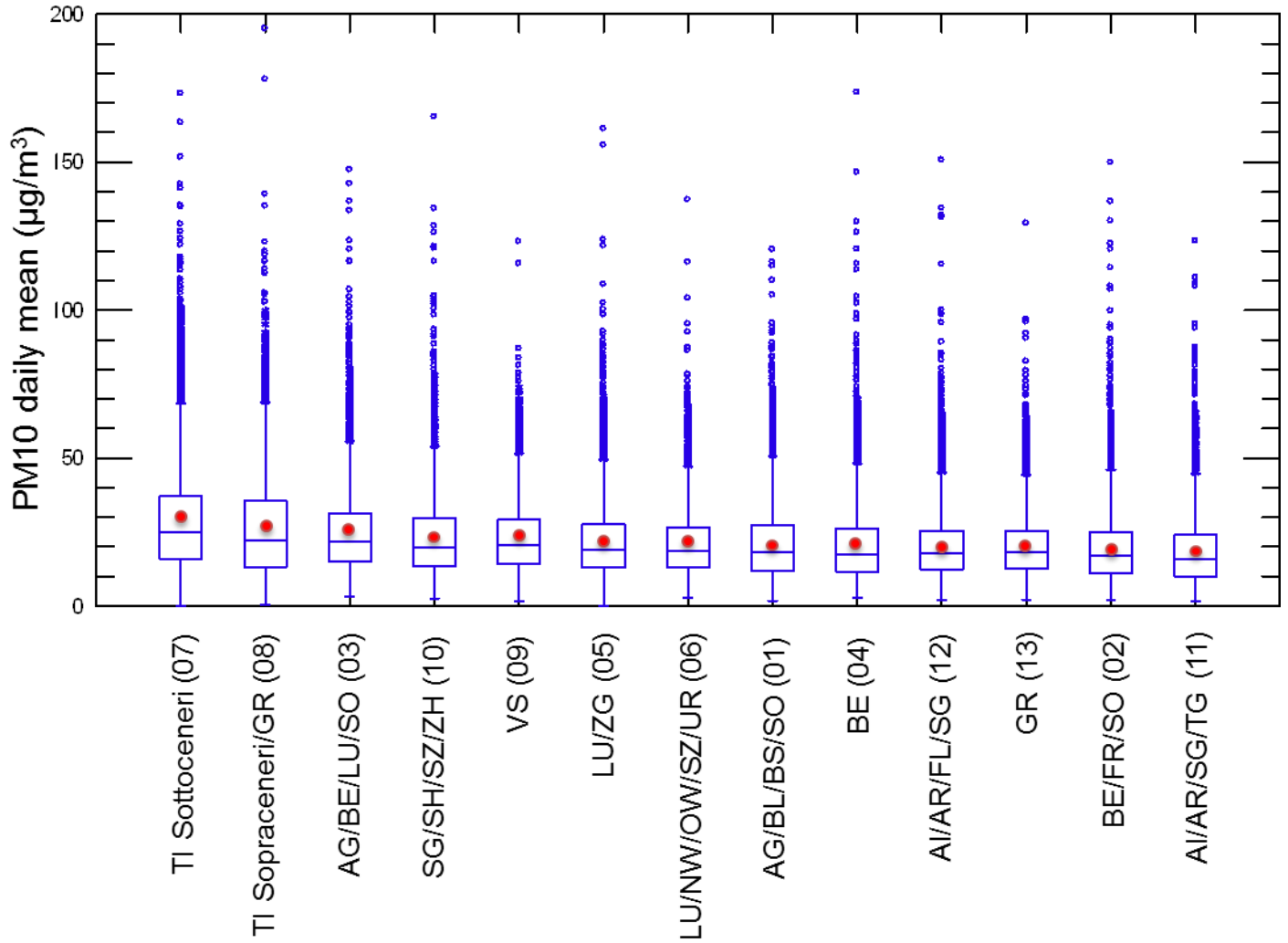


Figure 2. Distribution of the daily mean of PM10 for the period of 2001 to 2010 by analysis regions

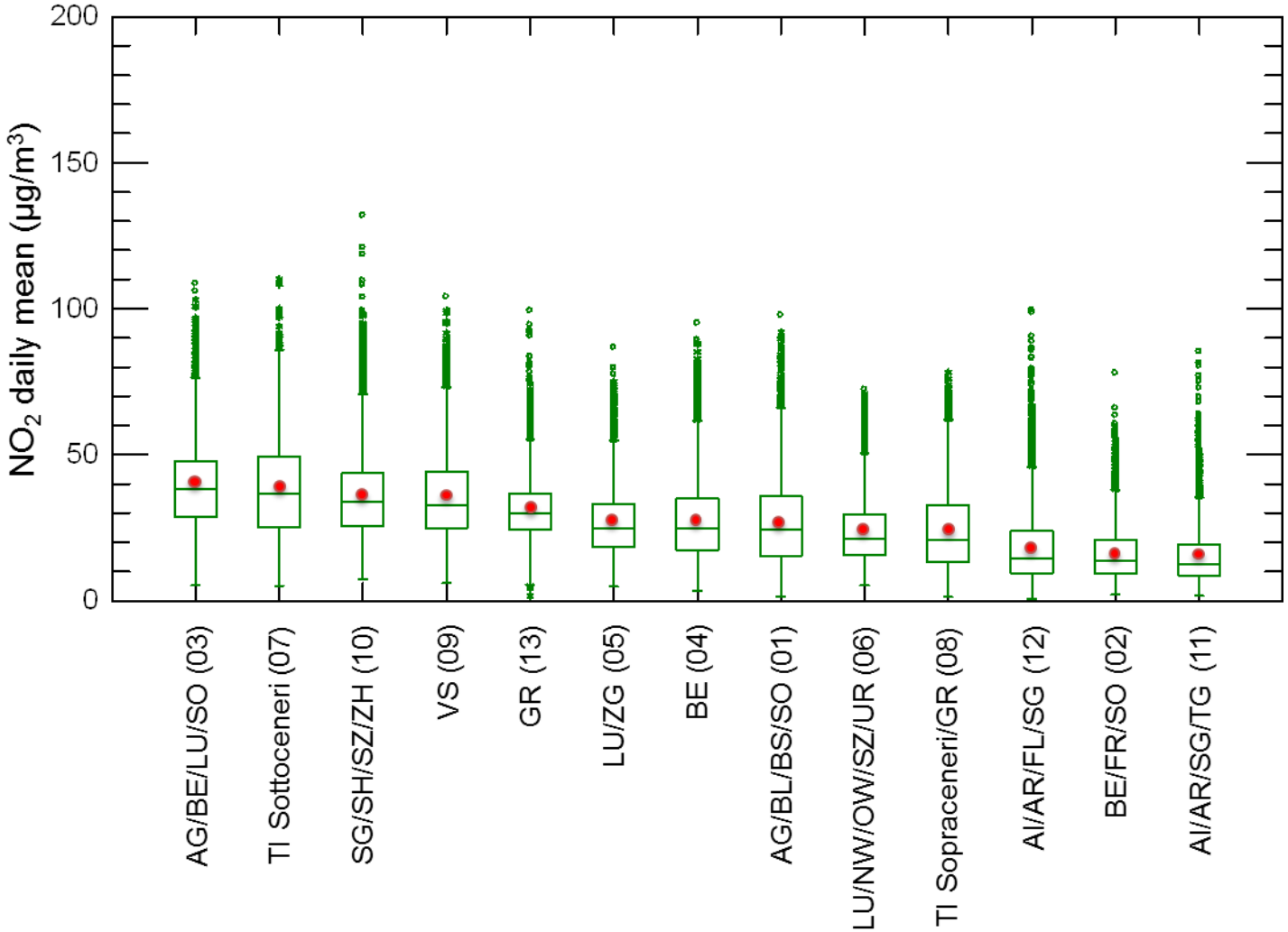


Figure 3. Distribution of the daily mean of NO_2 for the period of 1995 to 2010 by analysis regions

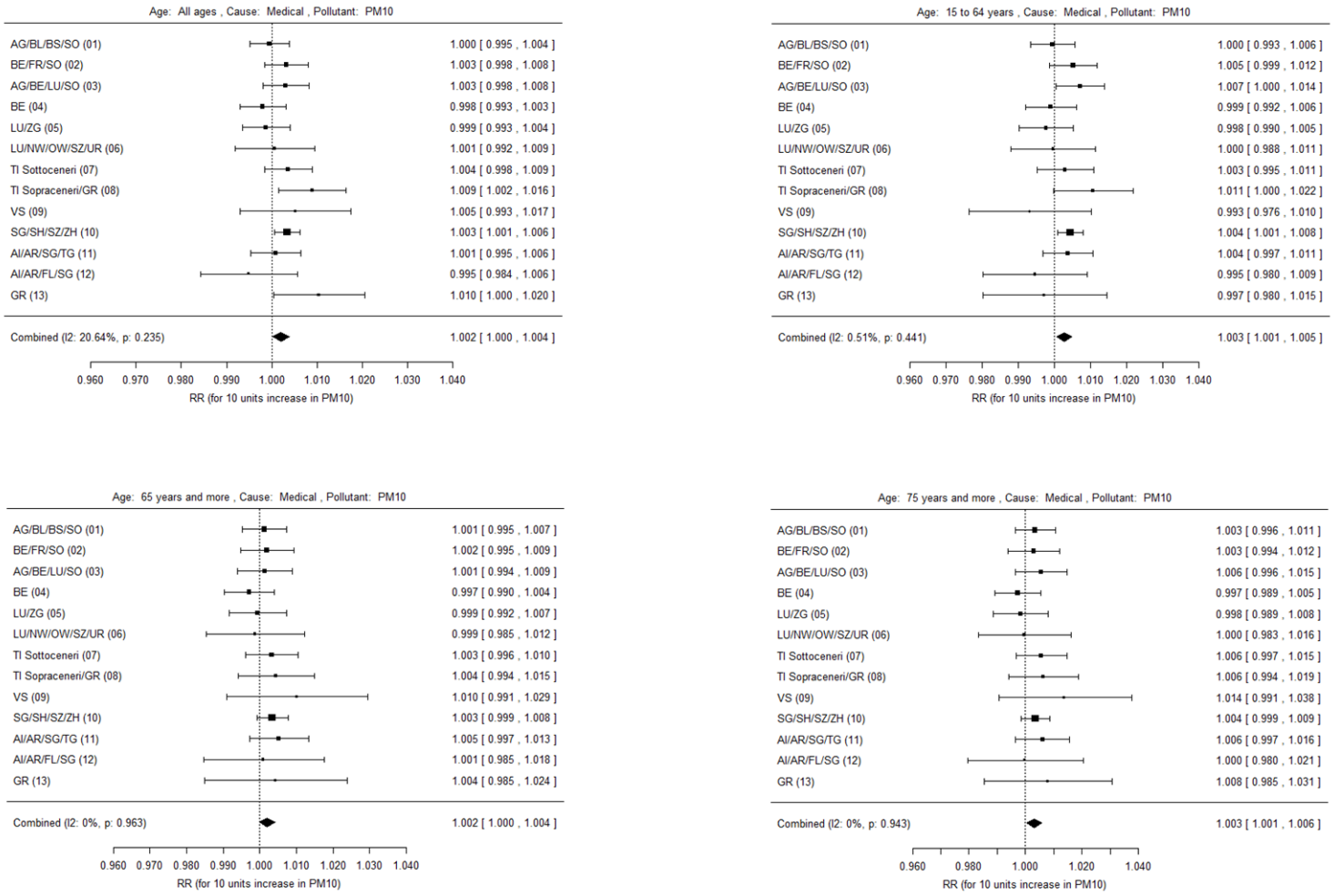


Figure 4. Meta-analytic relative risks of emergency hospital admissions due to medical causes for a 10 µg/m^3 increase in PM10 by age groups. PM10 exposure was the average of the level of PM10 on the day of the event and the day before the event. Please notice that the forest plots given above contain the uncorrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

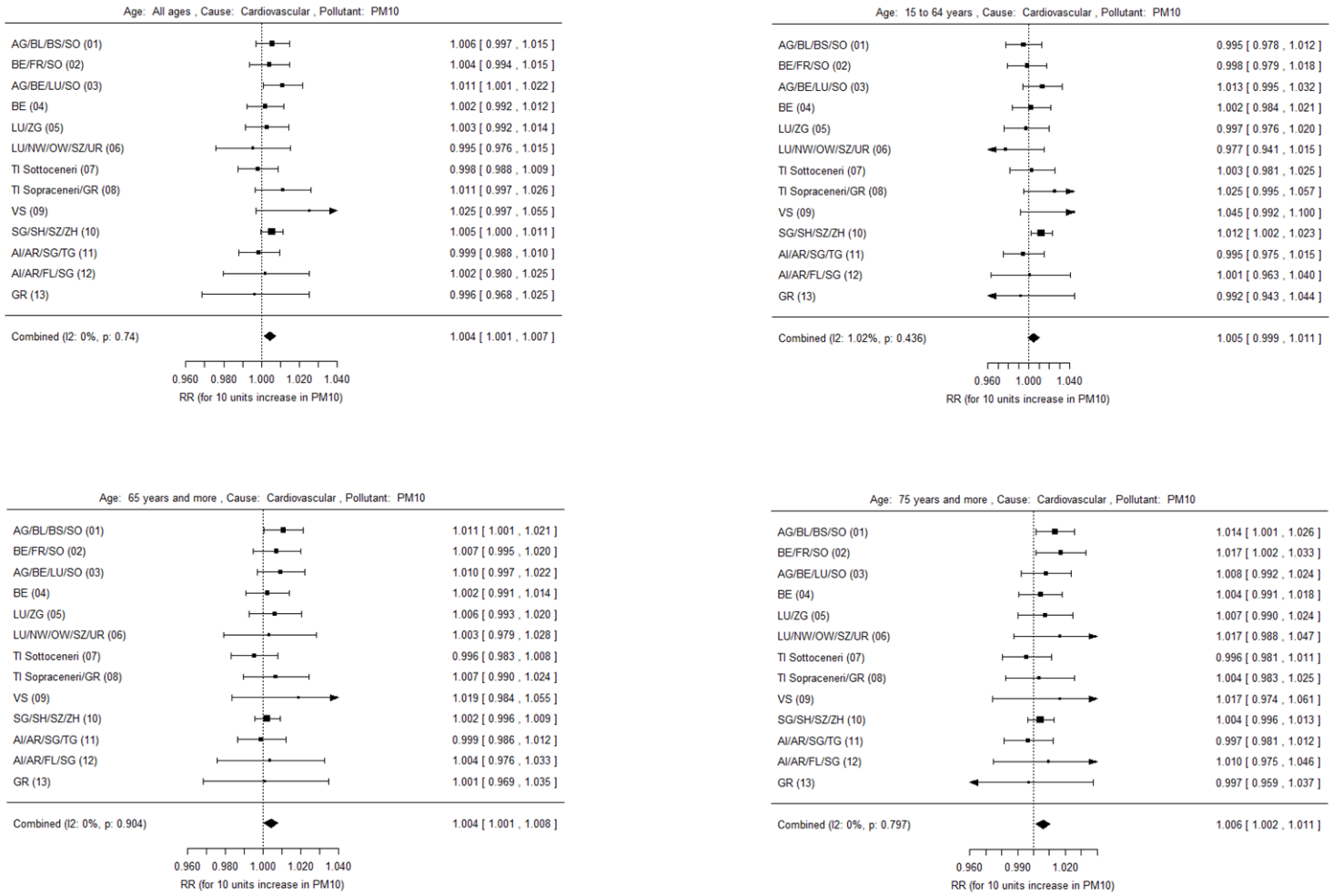


Figure 5. Meta-analytic relative risks of emergency hospital admissions due to cardiovascular causes for a 10 µg/m^3 increase in PM10 by age groups. PM10 exposure was the average of the level of PM10 on the day of the event and the day before the event. Please notice that the forest plots given above contain the uncorrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

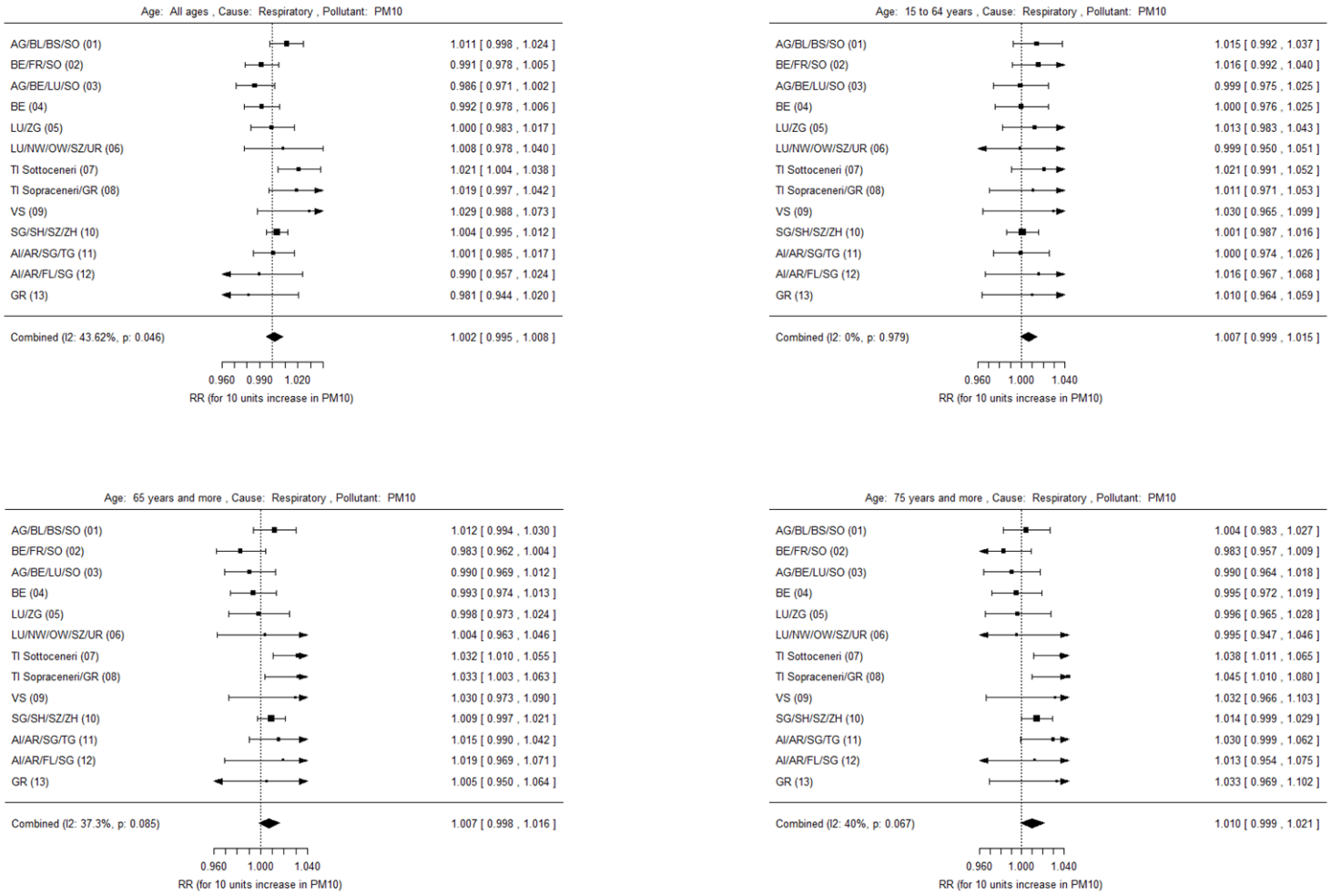


Figure 6. Meta-analytic relative risks of emergency hospital admissions due to respiratory causes for a 10 µg/m^3 increase in PM10 by age groups. PM10 exposure was the average of the level of PM10 over the day of the event and the three days before the event. Please notice that the forest plots given above contain the un-corrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region

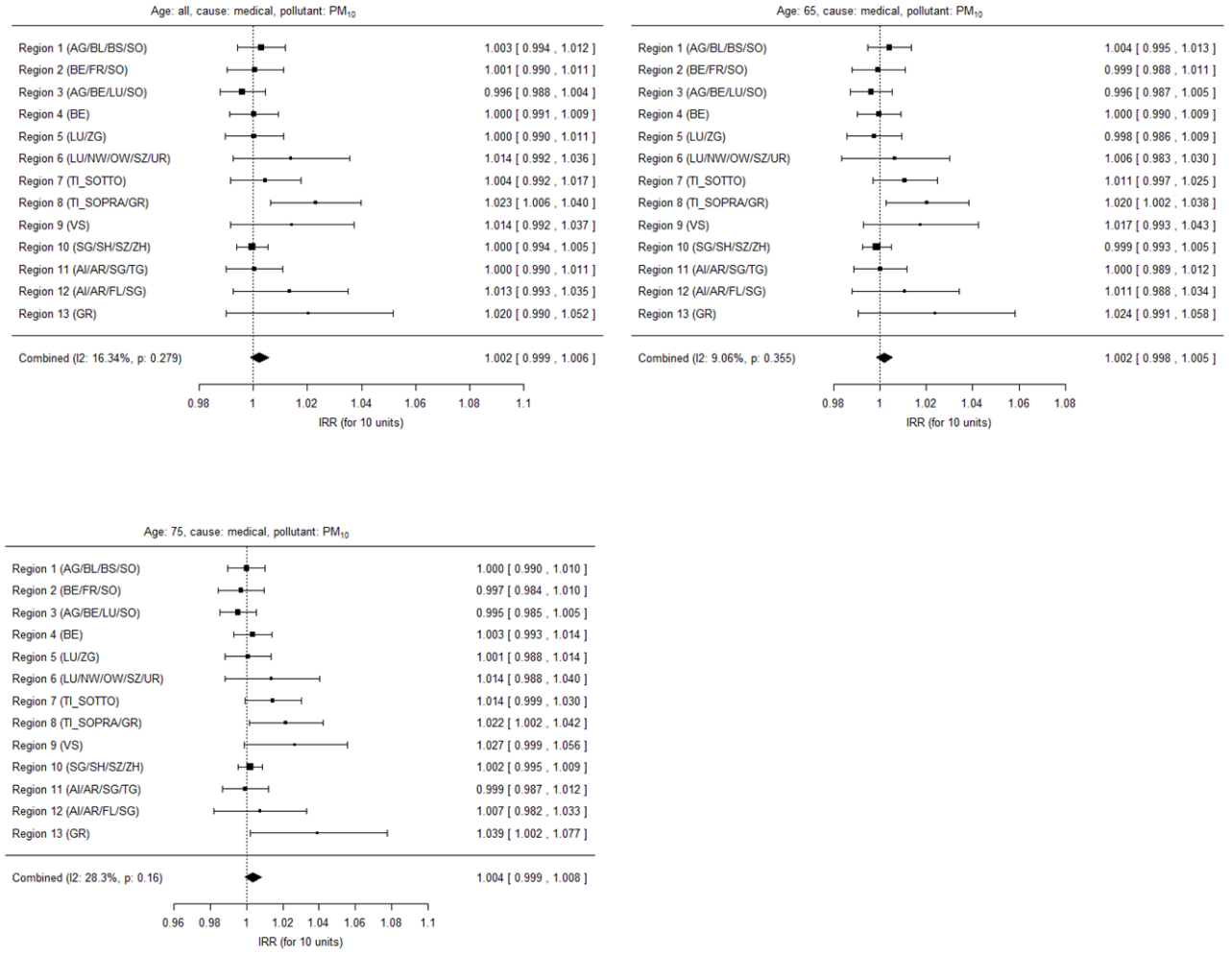


Figure 7. Meta-analytic relative risks of mortality due to medical causes for a 10 µg/m^3 increase in PM10 by age groups. PM10 exposure was the average of the level of PM10 on the day of the event and the day before the event. Please notice that the forest plots given above contain the uncorrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

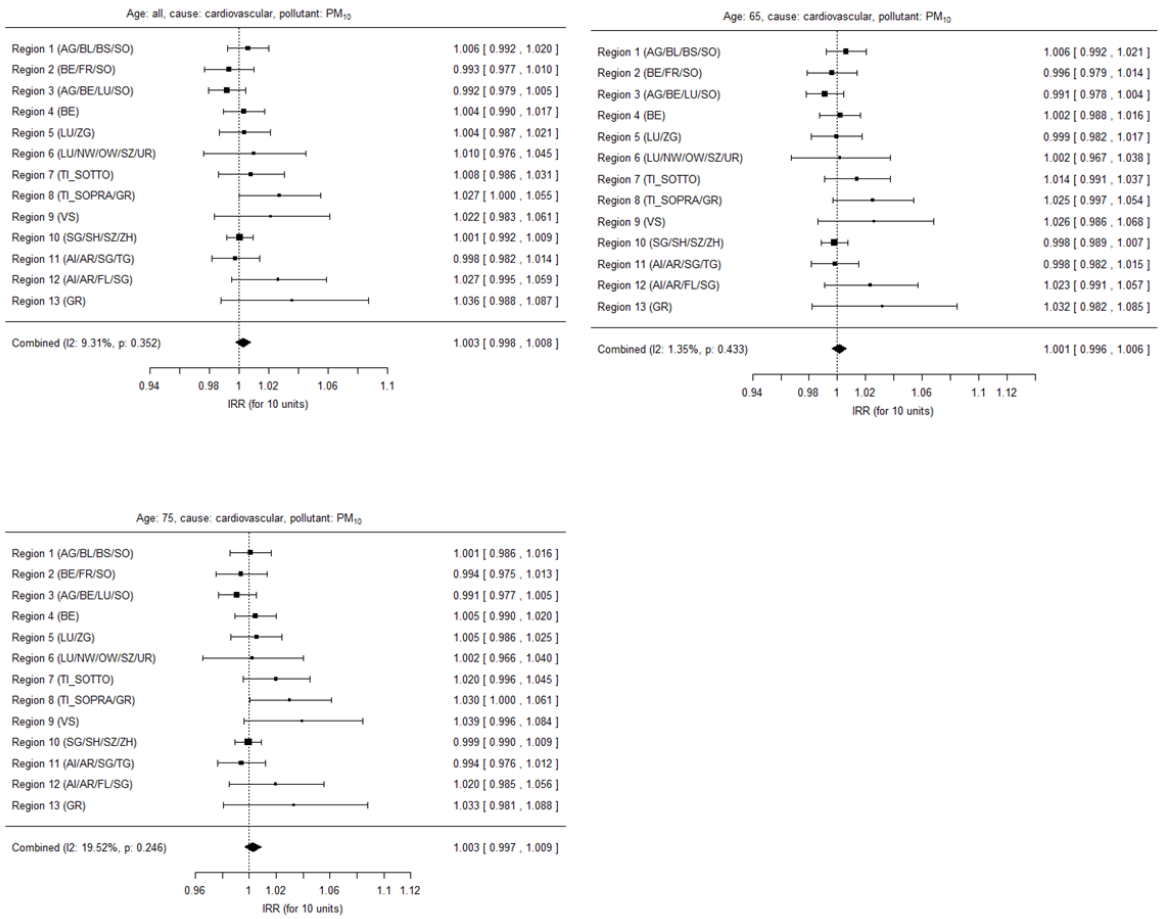


Figure 8. Meta-analytic relative risks of mortality due to cardiovascular causes for a 10 µg/m^3 increase in PM10 by age groups. PM10 exposure was the average of the level of PM10 on the day of the event and the day before the event. Please notice that the forest plots given above contain the uncorrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

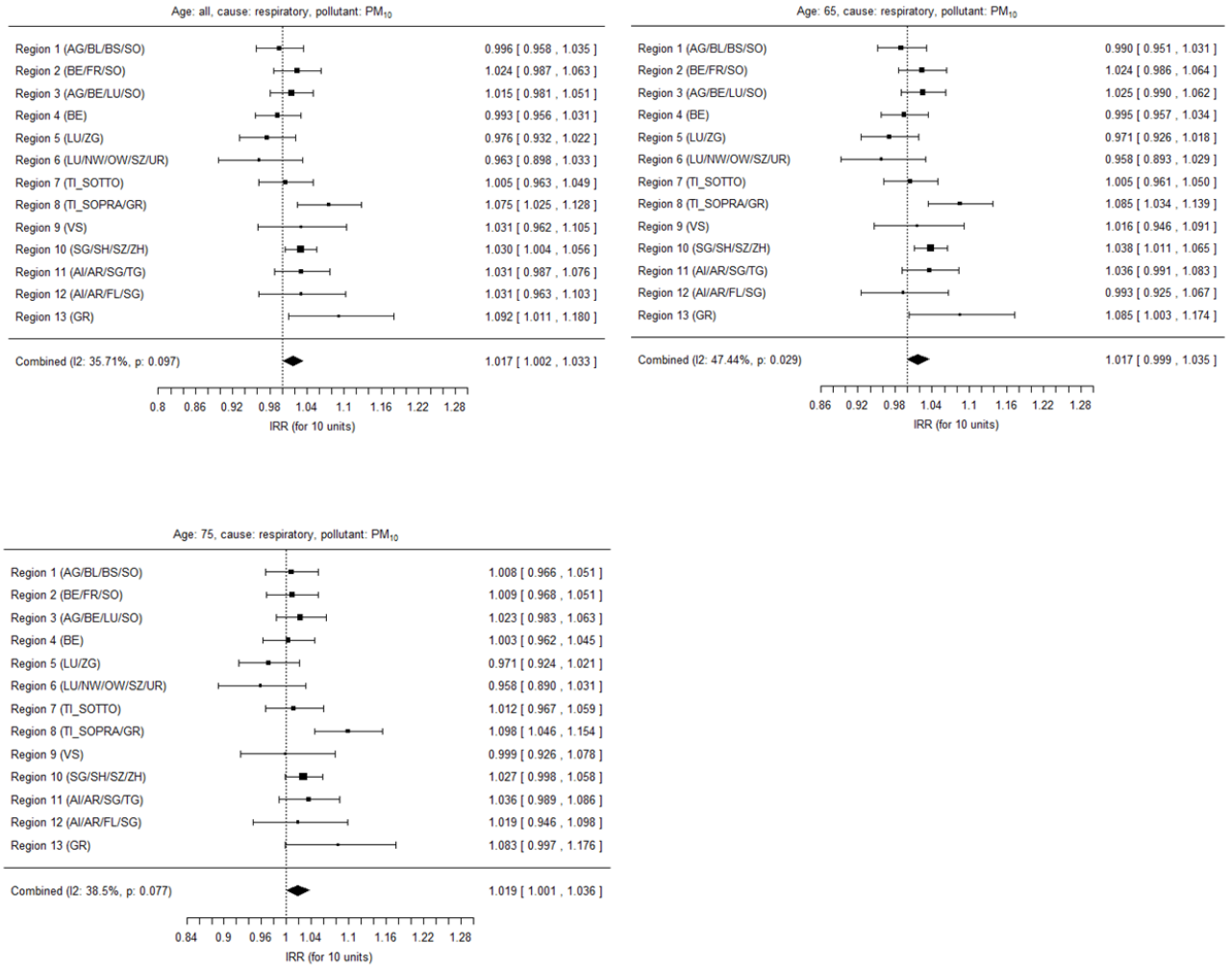


Figure 9. Meta-analytic relative risks of mortality due to respiratory causes for a 10 µg/m^3 increase in PM10 by age groups. PM10 exposure was the average of the level of PM10 over the day of the event and the three days before the event. Please notice that the forest plots given above contain the un-corrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

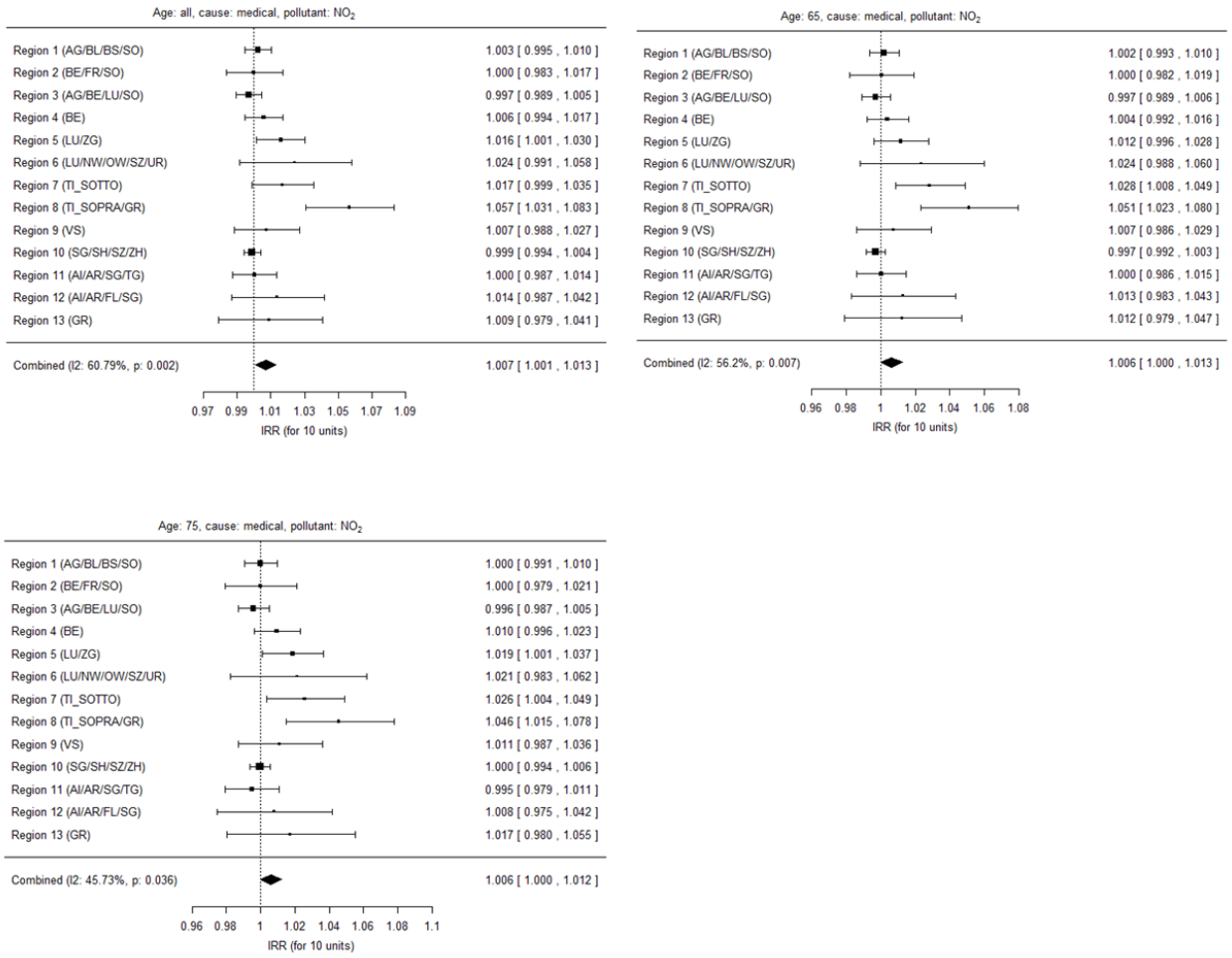


Figure 10. Meta-analytic relative risks of mortality due to medical causes for a 10 µg/m^3 increase in NO_2 by age groups. NO_2 exposure was the average of the level of NO_2 on the day of the event and the day before the event. Please notice that the forest plots given above contain the uncorrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

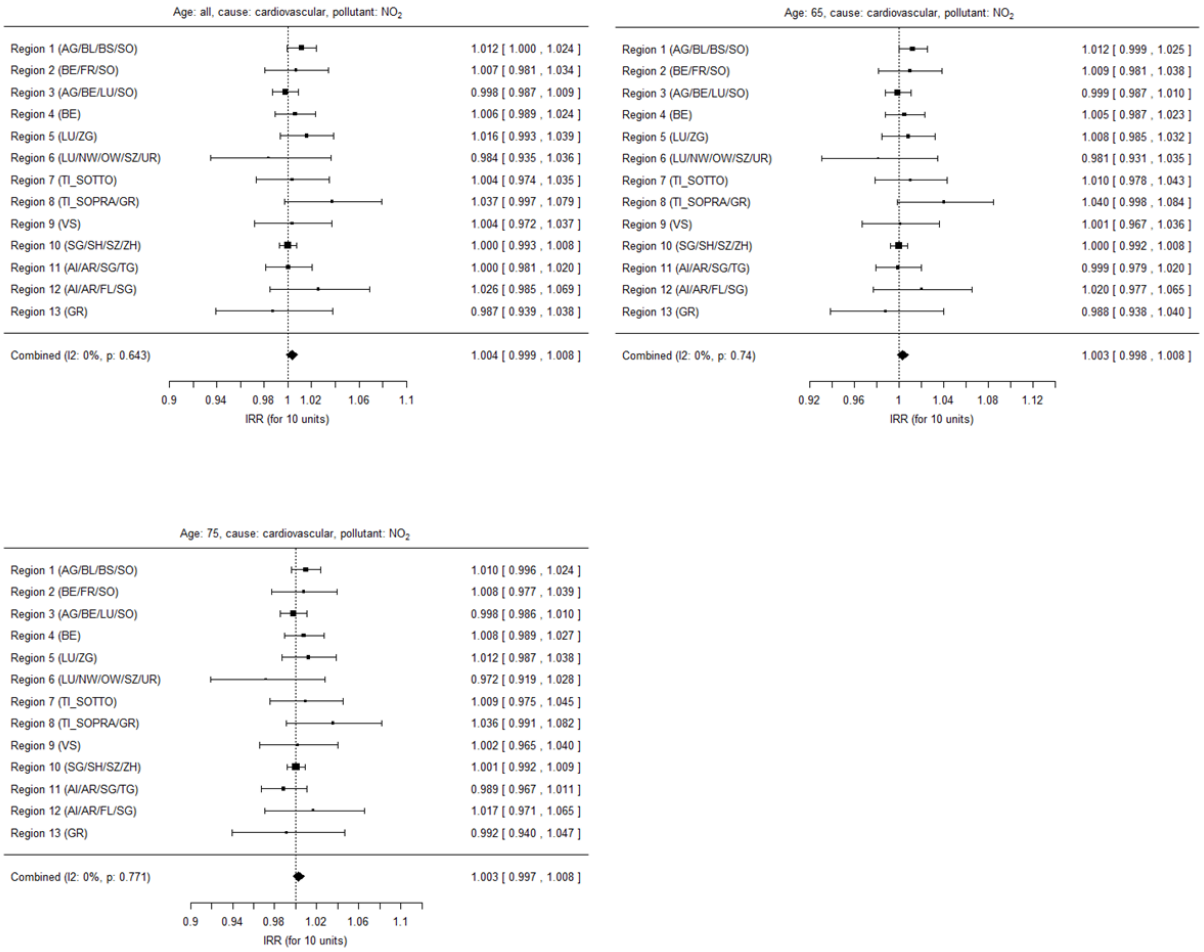


Figure 11. Meta-analytic relative risks of mortality due to caridovascular causes for a 10 µg/m^3 increase in NO_2 by age groups. NO_2 exposure was the average of the level of NO_2 on the day of the event and the day before the event. Please notice that the forest plots given above contain the uncorrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

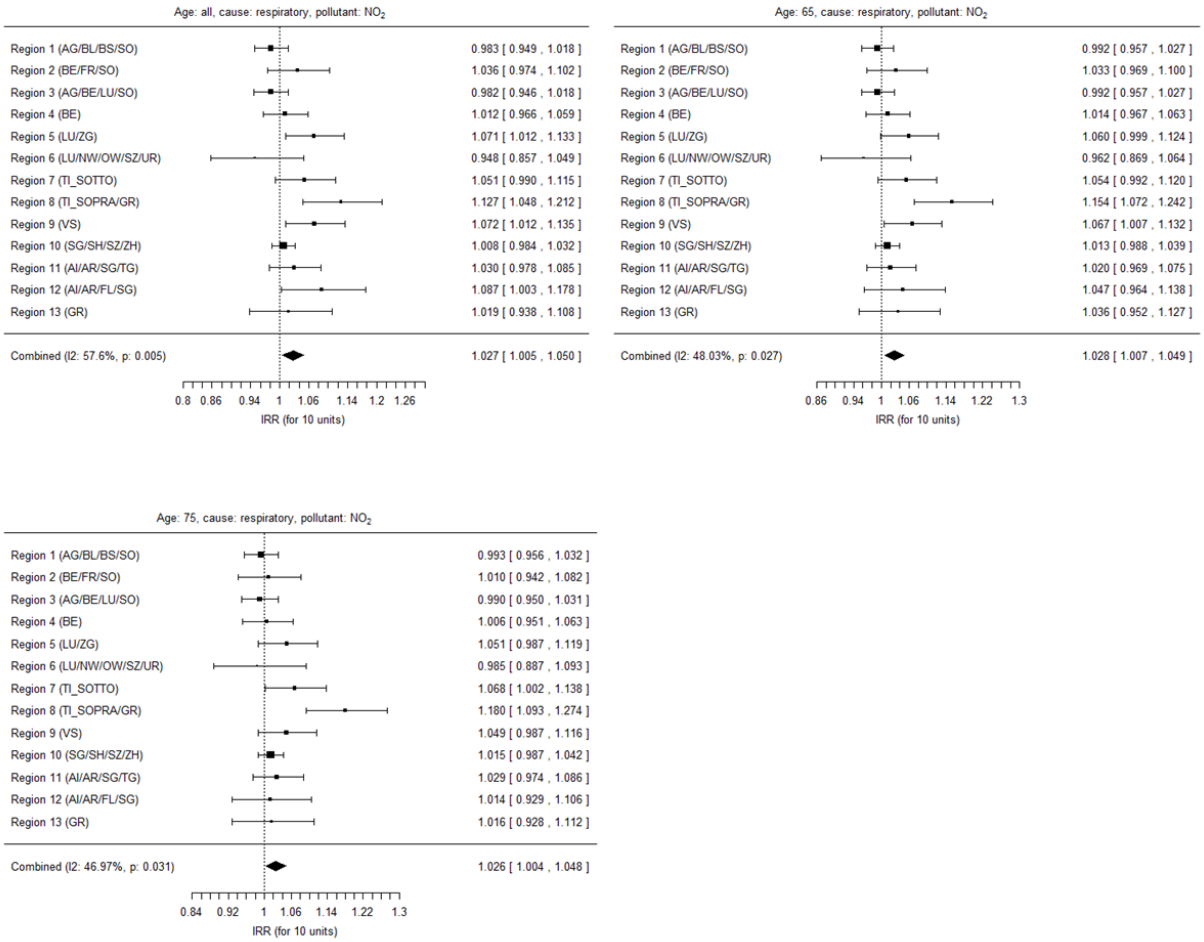


Figure 12. Meta-analytic relative risks of mortality due to respiratory causes for a 10 µg/m^3 increase in NO_2 by age groups. NO_2 exposure was the average of the level of NO_2 over the day of the event and the three days before the event. Please notice that the forest plots given above contain the uncorrected regional estimates. It is adviced to use the 'combined' risk ratio when referring to the effect of the pollutant in a specific region.

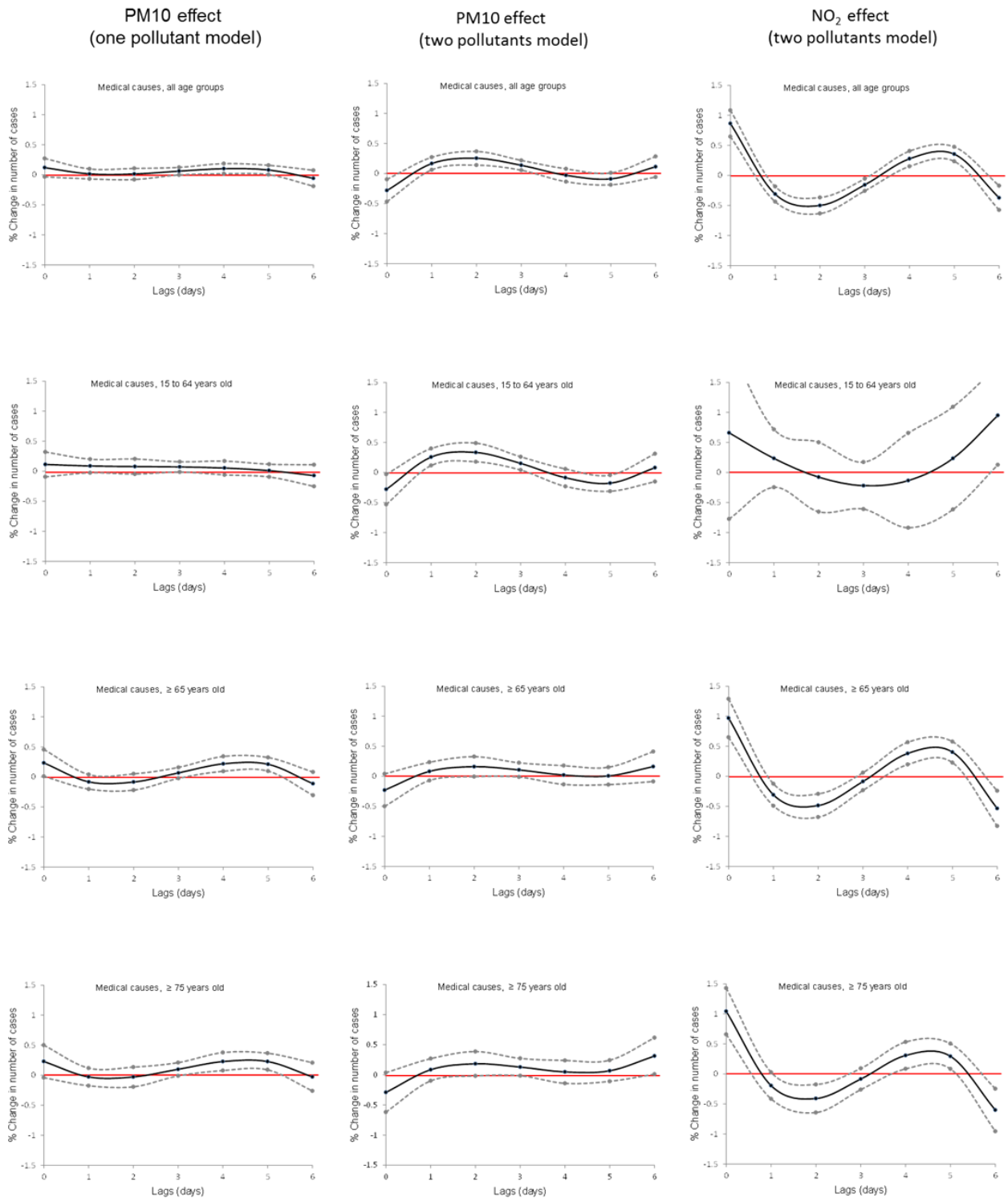


Figure 13. Estimates of the parallel effects of PM10 and NO_2 on the event day (Lag = 0 days) and 6 previous days on emergency hospital admissions due to medical causes (calculated using polynomial lag models). The effects are given as % change in the number of cases (with 95%-confidence intervals) for a 10 µg/m^3 increase in the pollutant level on the respective day for different age groups

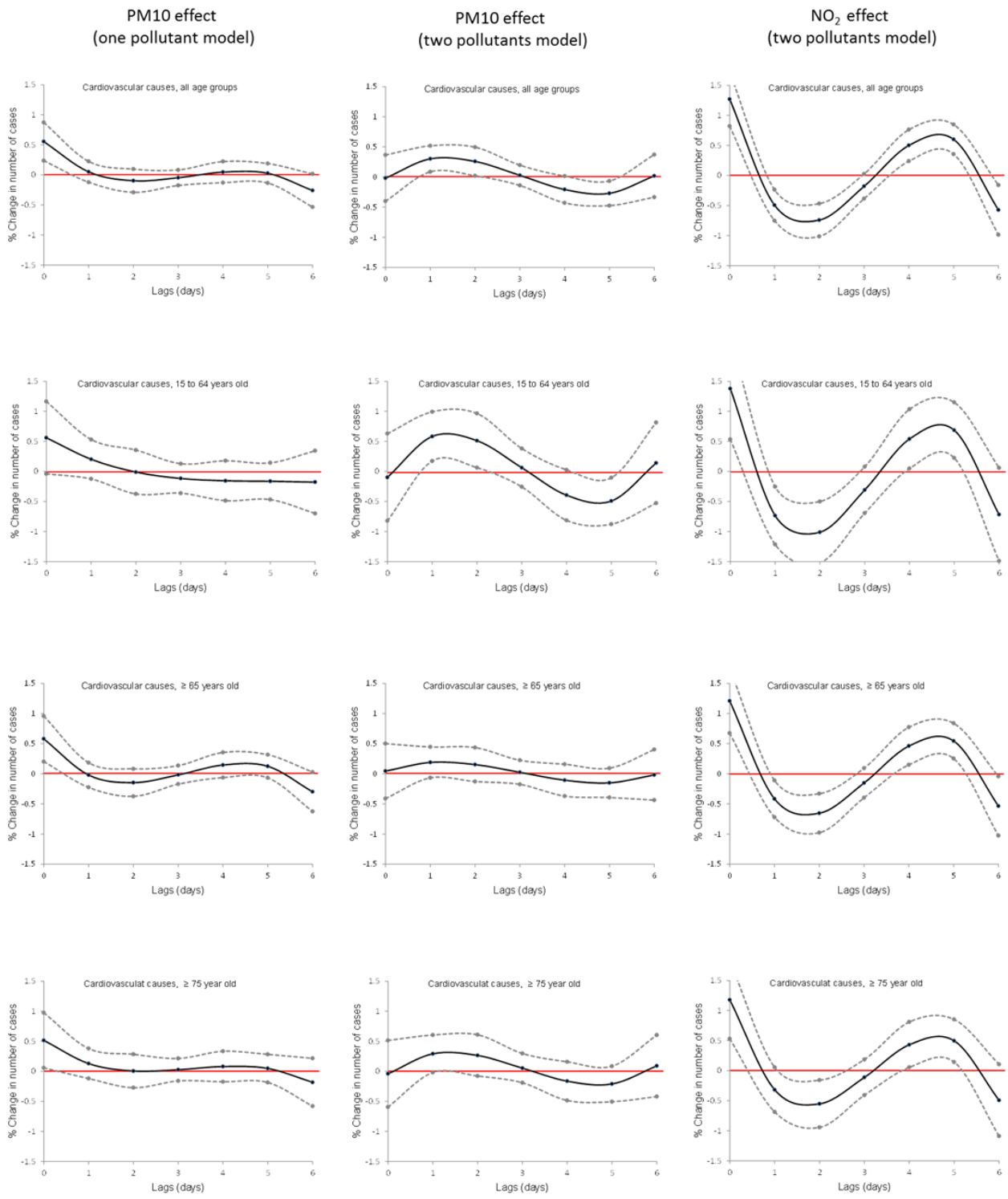


Figure 14. Estimates of the parallel effects of PM10 and of NO_2 loads on the event day (Lag = 0 days) and 6 previous days on emergency hospital admissions due to cardiovascular causes (calculated using polynomial lag models). The effects are given as % change in the number of cases (with 95%-confidence intervals) for a 10 µg/m^3 increase in the pollutant level of the respective day for different age groups

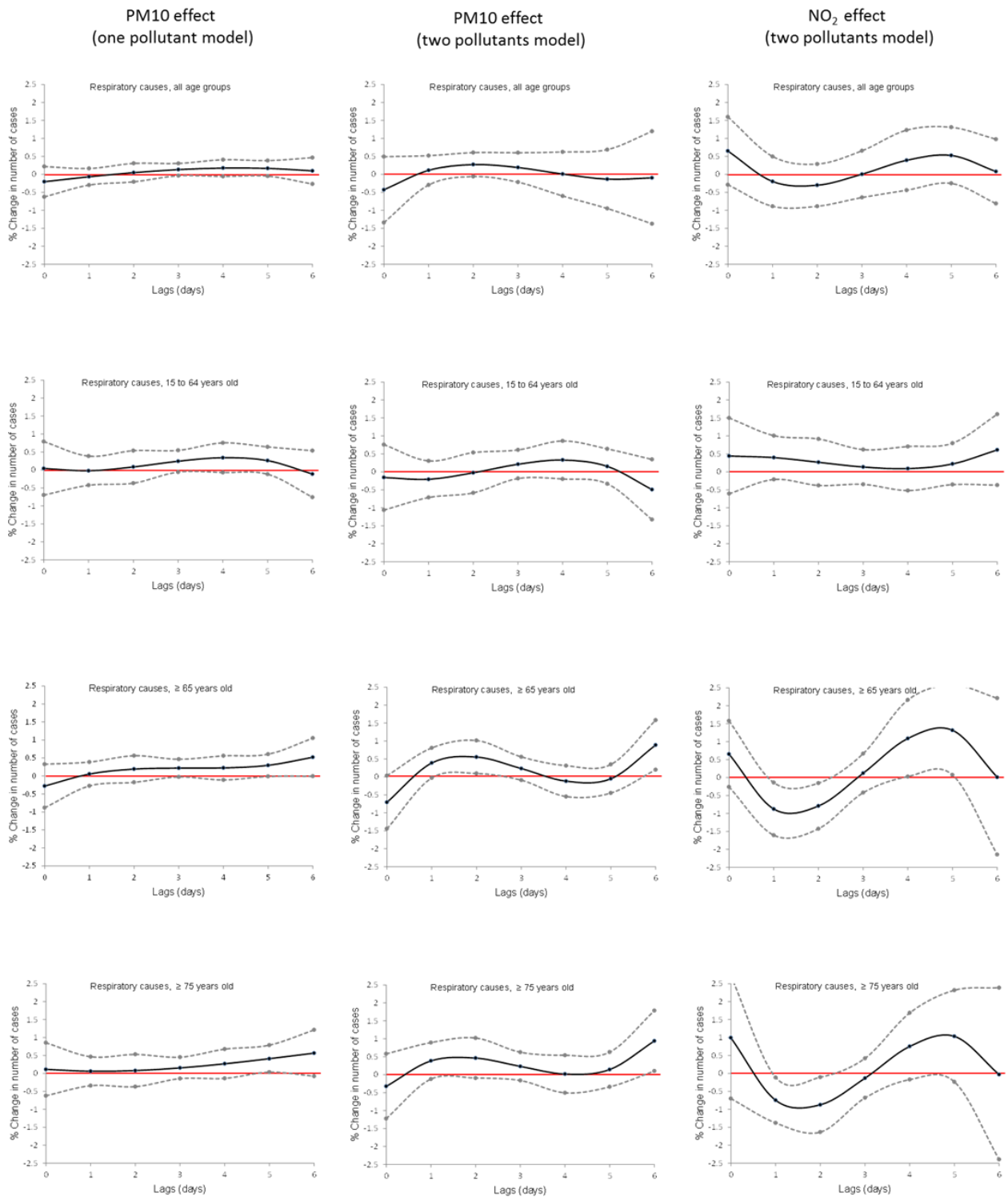


Figure 15. Figure 15. Estimates of the parallel effects of PM10 and NO_2 loads on the event day (Lag = 0 days) and 6 previous days on emergency hospital admissions due to respiratory causes (calculated using polynomial lag models). The effects are given as % change in the number of cases (with 95%-confidence intervals) for a 10 µg/m^3 increase in the pollutant level of the respective day for different age groups

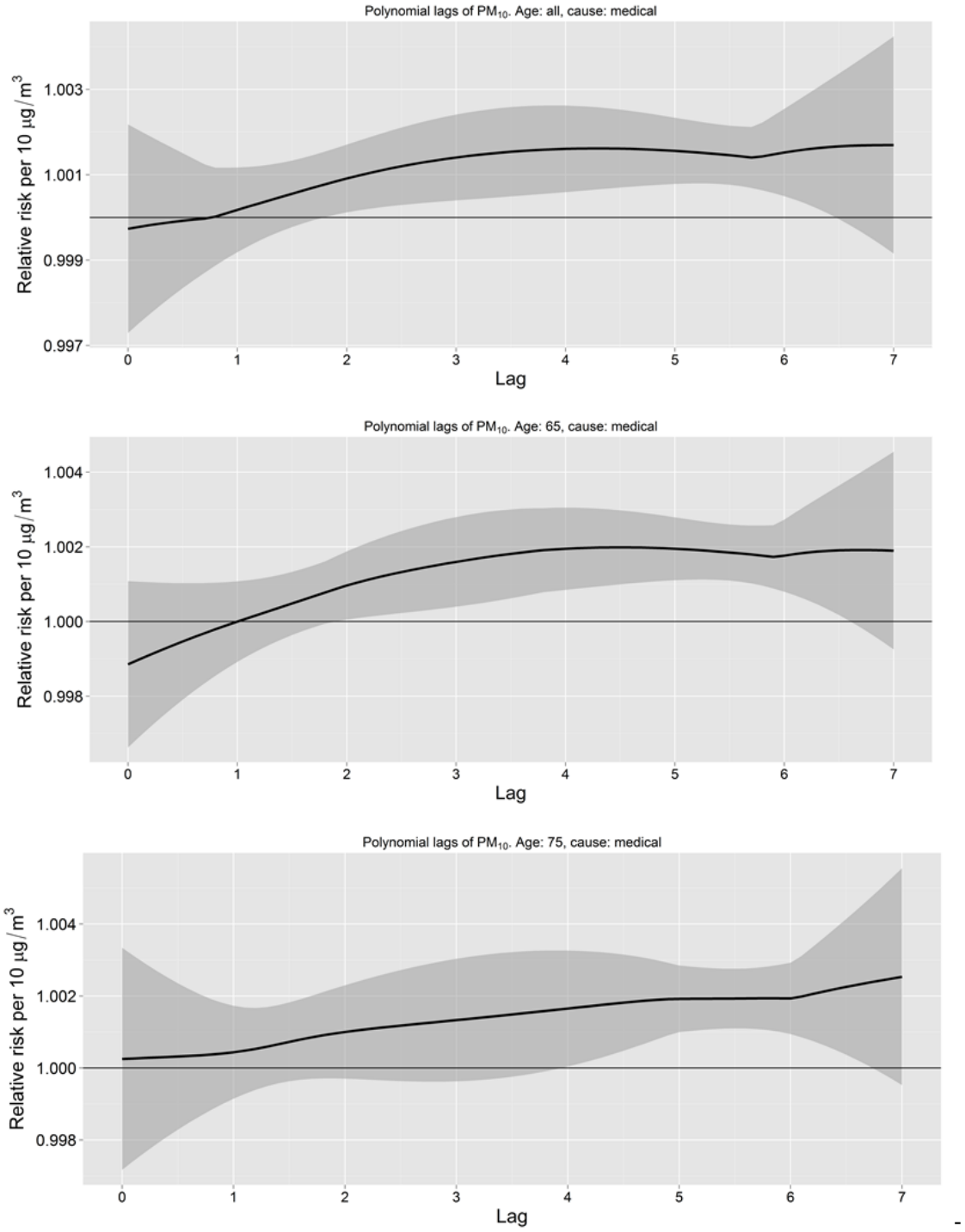


Figure 16. Relative risks of mortality due to medical causes (with 95%-confidence intervals) associated with PM10 levels on the day of the event (Lag = 0) and the seven days preceding the event, by age group. Estimates were calculated using polynomial lag models and are given for a 10 µg/m^3 increase in the level of PM10 on the respective day

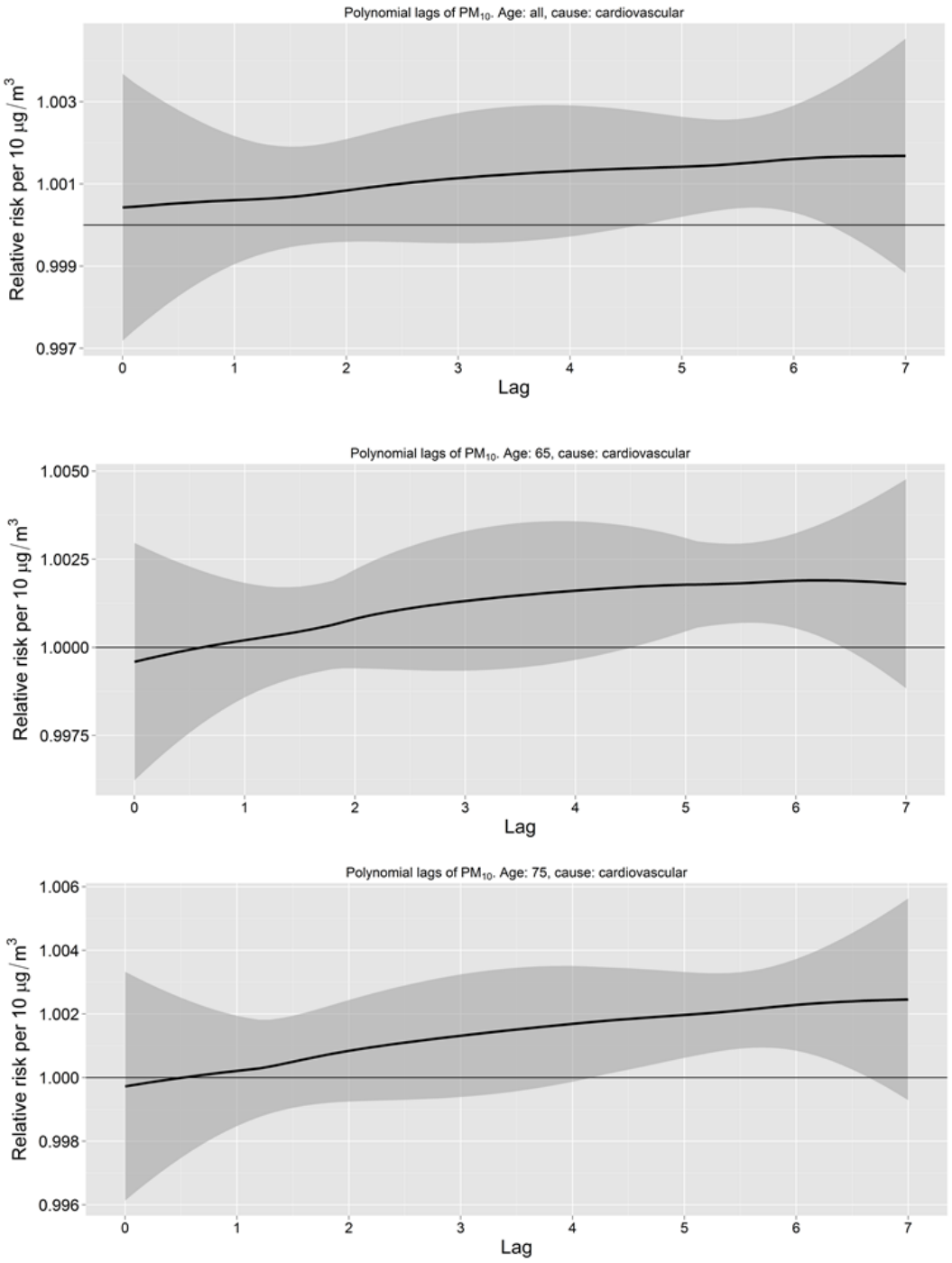


Figure 17. Relative risks of mortality due to cardiovascular causes (with 95%-confidence intervals) associated with PM10 levels on the day of the event (Lag = 0) and the seven days preceding the event, by age group. Estimates were calculated using polynomial lag models and are given for a 10 µg/m^3 increase in the level of PM10 on the respective day

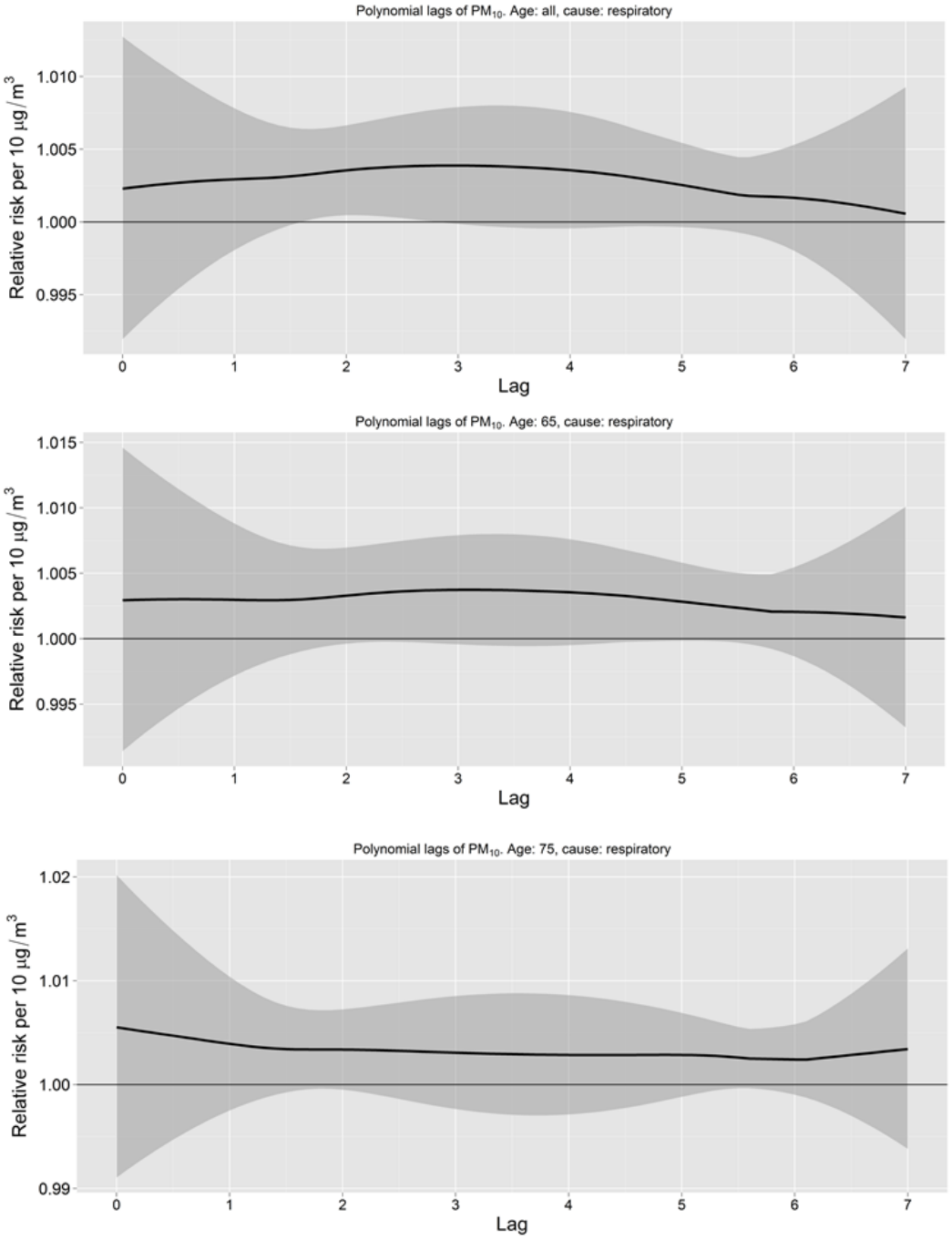


Figure 18. Relative risks of mortality due to respiratory causes (with 95%-confidence intervals) associated with PM10 levels on the day of the event (Lag = 0) and the seven days preceding the event, by age group. Estimates were calculated using polynomial lag models and are given for a 10 µg/m^3 increase in the level of PM10 on the respective day

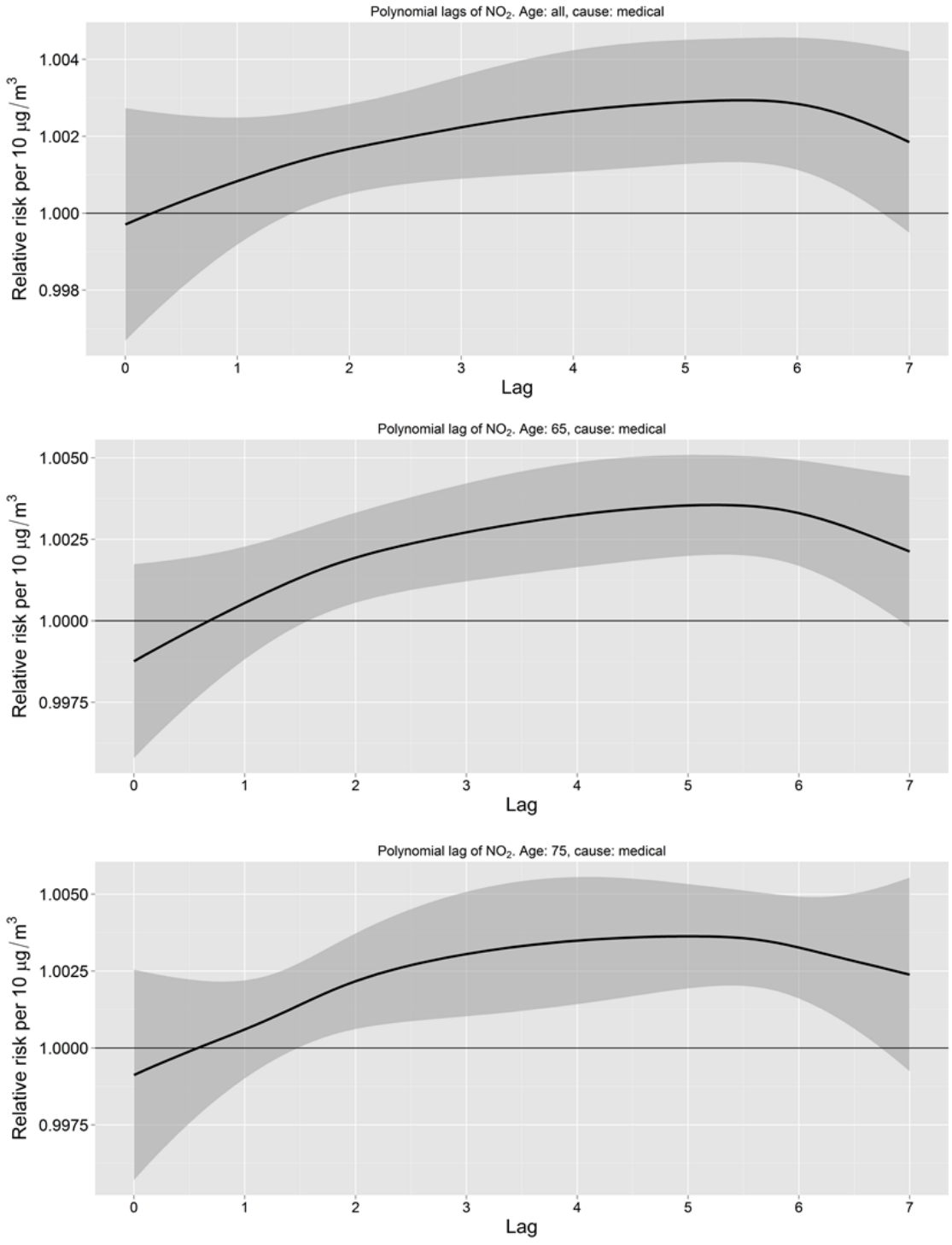


Figure 19. Relative risks of mortality due to medical causes (with 95%-confidence intervals) associated with PM10 levels on the day of the event (Lag = 0) and the seven days preceding the event, by age group. Estimates were calculated using polynomial lag models and are given for a 10 µg/m^3 increase in the level of NO_2 on the respective day

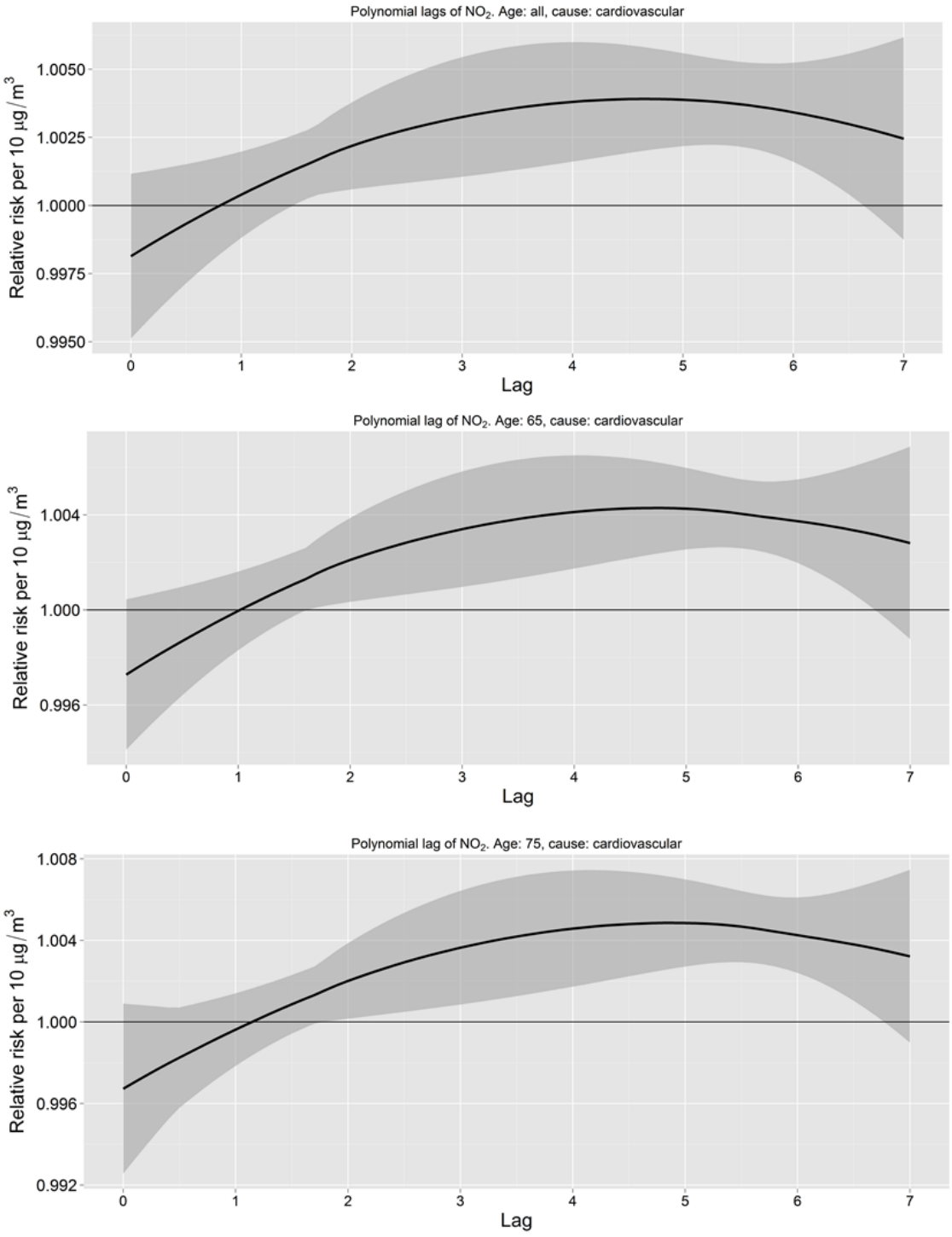


Figure 20. Relative risks of mortality due to cardiovascular causes (with 95%-confidence intervals) associated with PM10 levels on the day of the event (Lag = 0) and the seven days preceding the event, by age group. Estimates were calculated using polynomial lag models and are given for a 10 µg/m^3 increase in the level of NO_2 on the respective day

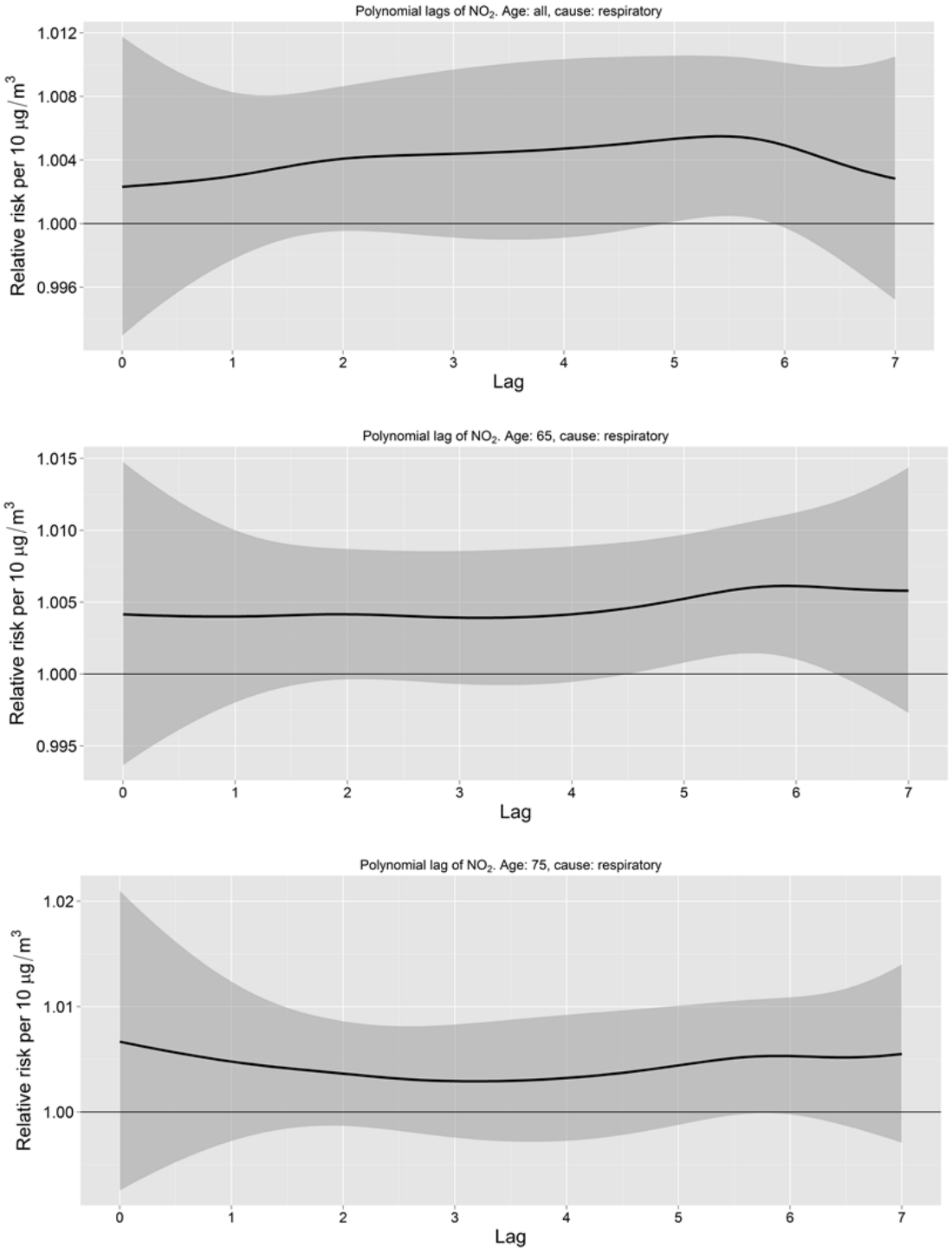


Figure 21. Relative risks of mortality due to respiratory causes (with 95%-confidence intervals) associated with PM10 levels on the day of the event (Lag = 0) and the seven days preceding the event, by age group. Estimates were calculated using polynomial lag models and are given for a 10 µg/m^3 increase in the level of NO_2 on the respective day

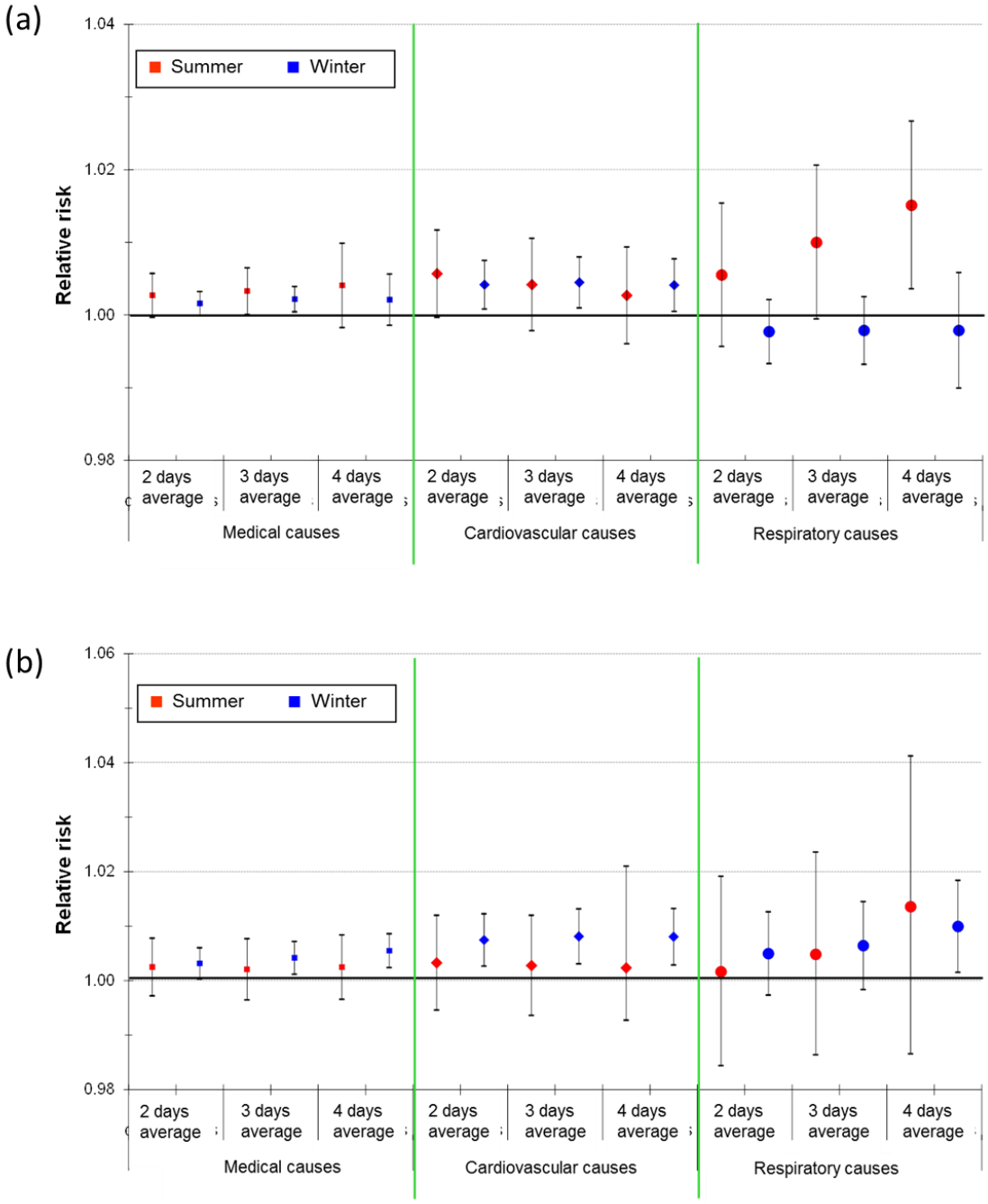


Figure 22. Difference between summer and winter effects of a 10 µg/m^3 increase in PM10 on emergency hospital admissions. (a) For the all ages group and (b) for the ≥75year old group.

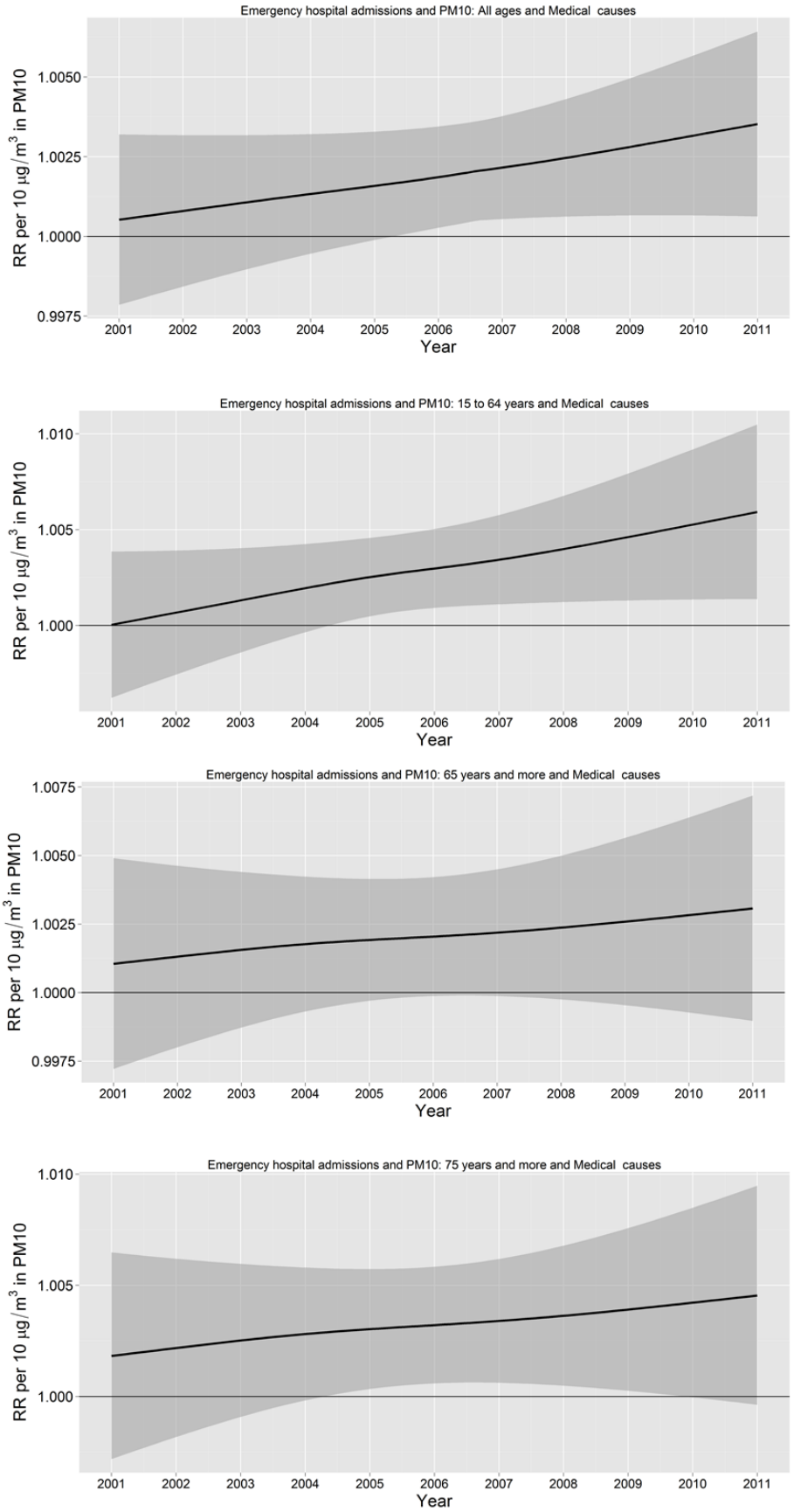


Figure 23. Time trend of the effect of PM10 on emergency hospital admissions due to medical causes by age groups. The effect is given as relative risk (RR) for a 10 µg/m^3 increase in the mean level of PM10 on the day of the event and the day before the event.
The time trend was calculated as a linear function. The grey bands represent the 95% confidence intervals.

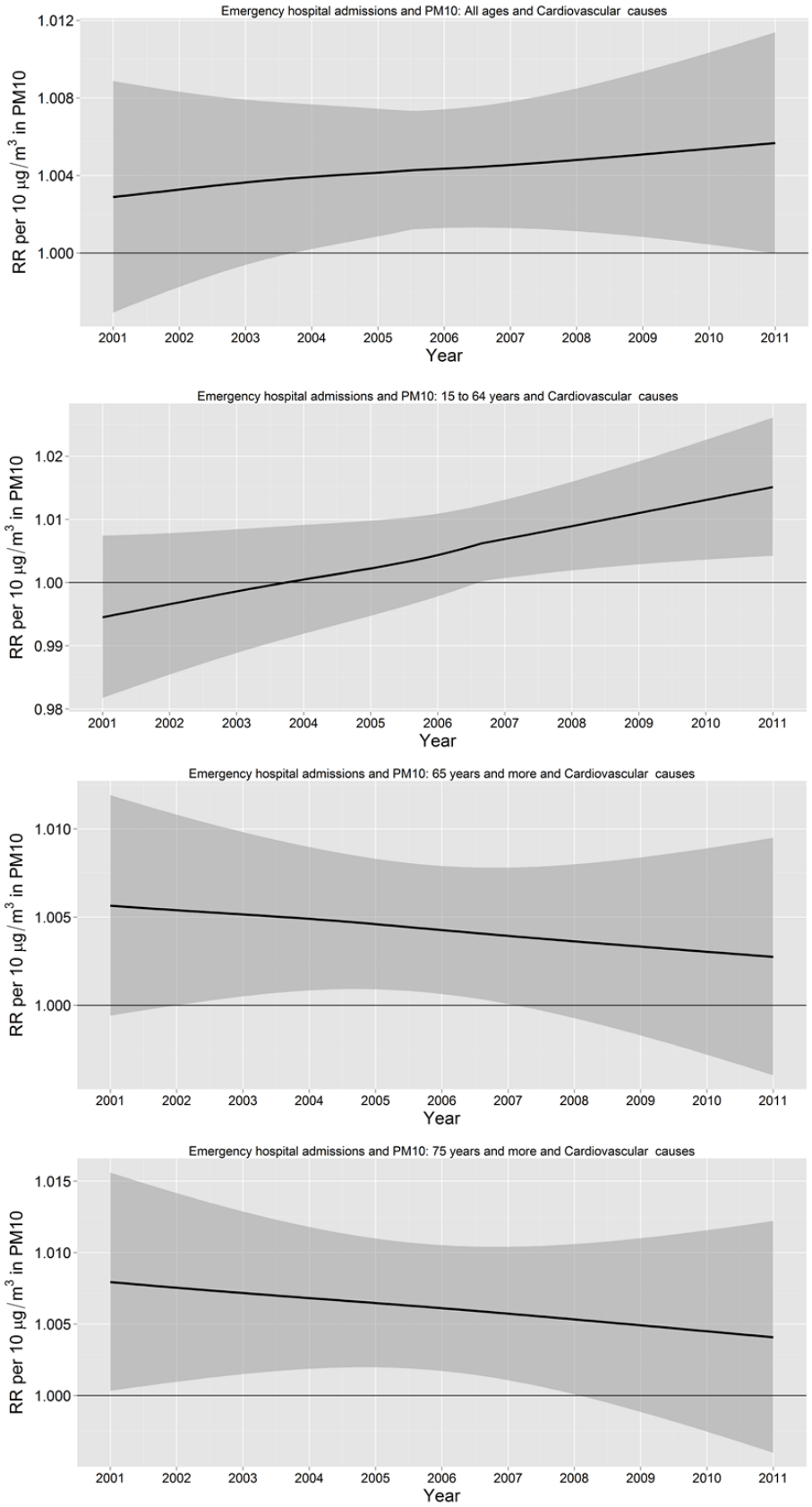


Figure 24. Time trend of the effect of PM10 on emergency hospital admissions due to cardiovascular causes by age groups. The effect is given as relative risk (RR) for a 10 µg/m^3 increase in the mean level of PM10 on the day of the event and the day before the event.
The time trend was calculated as a linear function. The grey bands represent the 95% confidence intervals.

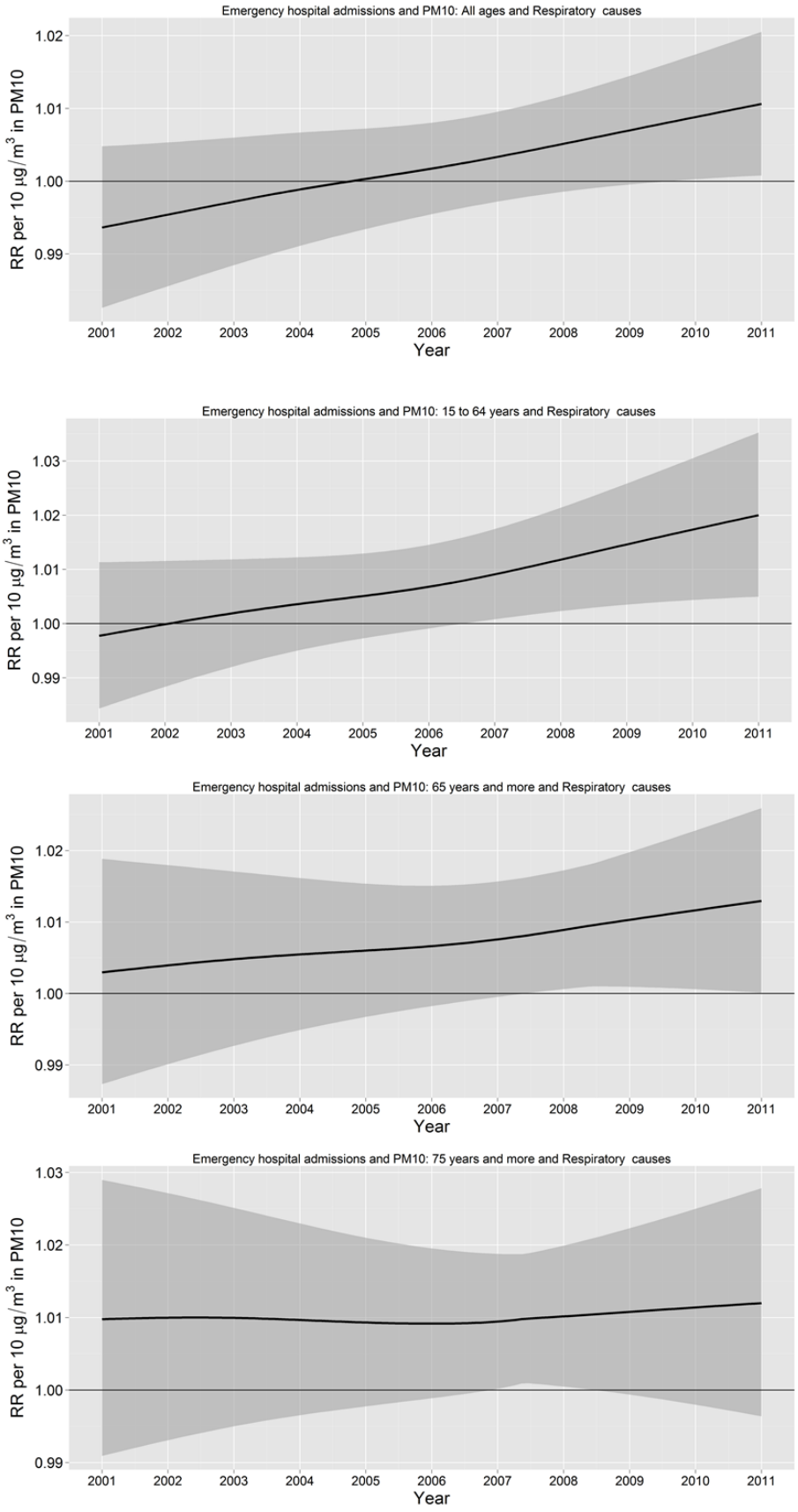


Figure 25. Time trend of the effect of PM10 on emergency hospital admissions due to respiratory causes by age groups. The effect is given as relative risk (RR) for a 10 µg/m^3 increase in the average level of PM10 over the day of the event and the three days preceding the event.
The time trend was calculated as a linear function. The grey bands represent the 95% confidence intervals.
.

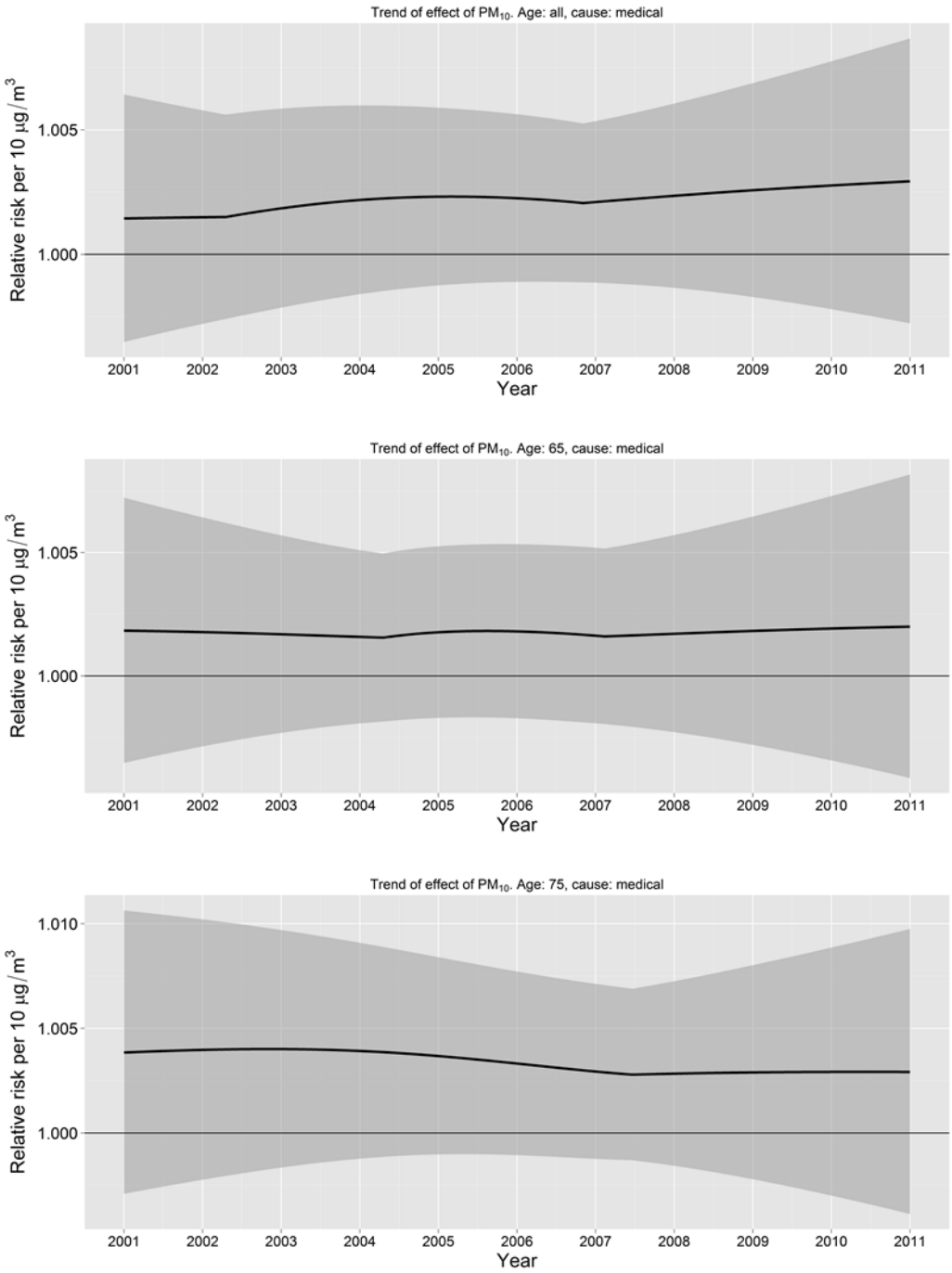


Figure 26. Time trend of the effect of PM10 on mortality due to medical causes by age groups. The effect is given as relative risk for a 10 µg/m^3 increase in the mean level of PM10 on the day of the event and the day before the event. The grey bands represent the 95% confidence intervals.

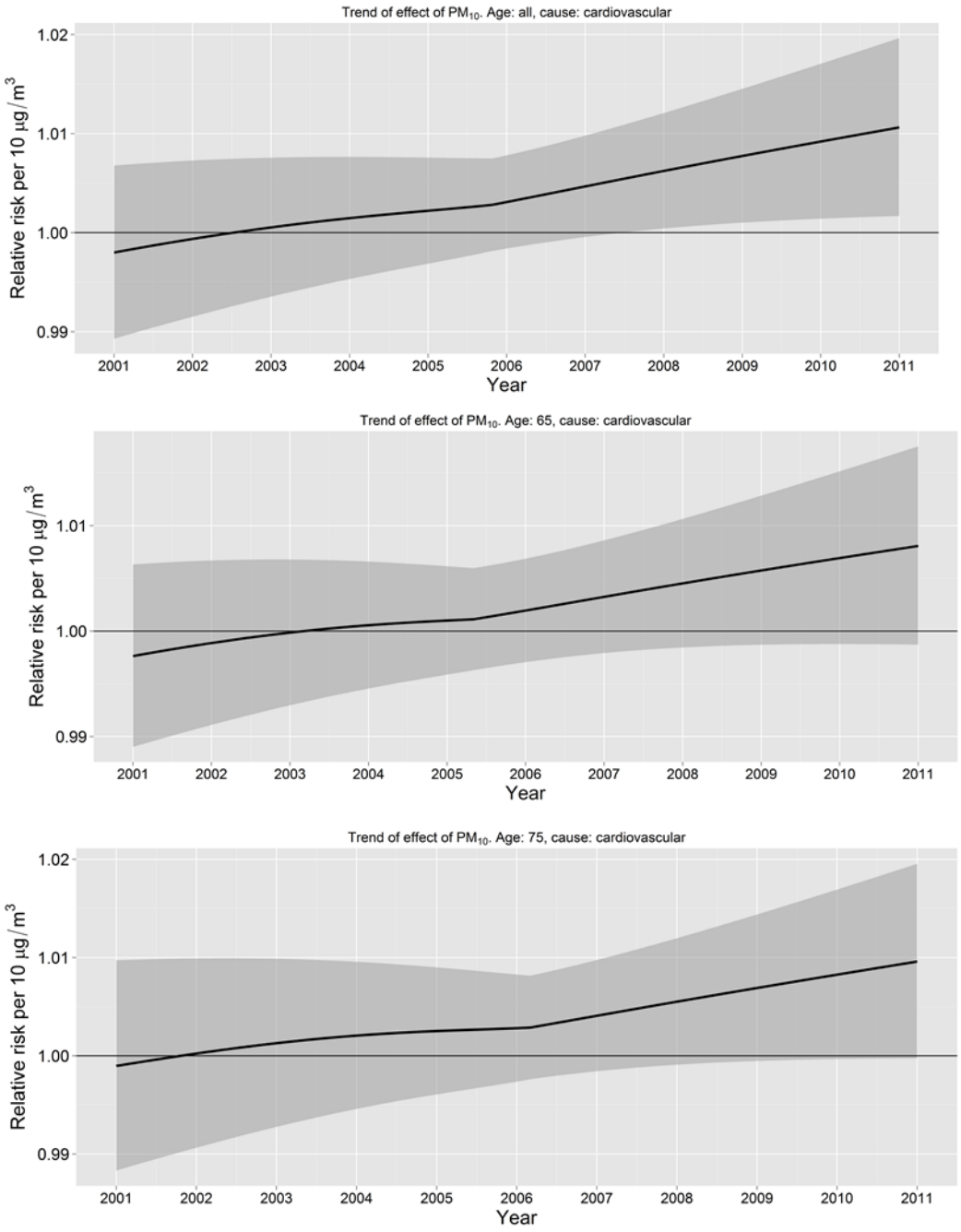


Figure 27. Time trend of the effect of PM10 on mortality due to cardiovascular causes by age groups. The effect is given as relative risk for a 10 µg/m^3 increase in the mean level of PM10 on the day of the event and the day before the event. The grey bands represent the 95% confidence intervals.

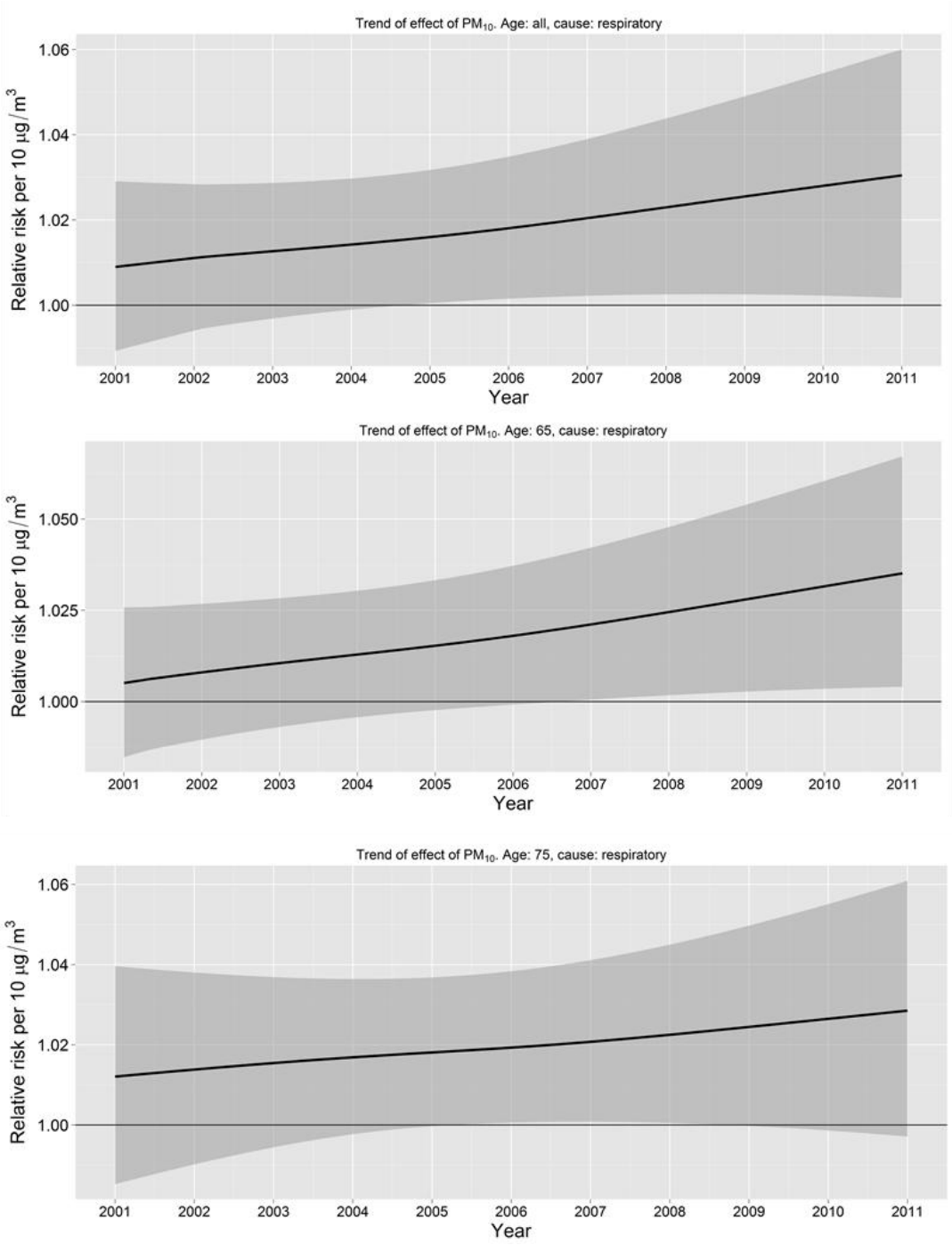


Figure 28. Time trend of the effect of PM10 on mortality due to respiratory causes by age groups. The effect is given as relative risk for a 10 µg/m^3 increase in the average level of PM10 over the day of the event and the three days preceding the event. The grey bands represent the 95% confidence intervals.

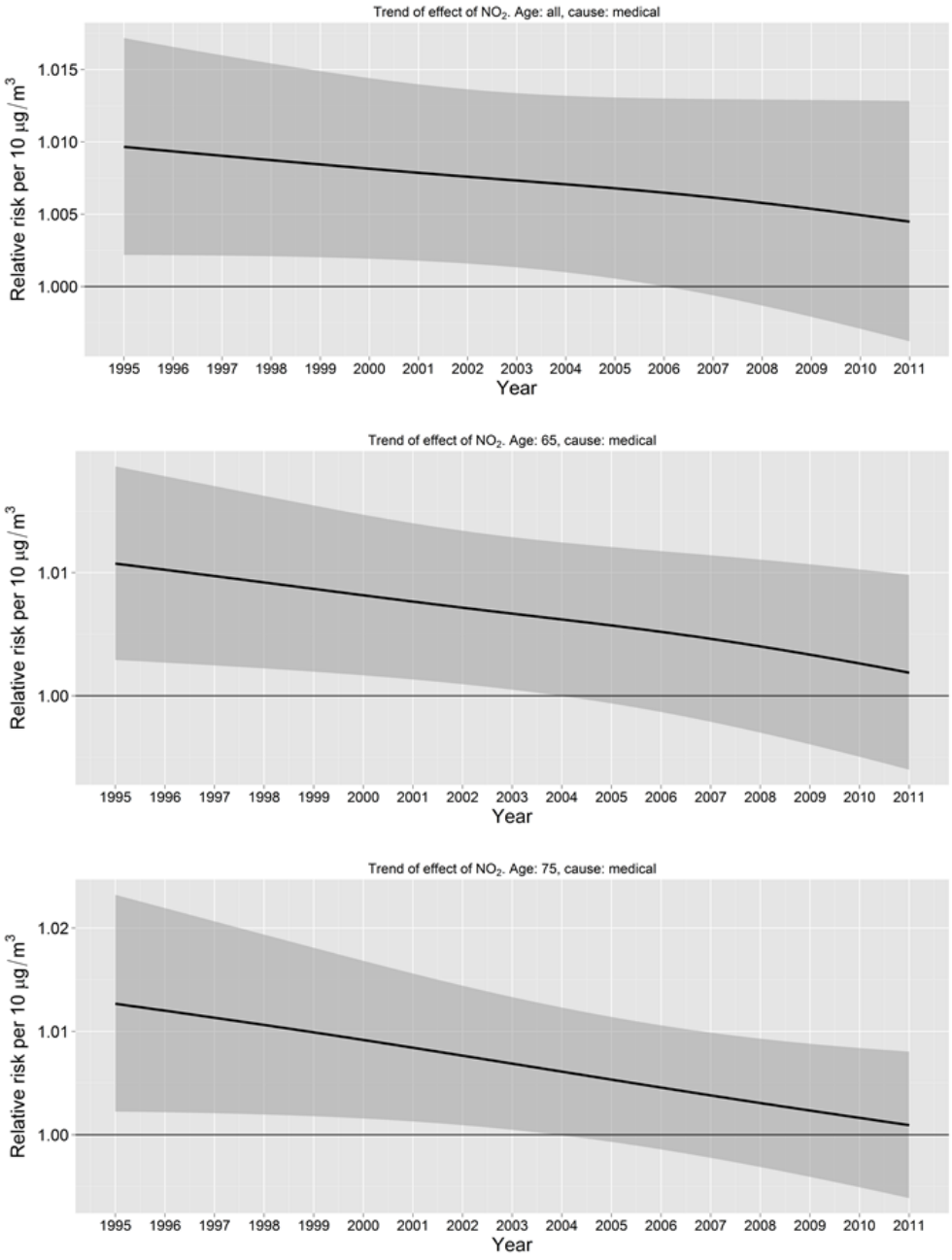


Figure 29. Time trend of the effect of NO_2 on mortality due to medical causes by age groups. The effect is given as relative risk for a 10 µg/m^3 increase in the mean level of NO_2 on the day of the event and the day before the event. The grey bands represent the 95% confidence intervals.

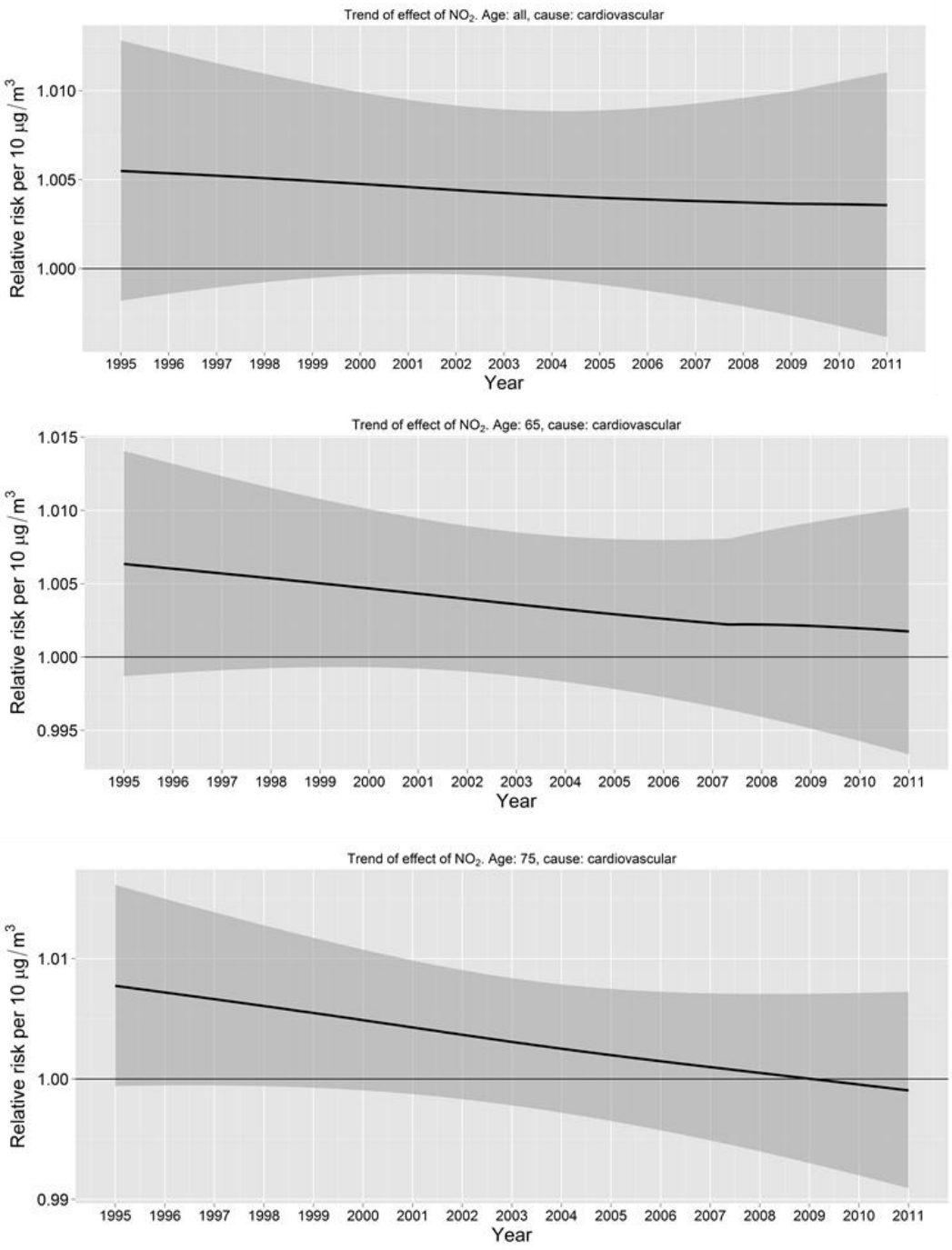


Figure 30. Time trend of the effect of NO_2 on mortality due to cardiovascular causes by age groups. The effect is given as relative risk for a 10 µg/m^3 increase in the mean level of NO_2 on the day of the event and the day before the event. The grey bands represent the 95% confidence intervals.

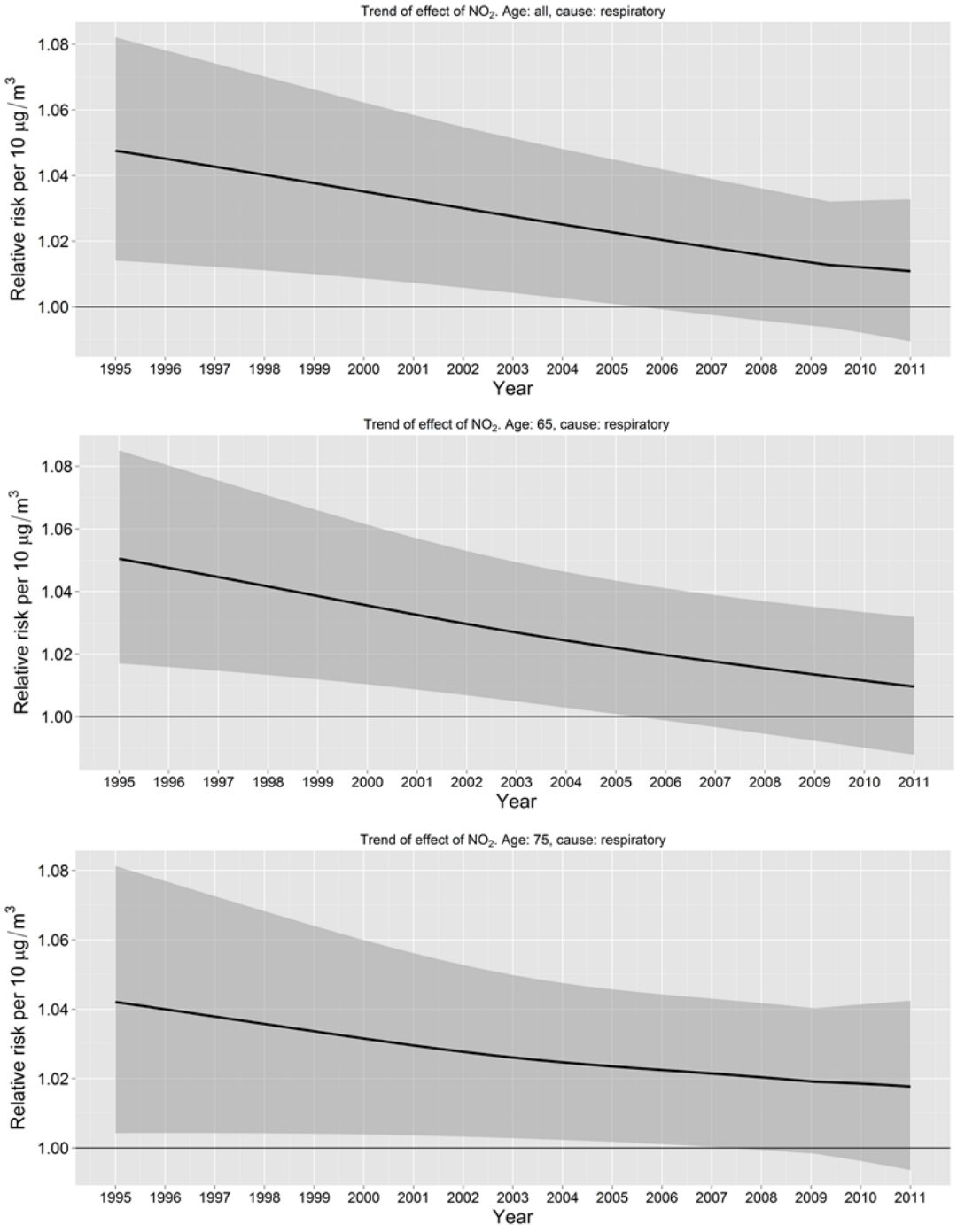


Figure 31. Time trend of the effect of NO_2 on mortality due to respiratory causes by age groups. The effect is given as relative risk for a 10 µg/m^3 increase in the mean level of NO_2 over the day of the event and the three days preceding the event. The grey bands represent the 95% confidence intervals.

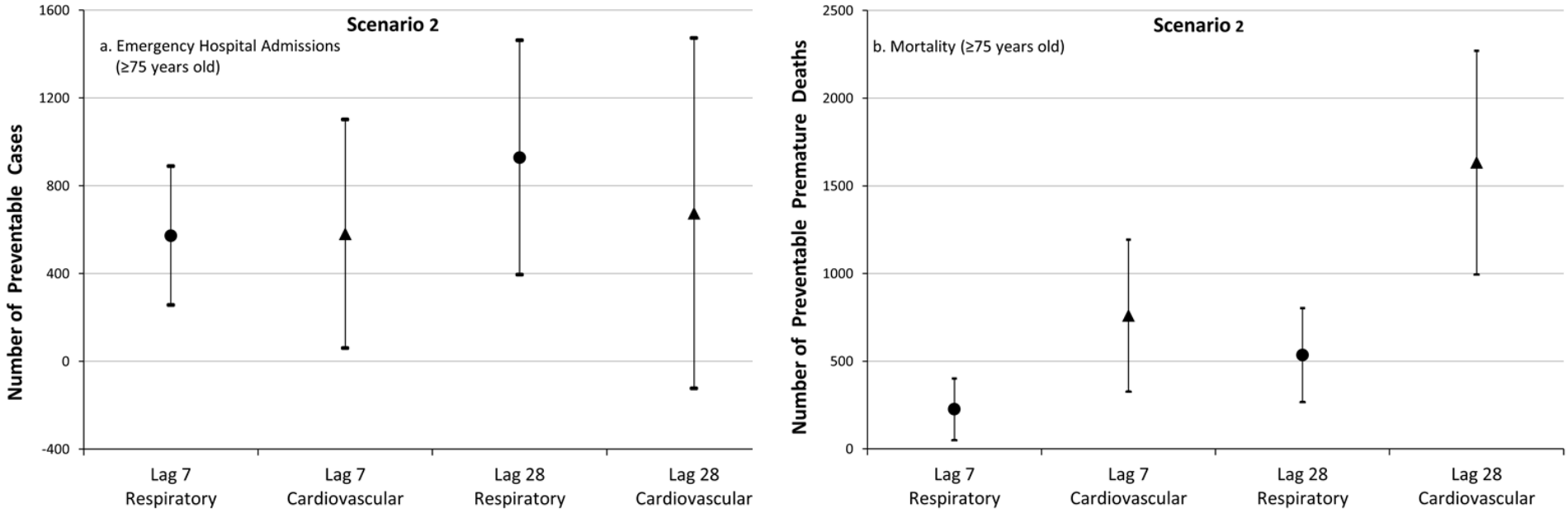


Figure 32. Comparison of total numbers of preventable cases from a reduction of daily PM10 levels by 20% (Scenario 2) during the study period 2001-2010 using different windows of exposure to develop the risk estimations.
Lag 7: For these calculations, effects of air pollution over 7 days were considered.
Lag 28: For these calculations, effects of air pollution over 28 days were considered.
Whiskers represent the 95% confidence interval for the estimates (estimates are non-statistically significant if its 95% CI crosses the zero value).