



SUPPLEMENTARY APPENDIX

Research Report 220

Air Pollution in Relation to COVID-19 Morbidity and Mortality: A Large Population-Based Cohort Study in Catalonia, Spain (COVAIR-CAT)

Cathryn Tonne et al.

Appendix A: Supplementary Tables and Figures

Appendix A was reviewed for spelling, grammar, and cross-references to the main report. It has not been formatted or fully edited by HEI. This document was reviewed by the HEI Review Committee.

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Appendix A

Air Pollution in Relation to COVID-19 Morbidity and Mortality: A Large Population-Based Cohort Study in Catalonia, Spain (COVAIR-CAT)

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Cohort Construction

Table A1. Databases Used in Cohort Construction

Name	Description
CMDB-AP	Primary care database
CMDB-HA	Hospital discharges database
CMDB-URG	Emergency care database
ECAP	Primary care source database
SUVEC	Epidemiological surveillance emergency service of Catalonia
RCA	Catalan Central Registry of Insured Individuals
AQuAS	Agency for Health Quality and Assessment of Catalonia

Table A2. Variable Definitions

Variable	Content	Source	Defined by	Comments
Age	Age on 01/01/2020, in years	RCA	Date of birth	Variable provided in categories of 3 years band because of confidentiality. We generated a random integer between the three possibilities to ascertain the final continuous age (e.g., for age category 50-52, we randomly select a number between 50, 51 and 52)
Sex	Female / Male	RCA	Sex at birth	
Individual income group	Three categories of low (<18,000 euros per year), middle (18,000-100,000 euros) and high (>100,000 euros)	RCA	Co-payment system for drug dispensations	This variable is already categorical. We considered individuals exempt from co-payment (nonworking population or people receiving non-contributory pension) as the low category.
Tobacco smoking status	Nonsmoker / Former smoker / Active smoker	ECAP	General practitioner recording	For the main analysis, we considered those missing as nonsmoker. This information was collected in 2015 and 2018; we used the latest available.
Health risk group (grupos de morbilidad ajustados, GMA)	Healthy / Low / Moderate / High	RCA	Briefly, the index encompasses multimorbidity and levels of patient complexity, accounting for acute, chronic, or oncological morbidities, if single or multi morbidity, medications, and demand on the health system.	To obtain the health status groups, we used the distribution of the score, as suggested, classifying those Health up to percentile 50th, Low up to 80th, Moderate up to 95th and High above 95th.[1] The index is associated with the use of healthcare resources.[2]
Diabetes mellitus	Yes / No	CMDB-AP and CMDB-HA	ICD-09: 250.x0, 250.x2, 357.2, 362.01, 362.02, 362.03, 362.04, 362.05, 362.06, 362.07, 366.41 249*, 250.x1, 250.x3	Diagnosis up to 01/03/2020

Variable	Content	Source	Defined by	Comments
			ICD-10: E11*, E12*, E13*	
Obesity	Yes / No	CMDB-AP	ICD-10: E66*	Diagnosis up to 01/03/2020
Body mass index	BMI, kg/m ²	ECAP	General practitioner recording	Information collected in 2015 and 2018; we used the latest available.
Chronic Obstructive Pulmonary Disorder	Yes / No	CMDB-AP and CMDB-HA	ICD-09: 491.0, 491.1, 491.8, 491.9, 491.20, 491.21, 491.22, 492.0, 492.8, 496* ICD-10: J41*, J42*, J43*, *J44*	Diagnosis up to 01/03/2020
Hypertension	Yes / No	CMDB-AP	ICD-10: I10*	Diagnosis up to 01/03/2020
Other cardiovascular disorders	Yes / No	CMDB-AP and/or CMDB-HA	ICD-09: 410*, 433.x1, 434* ICD-10: I10*, I48*, I20*, I21*, I22*, I23*, I24*, I25*, I61*, I63*, G45*, I65*, I66*, I67*, I67.2, I67.8, I67.9, I69*, I70*, I73, I73.9	Diagnosis up to 01/03/2020. It includes atrial fibrillation, acute myocardial infarction, stroke, other vascular disorders
Dyslipidemia	Yes / No	CMDB-AP	ICD-10: E78*	Diagnosis up to 01/03/2020
Nursing home status	Yes / No	SUVEC	Place of residence	Available for COVID-19 cases
Urbanicity (Area of residence)	City Town and Suburb Rural	RCA	1) Cities (Densely populated areas: at least 50% of the population lives in urban centres) 2) Towns and suburbs (Intermediate density areas: less than 50% of the population lives in rural grid cells and less than 50% of the population lives in urban centers), 3) Rural areas (Thinly populated areas: more than 50 % of the population lives in rural grid cells).	The boundaries of the degree of urbanisation areas are derived from the LAU2 2018 boundaries from the European Commission-Eurostat/GISO, based on data from EuroGeographics and the Eurostat 2011 Population grid

Variable	Content	Source	Defined by	Comments
Small Area Socioeconomic Index	Socioeconomic index at primary care service area level	RCA		Índex socioeconòmic territorial, based on data from 2017
Deprivation index	Deprivation index at primary care service area level	RCA/Census		Índice de privación 2011
Percentage of non-Spanish residents	Proportion of non-Spanish residents at census tract	RCA/Census		From 2018
Gini index	Inequity index at census tract	RCA/Census		Census 2011
Distance to closest primary care unit	Distance in meters from residence to closest primary care unit	RCA		2021
Average weekly TPP	Weekly test-positive proportion at AGA level	AQuaS	Aggregated public data	
Clinical COVID-19 diagnosis	Clinical diagnosis	CMDB-AP, CMDB-HA, CMDB-URG	ICD-10: B34.2, B97.2, J12.81, J12.89, U07.1	
Laboratory confirmed COVID-19 diagnosis	RT-PCR or Antigen test for SARS-CoV-2	SUVEC	Positive RT-PCR / Antigen test	
All-cause hospitalization after COVID-19 diagnosis	All-cause hospitalization after 30 days of first COVID-19 (clinical/ laboratory) diagnosis	CMDB-HA		We also allowed hospitalizations that occurred before 10 days of the diagnosis
Cardiovascular-related hospitalization after COVID-19 diagnosis	Cardiovascular cause as main reason of hospitalization after 30 days of first COVID-19 (clinical/ laboratory) diagnosis	CMDB-HA	ICD-10: I*	We also allowed hospitalizations that occurred before 10 days of the diagnosis
Respiratory-related hospitalization after COVID-19 diagnosis	Respiratory cause as main reason of hospitalization after 30 days of first COVID-19 (clinical/ laboratory) diagnosis	CMDB-HA	ICD-10: J*	We also allowed hospitalizations that occurred before 10 days of the diagnosis
Infection-related hospitalization after COVID-19	Infection cause as main reason of hospitalization after 30 days of first	CMDB-HA	ICD-10: A*	We also allowed hospitalizations that occurred before 10 days

Variable	Content	Source	Defined by	Comments
diagnosis	COVID-19 (clinical/ laboratory) diagnosis			of the diagnosis
Ill defined-related hospitalization after COVID-19 diagnosis	Ill-defined cause as main reason of hospitalization after 30 days of first COVID-19 (clinical/ laboratory) diagnosis	CMDB- HA	ICD-10: R*	We also allowed hospitalizations that occurred before 10 days of the diagnosis
ICU admission after COVID-19 diagnosis	ICU admission during the all-cause hospitalization after 30 days of first COVID-19 (clinical/ laboratory) diagnosis	CMDB- HA		We also allowed hospitalizations that occurred before 10 days of the diagnosis
Hospital length of stay	Days of hospitalization during the all-cause hospitalization after 30 days of first COVID-19 (clinical/ laboratory) diagnosis	CMDB- HA		We also allowed hospitalizations that occurred before 10 days of the diagnosis

Exposure model

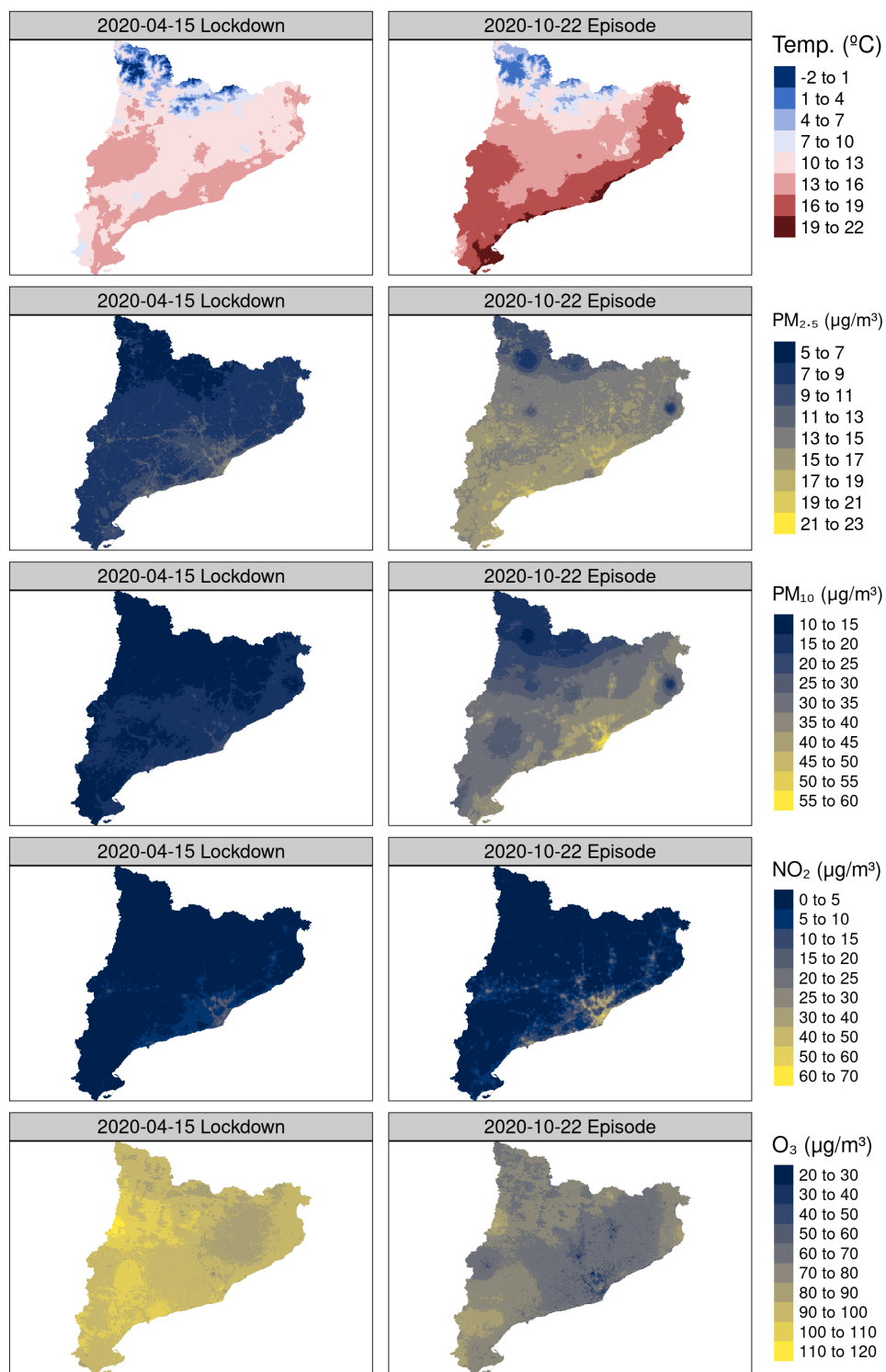


Figure A1. Model predictions for two selected dates coinciding with COVID-19 lockdown (2020-04-15) and declared air pollution episode in Barcelona due to Saharan dust advection (2020-10-22).

Table A3. Model Validation Statistics by Exposure Type and Period Computed Using Nested Cross Validation at the Station Level

Exposure	Period	RMSE	R ²	intercept	slope	RMSE spatial	R ² spatial	RMSE temporal	R ² temporal
Temp. (°C)	2018-20	1.21	0.97	-0.07	1.00	0.85	0.94	0.85	0.98
	2018	1.20	0.98	-0.05	1.00	0.88	0.94	0.83	0.99
	2019	1.23	0.97	-0.11	1.00	0.86	0.93	0.87	0.98
	2020	1.19	0.97	-0.05	1.00	0.84	0.94	0.84	0.98
NO ₂	2018-20	6.69	0.78	0.18	0.98	4.86	0.78	4.53	0.78
	2018	7.39	0.74	0.25	0.97	5.86	0.75	4.44	0.73
	2019	7.21	0.77	0.18	0.98	5.45	0.78	4.70	0.76
	2020	5.55	0.81	0.17	0.97	4.13	0.77	3.84	0.83
PM _{2.5}	2018-20	4.29	0.59	-1.02	1.07	1.68	0.71	3.98	0.54
	2018	3.90	0.54	-1.00	1.07	1.52	0.70	3.64	0.47
	2019	4.51	0.61	-1.17	1.08	2.07	0.71	4.05	0.56
	2020	4.32	0.55	-0.91	1.06	1.82	0.53	3.95	0.55
PM ₁₀	2018-20	6.54	0.63	-0.30	1.00	3.18	0.49	5.79	0.65
	2018	6.25	0.51	0.32	0.97	4.08	0.41	5.17	0.51
	2019	6.94	0.64	-0.36	1.01	3.63	0.39	5.97	0.69
	2020	6.30	0.65	-0.42	1.01	2.97	0.45	5.58	0.68
O ₃	2018-20	9.64	0.87	0.69	1.00	5.35	0.58	8.01	0.90
	2018	9.93	0.89	1.15	0.99	6.16	0.60	7.82	0.93
	2019	9.70	0.87	0.49	1.00	5.39	0.67	8.08	0.90
	2020	9.37	0.83	0.68	0.99	5.55	0.40	7.59	0.88

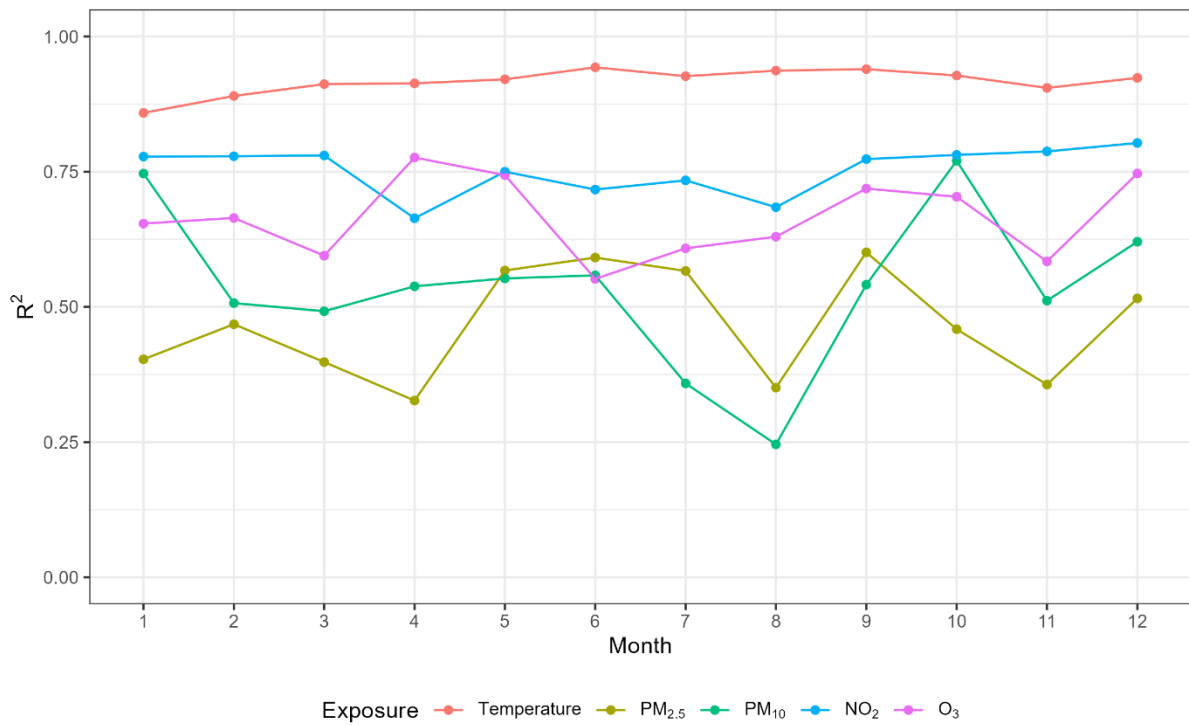


Figure A2. Monthly R² between observed and out-of-sample predicted exposures (using nested cross-validation at the station level) by exposure in 2020.

Data Analysis

(A)

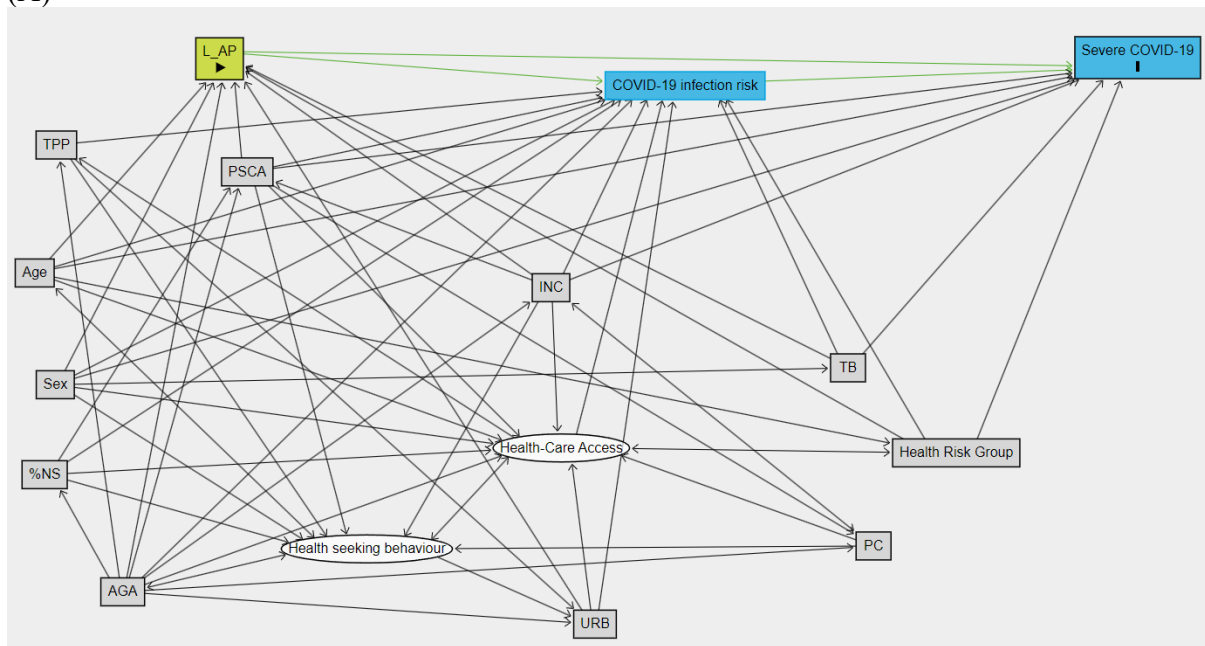
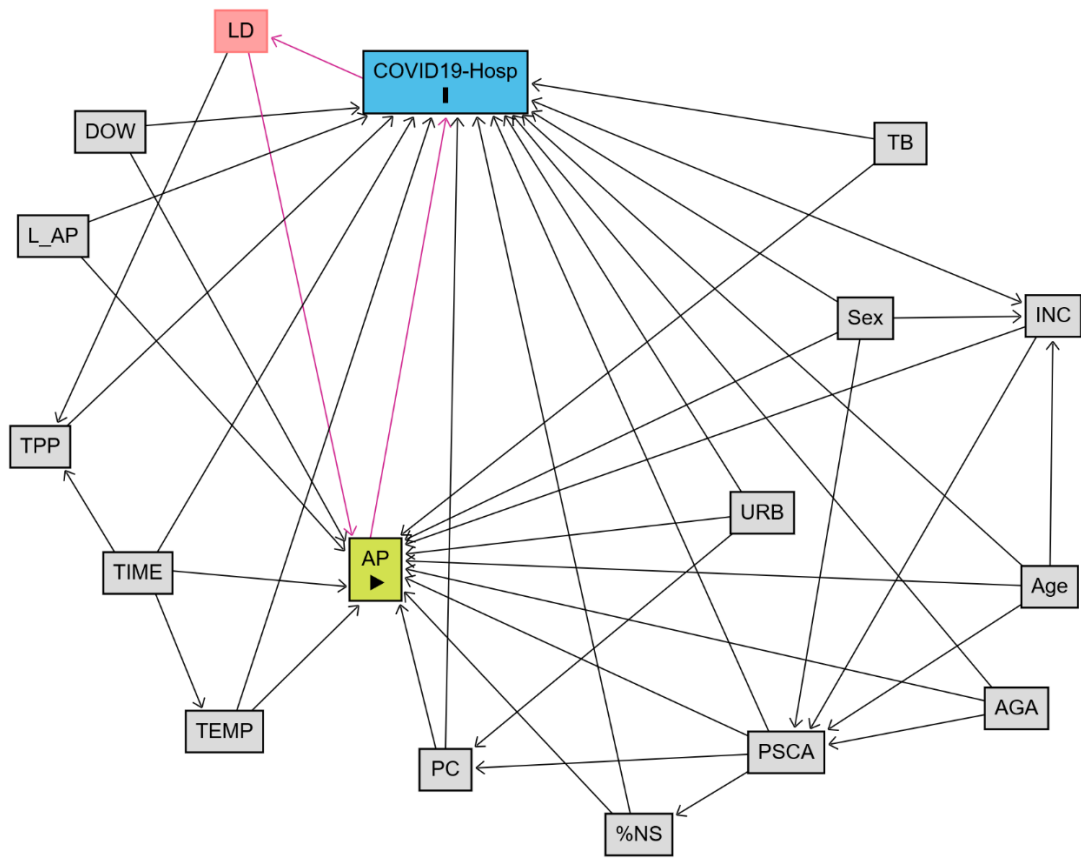
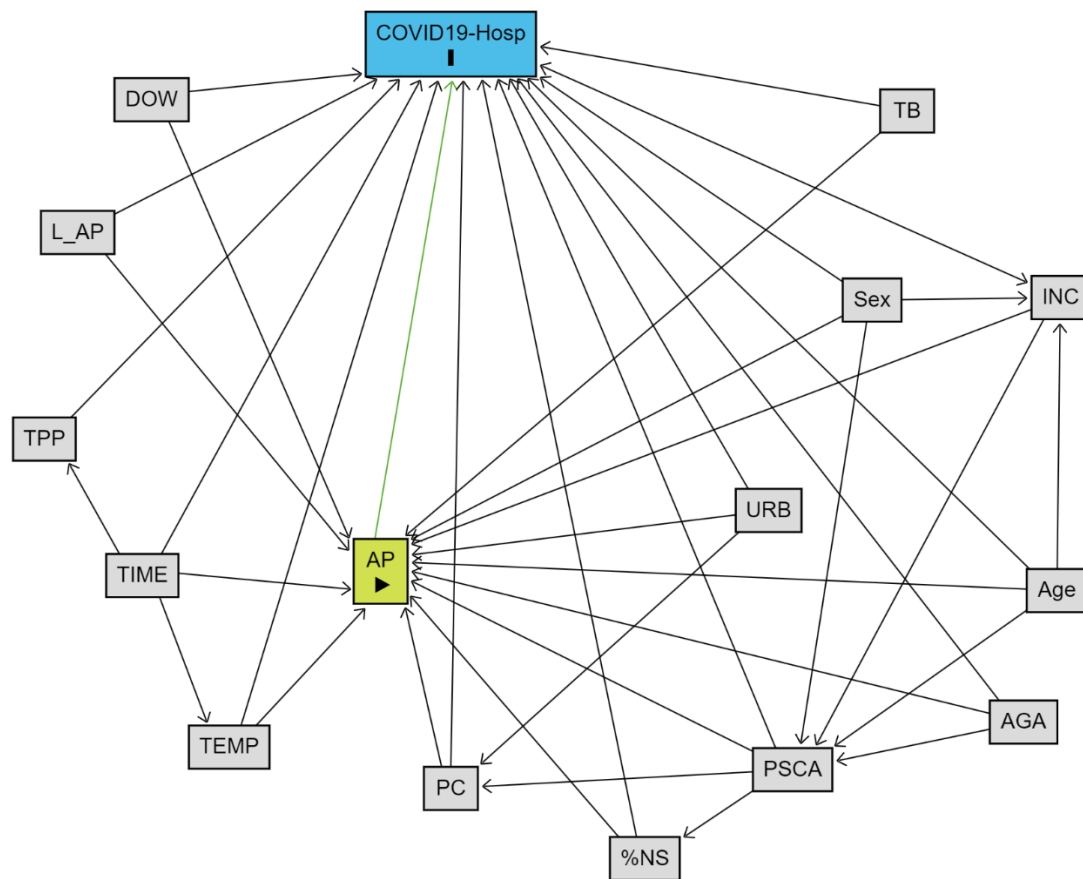


Figure A3. Directed Acyclic Graphs used for Aim 1 (A) and Aim 2 during the first (B) and second (C) pandemic waves. Figure continues next 2 pages. The legend and abbreviations appear on the 3rd page.

(B)



(C)



- exposure
- outcome
- ancestor of exposure
- ancestor of outcome
- ancestor of exposure *and* outcome
- adjusted variable
- unobserved (latent)
- other variable
- causal path
- biasing path

Abbreviations: TPP, test-positive proportion; SES, socioeconomic status; TB, tobacco smoking; INC, individual income; AGA, healthcare management area; PSCA, Small Area Socioeconomic Index; URB, urbanicity; %NS, proportion of non-Spanish nationals; PC, distance to the closest primary care unit; TPP, the weekly average of test-positive proportion at AGA level; L_AP, long-term exposure to air pollution; TEMP, temperature; DOW, day (weekend or not). Created with DAGitty.net (www.dagitty.net).

Table A4. AICs for the Different Versions of Distributed Lag Linear and Non-Linear Models (DLM and DLNM, respectively) Tested in Main and Sensitivity Analysis (Bold values indicate models with lowest AIC for each combination of pollutant and wave)

Pollutant	Period	DLM (Main model)		DLNM ^a		
		DF ^b for Lag dimension		DF ^b for Exposure dimension		
		4	5	3	4	5
NO ₂	Wave 1	263673.86	263675.41	263682.65	263689.24	263688.13
	Wave 2	155889.62	155879.98	155865.75	155849.19	155859.49
PM _{2.5}	Wave 1	261929.39	261930.97	261925.80	261926.02	261924.79
	Wave 2	156160.21	156154.24	156152.97	156143.42	156148.99
PM ₁₀	Wave 1	263728.36	263719.79	263720.48	263724.69	263706.76
	Wave 2	156141.63	156140.80	156141.41	156140.90	156139.52
O ₃	Wave 1	263753.00	263753.71	263724.31	263721.80	263717.93
	Wave 2	156148.17	156141.28	156145.73	156151.60	156159.09

AIC = Akaike information criteria.

^aDF=Degrees of Freedom.

^bDF for Lag dimension in DLNM were set to 5.

Results

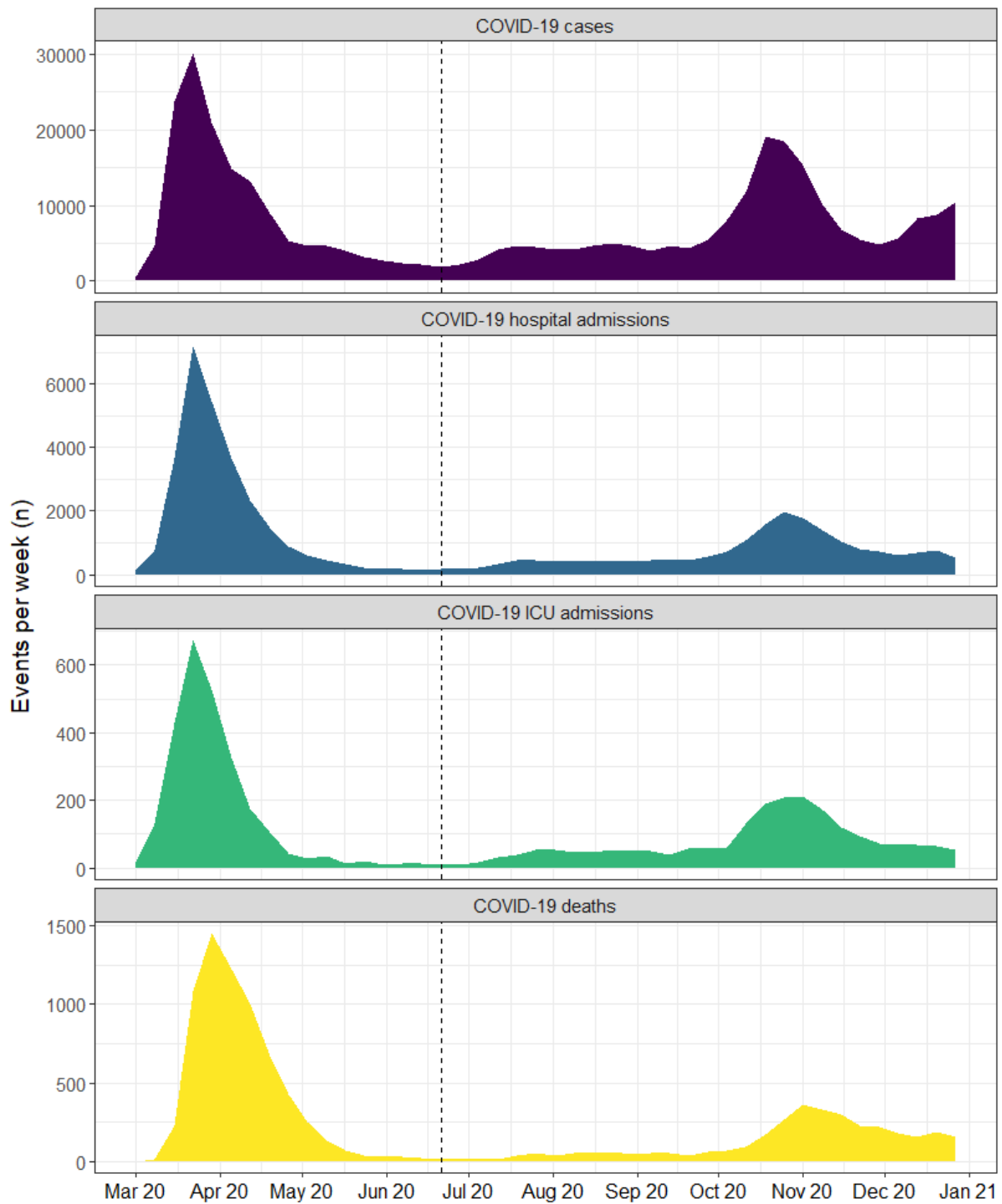


Figure A4. Weekly COVID-19 cases and severe COVID-19–related events during 2020 in Catalonia, Spain. The vertical dashed black line refers to the limit between first and second waves (June 21, 2020).

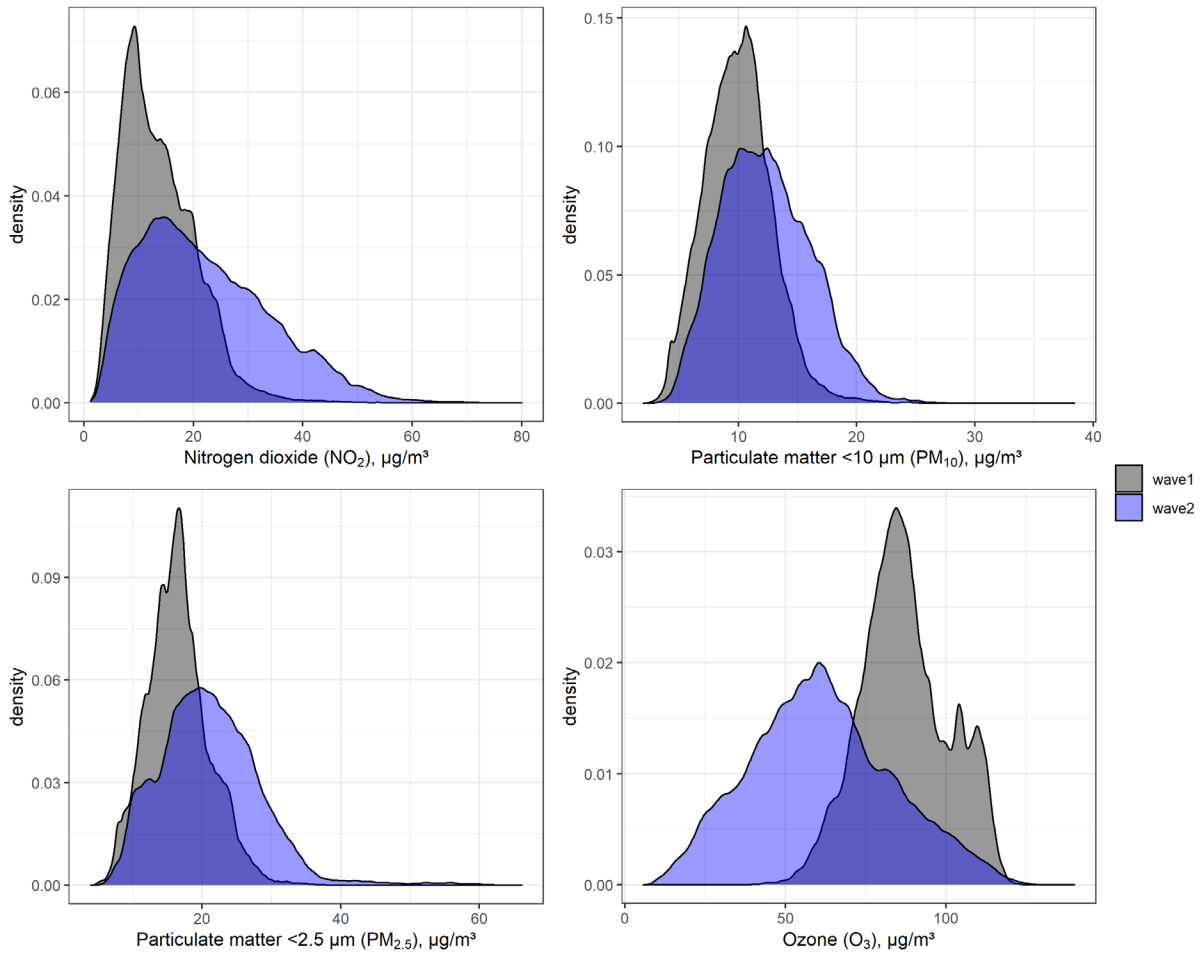


Figure A5. Distribution of daily air-pollution exposures in person-days of follow-up among individuals diagnosed with COVID-19 in primary care.

Table A5. Summary Statistics for Daily Exposure to Ambient Air Pollutants Within Person-Time of Follow-Up

Pollutant ($\mu\text{g}/\text{m}^3$)	Epidemic Wave	Median	1st Quartile	3rd Quartile	IQR^a
NO₂	First	12.58	8.56	17.99	14
	Second	20.24	12.87	29.97	
PM_{2.5}	First	9.95	8.01	11.76	5
	Second	12.06	9.49	14.91	
PM₁₀	First	16.28	13.53	19.07	8
	Second	20.59	16.11	25.45	
O₃	First	85.94	77.92	96.17	31
	Second	60.14	45.74	75.51	

Table A6. Spearman Correlations Between (A) Annual Average (2019) and (B) Daily Exposure (2020) from the COVAIR Model

(A)

	NO₂	PM_{2.5}	PM₁₀	O₃ (warm season)
NO₂	1			
PM_{2.5}	0.89	1		
PM₁₀	0.84	0.95	1	-0.70
O₃ (warm season)	-0.82	-0.76		1

(B)

	NO₂	PM_{2.5}	PM₁₀	O₃ (warm season)
NO₂	1			
PM_{2.5}	0.62	1		
PM₁₀	0.57	0.89	1	
O₃ (warm season)	-0.46	-0.28	-0.23	1

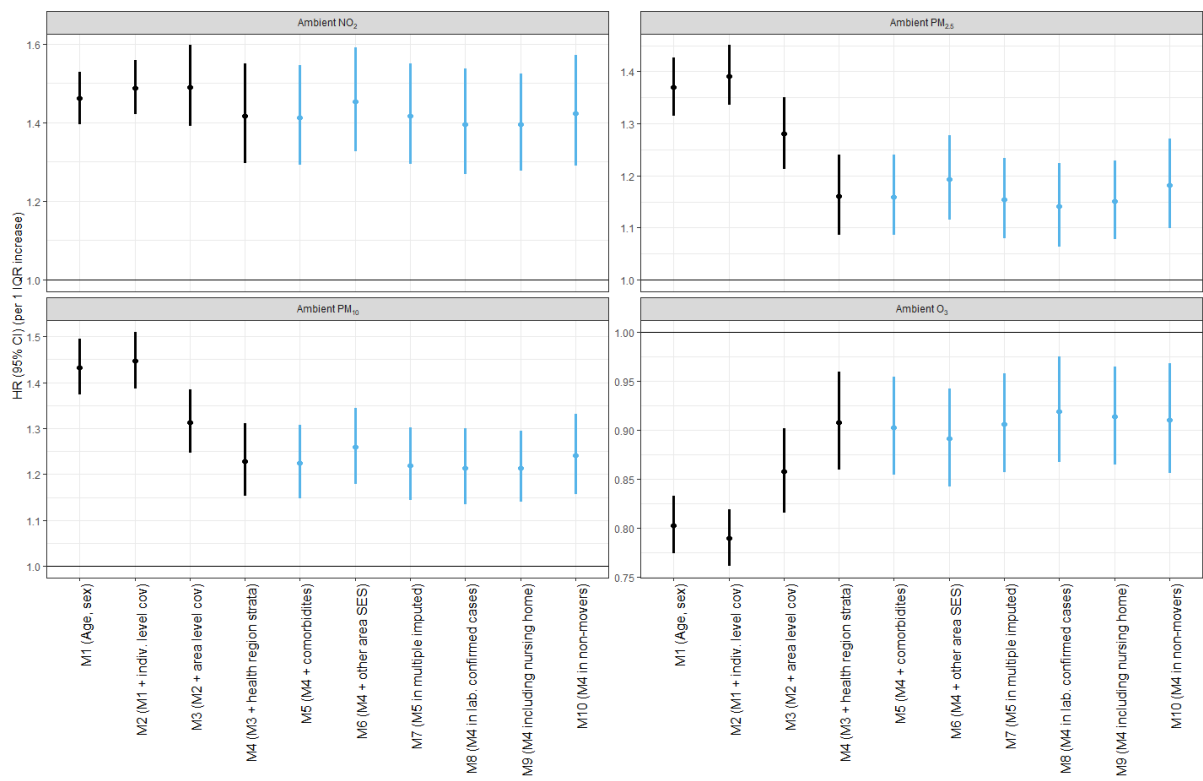


Figure A6. Sequential adjustment and sensitivity analyses for associations between long-term air pollution exposure and COVID-19–related ICU admission (single-pollutant models). Main analysis (black); *a priori* sensitivity analysis (blue).

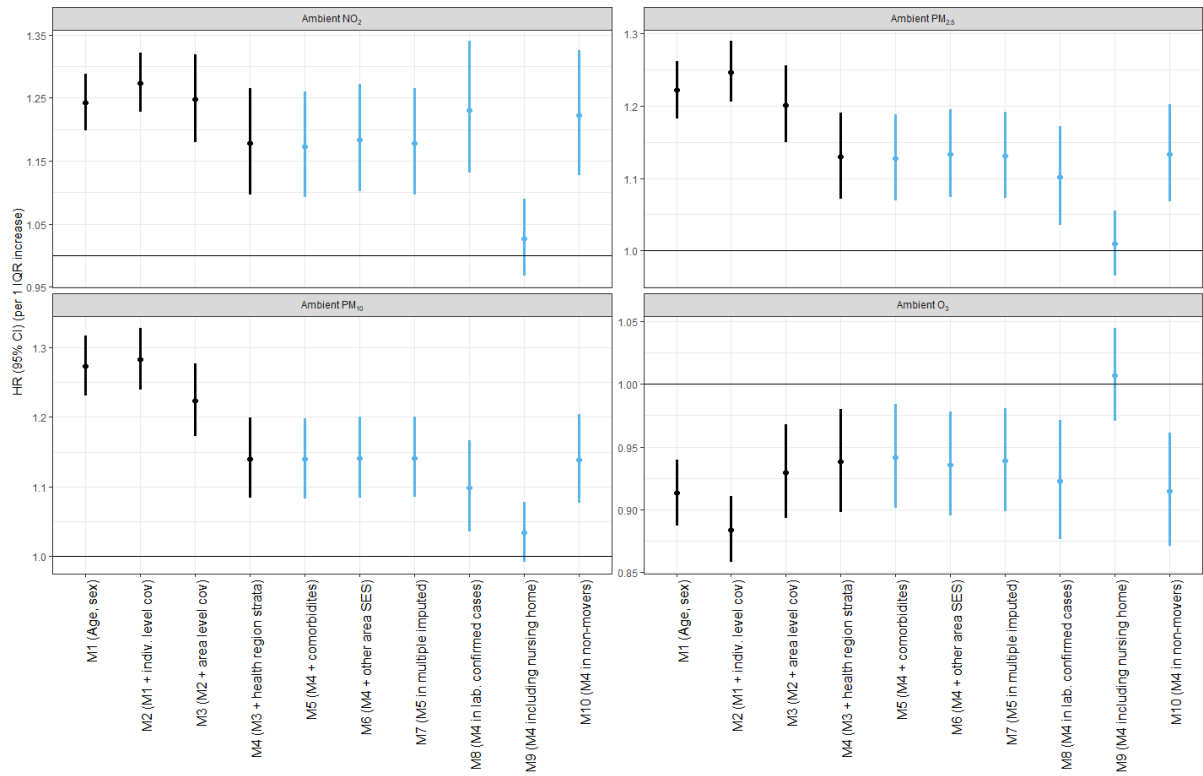


Figure A7. Sequential adjustment and sensitivity analyses for associations between long-term air pollution exposure and COVID-19–related death (single-pollutant models). Main analysis (black); *a priori* sensitivity analysis (blue).

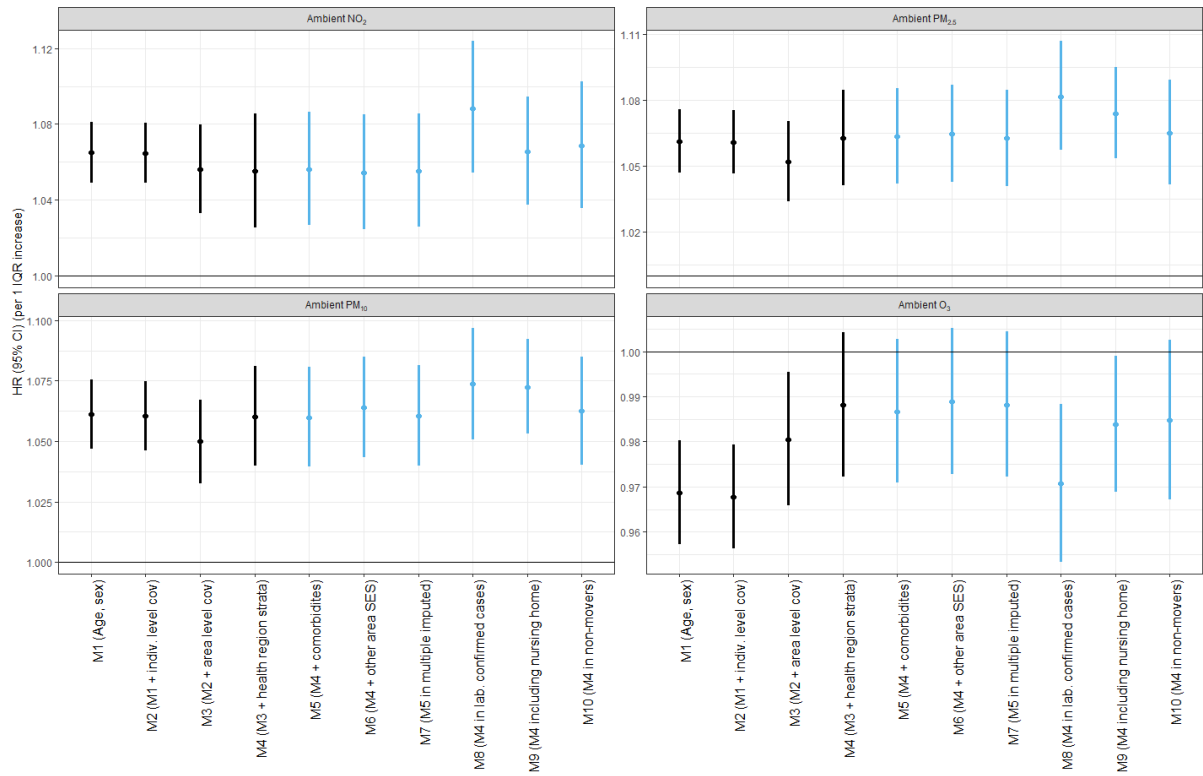


Figure A8. Sequential adjustment and sensitivity analyses for associations between long-term air pollution exposure and COVID-19–related hospital length of stay (single-pollutant models). Main analysis (black); *a priori* sensitivity analysis (blue).

Table A7. Adjusted Long-Term Associations Between Air Pollution and COVID-19–Related Outcomes in Single-Pollutant Models by COVID-19 Wave

		First wave	Second wave
	Exposure	HR (95% CI)	HR (95% CI)
Hospitalization			
	NO₂ (IQR increase: 16.1)	1.32 (1.27-1.37)	1.16 (1.11-1.22)
	PM_{2.5} (IQR increase: 3.2)	1.25 (1.21-1.28)	1.11 (1.07-1.14)
	O₃ (warm season) (IQR increase: 10.8)	0.88 (0.86-0.90)	0.95 (0.92-0.97)
ICU admission			
	NO₂ (IQR increase: 16.1)	1.48 (1.32-1.67)	1.34 (1.18-1.53)
	PM_{2.5} (IQR increase: 3.2)	1.19 (1.09-1.30)	1.12 (1.02-1.23)
	O₃ (warm season) (IQR increase: 10.8)	0.90 (0.84-0.97)	0.92 (0.85-0.99)
Death			
	NO₂ (IQR increase: 16.1)	1.15 (1.06-1.25)	1.25 (1.10-1.41)
	PM_{2.5} (IQR increase: 3.2)	1.12 (1.06-1.20)	1.14 (1.04-1.25)
	O₃ (warm season) (IQR increase: 10.8)	0.94 (0.90-0.99)	0.93 (0.86-1.00)
Hospital LOS			
	NO₂ (IQR increase: 16.1)	1.06 (1.03-1.10)	1.03 (0.99-1.06)
	PM_{2.5} (IQR increase: 3.2)	1.07 (1.04-1.09)	1.05 (1.02-1.07)
	O₃ (warm season) (IQR increase: 10.8)	0.99 (0.97-1.01)	0.99 (0.97-1.02)

Time-stratified Cox model adjusted as Model 4: age (continuous term, penalized spline with 6 df) + sex (strata, 2 categories) + smoking status (factor, 3 categories) + individual income (factor, 3 categories) + health risk group (factor, 4 categories) + Small Area Socioeconomic Index (continuous term) + percentage of non-Spanish nationals (continuous term) + distance to the closest primary care unit (continuous term) + urbanicity (strata, 3 categories) + average weekly of test-positive proportion (continuous term) + health region (strata, 7 categories).

Table A8. Adjusted Long-Term Associations Between Air Pollutants and COVID-19–Related Hospitalization, in Single- and Two-Pollutant Models, Comparing All-Cause with Cause-Specific Hospitalizations

		All-cause (n=47,174)	COVID-19 or Respiratory ^a (n=36,505)	COVID-19 ^a (n=33,981)
	Exposure	HR (95% CI)	HR (95% CI)	HR (95% CI)
NO ₂ (increase: 16.1)	Single-pollutant	1.25 (1.22-1.29)	1.27 (1.23-1.32)	1.27 (1.23-1.32)
PM _{2.5} (increase: 3.2)	Single-pollutant	1.19 (1.16-1.21)	1.21 (1.18-1.24)	1.21 (1.18-1.24)
NO ₂ (increase: 16.1)	Adjusted for PM _{2.5}	1.12 (1.08-1.17)	1.13 (1.08-1.19)	1.12 (1.07-1.18)
NO ₂ (increase: 16.1)	Adjusted for O ₃	1.24 (1.19-1.29)	1.29 (1.23-1.35)	1.26 (1.20-1.32)
PM _{2.5} (increase: 3.2)	Adjusted for NO ₂	1.12 (1.08-1.15)	1.13 (1.09-1.17)	1.14 (1.10-1.18)
PM _{2.5} (increase: 3.2)	Adjusted for O ₃	1.16 (1.13-1.19)	1.19 (1.16-1.22)	1.18 (1.15-1.22)

^a Defined by the ICD-10 code first position.

Model adjusted as Model 4: age (continuous term, penalized spline with 6 df) + sex (strata, 2 categories) + smoking status (factor, 3 categories) + individual income (factor, 3 categories) + health risk group (factor, 4 categories) + Small Area Socioeconomic Index (continuous term) + percentage of non-Spanish nationals (continuous term) + distance to the closest primary care unit (continuous term) + urbanicity (strata, 3 categories) + average weekly of test-positive proportion (continuous term) + health region (strata, 7 categories).

Table A9. Adjusted Long-Term Associations Between Air Pollutants and COVID-19–Related Outcomes with Single- and Multi-Year Average Exposure

		COVID-19 hospital admission	COVID-19 ICU admission	COVID-19 Death	Hospital length of stay
Pollutant	Exposure year	HR (95% CI)	HR (95% CI)	HR (95% CI)	IRR (95% CI)
NO ₂ (increase: 16.1)	2019	1.25 (1.22-1.29)	1.42 (1.30-1.55)	1.18 (1.10-1.27)	1.06 (1.03-1.09)
	2018	1.22 (1.19-1.25)	1.32 (1.21-1.43)	1.15 (1.08-1.23)	1.06 (1.04-1.09)
	Mean 2018- 2019	1.24 (1.20-1.27)	1.37 (1.26-1.49)	1.17 (1.09-1.25)	1.06 (1.03-1.09)
PM _{2.5} (increase: 3.2)	2019	1.19 (1.16-1.21)	1.16 (1.09-1.24)	1.13 (1.07-1.19)	1.06 (1.04-1.08)
	2018	1.17 (1.14-1.20)	1.16 (1.08-1.25)	1.13 (1.07-1.20)	1.06 (1.04-1.09)
	Mean 2018- 2019	1.19 (1.16-1.21)	1.17 (1.09-1.25)	1.13 (1.07-1.20)	1.06 (1.04-1.09)
PM ₁₀ (increase: 4.2)	2019	1.21 (1.18-1.23)	1.23 (1.15-1.31)	1.14 (1.08-1.20)	1.06 (1.04-1.08)
	2018	1.18 (1.15-1.20)	1.22 (1.14-1.30)	1.14 (1.09-1.20)	1.06 (1.04-1.08)
	Mean 2018- 2019	1.20 (1.18-1.23)	1.23 (1.15-1.32)	1.15 (1.09-1.21)	1.06 (1.04-1.08)
O ₃ (increase: 10.8)	2019	1.19 (1.16-1.21)	0.91 (0.86-0.96)	0.94 (0.90-0.98)	0.99 (0.97-1.00)
	2018	1.17 (1.14-1.20)	0.90 (0.86-0.95)	0.92 (0.88-0.96)	0.98 (0.96-0.99)
	Mean 2018- 2019	1.19 (1.16-1.21)	0.90 (0.86-0.95)	0.93 (0.89-0.97)	0.98 (0.97-1.00)

*Model 4: age (continuous term, penalized spline with 6 df) + sex (strata, 2 categories) + smoking status (factor, 3 categories) + individual income (factor, 3 categories) + health risk group (factor, 4 categories) + Small Area Socioeconomic Index (continuous term) + percentage of non-Spanish nationals (continuous term) + distance to the closest primary care unit (continuous term) + urbanicity (strata, 3 categories) + average weekly of test-positive proportion (continuous term) + health region (strata, 7 categories).

Table A10. Adjusted Long-Term Associations Between Air Pollutants and COVID-19–Related Outcomes in Single Models Stratified by Smoking Status

		COVID-19 hospital admission	COVID-19 ICU admission	COVID-19 Death	Hospital length of stay
		HR (95% CI)	HR (95% CI)	HR (95% CI)	IRR (95% CI)
NO ₂ (increase: 16.1)	Main analysis, Model 4*	1.25 (1.22-1.29)	1.42 (1.30-1.55)	1.18 (1.10-1.27)	1.06 (1.03-1.09)
	Among smokers (former and active), Model 4a**	1.27 (1.20-1.33)	1.41 (1.21-1.63)	1.26 (1.11-1.43)	1.06 (1.01-1.11)
	Among non-smokers (no and missing), Model 4a**	1.25 (1.20-1.29)	1.43 (1.28-1.60)	1.14 (1.04-1.24)	1.06 (1.02-1.09)
PM _{2.5} (increase: 3.2)	Main analysis, Model 4*	1.19 (1.16-1.21)	1.16 (1.09-1.24)	1.13 (1.07-1.19)	1.06 (1.04-1.08)
	Among smokers (former and active), Model 4a**	1.23 (1.19-1.28)	1.26 (1.12-1.40)	1.15 (1.05-1.26)	1.08 (1.04-1.12)
	Among non-smokers (no and missing), Model 4a**	1.17 (1.14-1.20)	1.11 (1.02-1.21)	1.12 (1.05-1.19)	1.06 (1.03-1.08)
PM ₁₀ (increase: 4.2)	Main analysis, Model 4*	1.21 (1.18-1.23)	1.23 (1.15-1.31)	1.14 (1.08-1.20)	1.06 (1.04-1.08)
	Among smokers (former and active), Model 4a**	1.22 (1.18-1.27)	1.32 (1.19-1.46)	1.14 (1.04-1.24)	1.06 (1.03-1.10)
	Among non-smokers (no and missing), Model 4a**	1.20 (1.17-1.23)	1.17 (1.08-1.28)	1.14 (1.07-1.21)	1.06 (1.04-1.09)
O ₃ (increase: 10.8)	Main analysis, Model 4*	0.91 (0.89-0.92)	0.91 (0.86-0.96)	0.94 (0.90-0.98)	0.99 (0.97-1.00)
	Among smokers (former and active), Model 4a**	0.90 (0.88-0.93)	0.86 (0.79-0.95)	0.91 (0.84-0.98)	0.99 (0.96-1.02)
	Among non-smokers (no and missing), Model 4a**	0.91 (0.89-0.93)	0.93 (0.87-1.00)	0.95 (0.90-1.00)	0.99 (0.97-1.01)

*Model 4: age (continuous term, penalized spline with 6 df) + sex (strata, 2 categories) + smoking status (factor, 3 categories) + individual income (factor, 3 categories) + health risk group (factor, 4 categories) + Small Area Socioeconomic Index (continuous term) + percentage of non-Spanish nationals (continuous term) + distance to the closest primary care unit (continuous term) + urbanicity (strata, 3 categories) + average weekly of test-positive proportion (continuous term) + health region (strata, 7 categories).

**Model 4a: age (continuous term, penalized spline with 6 df) + sex (strata, 2 categories) + individual income (factor, 3 categories) + health risk group (factor, 4 categories) + Small Area Socioeconomic Index (continuous term) + percentage of non-Spanish nationals (continuous term) + distance to the closest primary care unit (continuous term) + urbanicity (strata, 3 categories) + average weekly of test-positive proportion (continuous term) + health region (strata, 7 categories).

Table A11. Cumulative Hazard Ratios^a (95% CI) Between Air Pollution and Hospital Admission by Lag Among Individuals Diagnosed with COVID-19 in Primary Care Between 1 March and 31 December 2020 (HRs estimated for an Interquartile Range increase in each air pollution from the median)

Pollutant	Lag	First Wave			Second Wave		
		HR	95%CI Low	95%CI High	HR	95%CI Low	95%CI High
NO ₂	0	1.08	1.02	1.14	1.15	1.11	1.20
	0_1	1.09	1.03	1.16	1.14	1.09	1.19
	0_2	1.07	1.01	1.15	1.10	1.05	1.15
	0_3	1.04	0.97	1.12	1.10	1.04	1.15
	0_4	1.00	0.91	1.09	1.10	1.04	1.17
	0_5	0.94	0.85	1.03	1.08	1.02	1.15
	0_6	0.88	0.79	0.97	1.06	0.99	1.14
	0_7	0.84	0.76	0.93	1.12	1.04	1.20
PM _{2.5}	0	0.99	0.94	1.04	1.09	1.05	1.14
	0_1	0.99	0.94	1.05	1.06	1.02	1.11
	0_2	1.01	0.95	1.06	1.04	0.99	1.09
	0_3	1.01	0.95	1.07	1.06	1.01	1.11
	0_4	1.00	0.93	1.06	1.08	1.03	1.15
	0_5	0.96	0.90	1.02	1.08	1.02	1.15
	0_6	0.92	0.86	0.98	1.06	0.99	1.13
	0_7	0.92	0.87	0.98	1.08	1.01	1.16
PM ₁₀	0	1.02	0.97	1.07	1.07	1.04	1.10
	0_1	0.98	0.94	1.03	1.06	1.03	1.10
	0_2	0.97	0.92	1.03	1.04	1.01	1.08
	0_3	1.01	0.95	1.07	1.04	1.00	1.08
	0_4	1.03	0.96	1.11	1.05	1.01	1.10
	0_5	1.00	0.92	1.08	1.06	1.01	1.11
	0_6	0.94	0.86	1.02	1.07	1.01	1.12
	0_7	0.97	0.88	1.06	1.09	1.03	1.15
O ₃	0	0.94	0.88	1.00	0.83	0.78	0.89
	0_1	0.94	0.88	1.00	0.86	0.80	0.91
	0_2	0.94	0.88	1.01	0.91	0.84	0.97
	0_3	0.95	0.89	1.02	0.91	0.84	0.99
	0_4	0.97	0.90	1.05	0.90	0.82	0.98
	0_5	1.02	0.95	1.10	0.91	0.83	1.00
	0_6	1.07	0.98	1.16	0.93	0.84	1.03
	0_7	1.02	0.94	1.11	0.88	0.80	0.98

^a Predictions were adjusted for: age, sex (stratification variable), tobacco smoking status, individual income, Small Area Socioeconomic Index, proportion of non-Spanish nationals, distance to the closest primary care unit, urbanicity (stratification variable), healthcare management area (AGA), the weekly average of test-positive proportion (TPP) at AGA level, long-term exposure to air pollution, temperature, time and day (weekend or not).

Table A12. Hazard Ratios for Hospital Admission per Interquartile Range (IQR^a) Increase in Long-Term Air Pollution in the Main Aim 2 Models

Pollutant	Wave	HR	95%CI Low	95%CI High
NO₂	First	1.30	1.22	1.40
	Second	0.98	0.89	1.07
PM_{2.5}	First	1.16	1.11	1.21
	Second	1.07	1.02	1.13
PM₁₀	First	1.16	1.12	1.21
	Second	1.06	1.00	1.12
O₃	First	0.91	0.88	0.94
	Second	0.99	0.94	1.04

^aIQR values for the year 2019. NO₂: 16.1; PM_{2.5}: 3.2; PM₁₀: 4.2; O₃: 10.8.

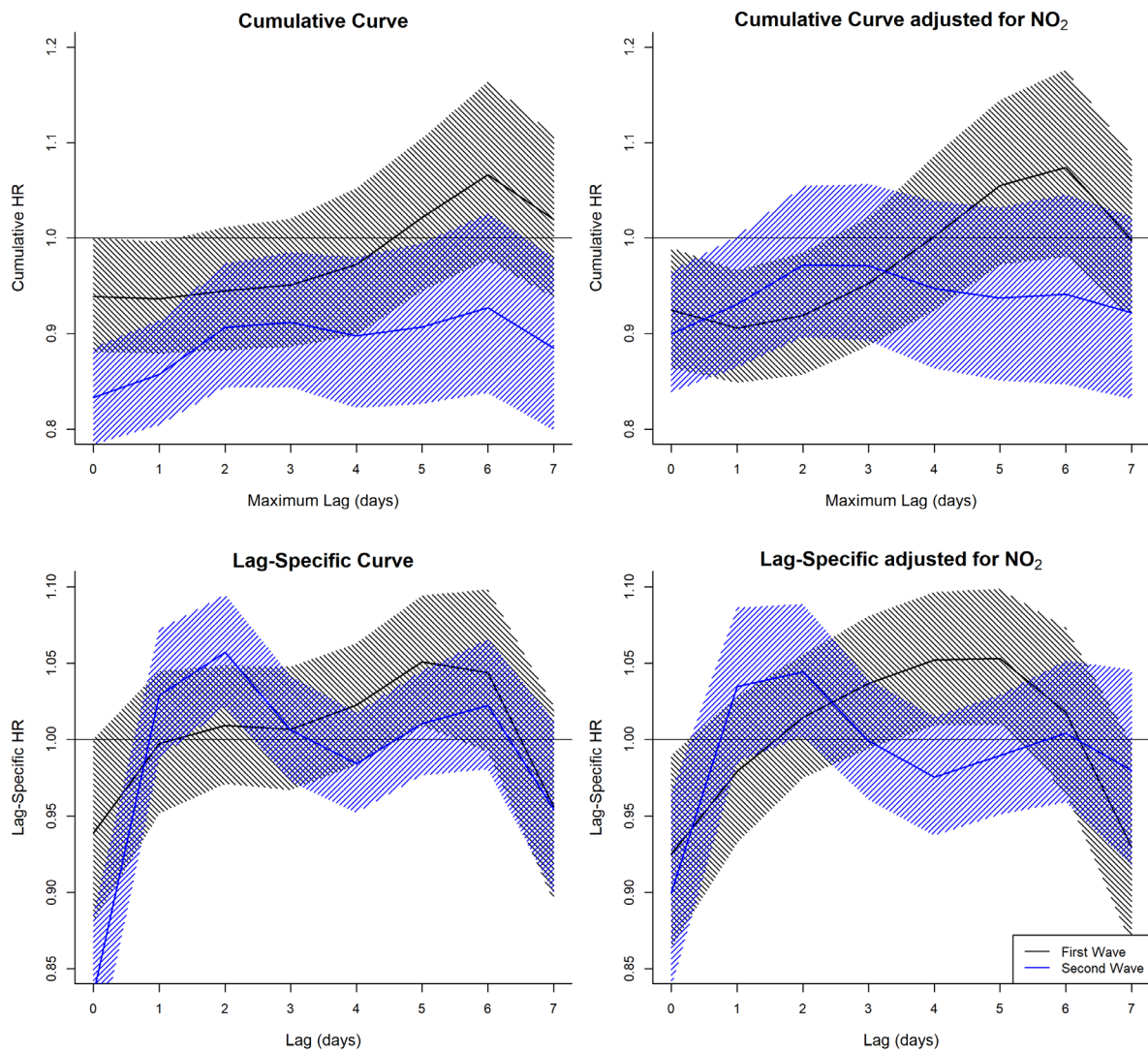


Figure A9. Cumulative and Lag-Specific Hazard Ratios^a for hospital admission per IQR increase in ozone (O₃) among individuals diagnosed with COVID-19 in primary care (n=240,902) by epidemic wave^b. Shading represents 95% confidence intervals.

^aPredictions were adjusted for: age, sex (stratification variable), tobacco smoking status, individual income, healthcare management area (AGA), Small Area Socioeconomic Index, proportion of non-Spanish nationals, distance to the closest primary care unit, urbanicity (stratification variable), the weekly average of test positive proportion (TPP) at AGA level, long-term exposure to air pollution, temperature, NO₂, time and day (weekend or not).

^bWave 1=1 March to 20 June 2020; Wave 2=21 June to 31 December.

Table A13. Cumulative Hazard Ratios (95% CI) Between Air Pollution and Hospital Admission at Selected Lags During the Second Wave in Sensitivity Analysis (HRs estimated for an Interquartile Range Increase)

Pollutant	Lag	Diagnosed or Test + ^a	Covid 1st cause ^b	Non-movers ^c	Death as competing event ^d	ABS Clustering ^e	Alternative definition of wave ^f	Nonlinearity ^g
NO ₂	0	1.06 (1.03 to 1.09)	1.14 (1.09 to 1.19)	1.14 (1.09 to 1.20)	1.15 (1.11 to 1.20)	1.15 (1.11 to 1.20)	1.14 (1.10 to 1.19)	1.11 (1.04 to 1.18)
	0_7	1.10 (1.04 to 1.15)	1.05 (0.97 to 1.15)	1.09 (1.01 to 1.18)	1.12 (1.04 to 1.20)	1.12 (1.03 to 1.21)	1.15 (1.07 to 1.23)	1.08 (0.99 to 1.19)
PM _{2.5}	0	1.02 (0.99 to 1.05)	1.09 (1.04 to 1.14)	1.09 (1.04 to 1.14)	1.09 (1.05 to 1.14)	1.09 (1.05 to 1.14)	1.10 (1.05 to 1.14)	1.08 (1.03 to 1.15)
	0_7	1.05 (1.00 to 1.11)	1.10 (1.01 to 1.20)	1.09 (1.01 to 1.17)	1.07 (1.00 to 1.15)	1.08 (0.99 to 1.18)	1.13 (1.06 to 1.21)	1.07 (0.97 to 1.19)
PM ₁₀	0	1.02 (1.00 to 1.04)	1.06 (1.02 to 1.10)	1.07 (1.03 to 1.10)	1.07 (1.04 to 1.10)	1.07 (1.04 to 1.10)	1.08 (1.04 to 1.11)	1.06 (1.00 to 1.12)
	0_7	1.07 (1.03 to 1.12)	1.09 (1.02 to 1.17)	1.10 (1.03 to 1.17)	1.08 (1.02 to 1.14)	1.09 (1.01 to 1.16)	1.12 (1.06 to 1.18)	1.06 (0.96 to 1.16)
O ₃ ^f	0	0.93 (0.89 to 0.97)	0.86 (0.79 to 0.92)	0.86 (0.80 to 0.92)	0.83 (0.78 to 0.88)	0.83 (0.78 to 0.89)	0.86 (0.81 to 0.91)	0.95 (0.83 to 1.08)
	0_7	1.01 (0.94 to 1.09)	0.88 (0.78 to 1.00)	0.90 (0.80 to 1.01)	0.88 (0.80 to 0.98)	0.88 (0.79 to 1.00)	0.90 (0.82 to 0.99)	0.98 (0.81 to 1.19)

ABS = primary care service areas.

^a including individuals who tested positive for COVID-19 infection or were diagnosed in hospital or in emergency care (n=317,714).

^b considering as outcome of interest only COVID-19 as the main/first cause of hospitalization, defined by the ICD-10 code first position.

^c excluding people who changed residential address during the period from 2015 to 2021 (n=177,079).

^d considering death as a competing risk for hospital admission.

^e considering autocorrelation of model errors among observations in the same primary care service area (Área Básica de Salud, ABS: 378 clusters).

^f defining end of first epidemic wave as last day of the first lockdown in Catalonia (25 May 2020).

^g B-spline with 4 df for the exposure-response.

Table A14. Association Between Ambient PM₁₀ and COVID-19 Hospital Admission by Vulnerability Indicators and Their Interaction on Additive and Multiplicative Scales

	PM ₁₀ ^a		Interaction in Multiplicative Scale	Interaction in Additive Scale	Type of interaction ¹
	Low	High	HR (95% CI)	RERI (95% CI)	
Age, years					
23-64	1.00 (Reference)	1.37 (1.32 to 1.41)	0.90 (0.87 to 0.94)	0.05 (-0.01 to 0.11)	Negative multiplicative zero additive
65+	1.77 (1.71 to 1.83)	2.18 (2.11 to 2.26)			
Male					
No	1.00 (Reference)	1.28 (1.24 to 1.33)	1.02 (0.98 to 1.06)	0.18 (0.12 to 0.23)	No multiplicative positive additive
Yes	1.50 (1.46 to 1.55)	1.97 (1.90 to 2.03)			
Hypertension					
No	1.00 (Reference)	1.35 (1.31 to 1.39)	0.91 (0.88 to 0.95)	-0.06 (-0.11 to 0.00)	Negative multiplicative zero additive
Yes	1.28 (1.24 to 1.33)	1.58 (1.52 to 1.63)			
Diabetes					
No	1.00 (Reference)	1.32 (1.28 to 1.35)	0.93 (0.89 to 0.98)	0.02 (-0.05 to 0.09)	Negative multiplicative zero additive
Yes	1.46 (1.41 to 1.52)	1.80 (1.74 to 1.87)			
Chronic Obstructive Pulmonary Disease					
No	1.00 (Reference)	1.31 (1.27 to 1.34)	0.93 (0.88 to 0.99)	0.01 (-0.09 to 0.10)	Negative multiplicative zero additive

Yes	1.43 (1.36 to 1.50)	1.74 (1.66 to 1.82)			
Low individual income					
No	1.00 (Reference)	1.25 (1.21 to 1.30)	1.05 (1.00 to 1.10)	0.07 (0.02 to 0.12)	Positive multiplicative positive additive
Yes	1.03 (1.00 to 1.07)	1.36 (1.31 to 1.41)			
Lower Area-Level Socioeconomic Index					
No	1.00 (Reference)	1.30 (1.26 to 1.34)	1.00 (0.96 to 1.04)	0.04 (-0.01 to 0.09)	No multiplicative zero additive
Yes	1.14 (1.10 to 1.18)	1.47 (1.43 to 1.52)			

^a PM₁₀ categories were defined by the median value (22.8), the low category has a mean of 20.0 (SD=2) while the high category has a mean of 24.8 (SD=1).

Table A15. Characteristics of Individuals Included in Aim 4 Overall and According to Outcome

	All individuals N=4 708 849 (%)		Influenza or Pneumonia Hospitalization N=17 608 (%)		Hospitalization for other LRIs ^a N=14 214 (%)	
Mean age (sd), y	53	(17)	72	(16)	73	(15)
Age ≥ 65 y	1 216 876	(25.8)	12 482	(70.9)	11 278	(79.3)
Male	2 237 141	(47.5)	9 655	(54.8)	6 866	(48.3)
<i>Income</i>						
Low	3 281 718	(69.7)	13 880	(78.8)	11 561	(81.3)
Middle	1 399 805	(29.7)	3 682	(20.9)	2 618	(18.4)
High	27 326	(0.6)	46	(0.3)	35	(0.2)
<i>Smoking Status</i>						
Nonsmoker	3 072 021	(65.2)	9 870	(56.1)	8 261	(58.1)
Former	684 531	(14.5)	4 152	(23.6)	3 321	(23.4)
Active	952 297	(20.2)	3 586	(20.4)	2 632	(18.5)
<i>Comorbidities</i>						
Diabetes	449 752	(9.6)	5 496	(31.2)	4 754	(33.4)
Hypertension	1 145 331	(24.3)	10 096	(57.3)	9 124	(64.2)
COPD	168 811	(3.6)	4 634	(26.3)	4 440	(31.2)
Obesity	1 063 305	(22.6)	6 423	(36.5)	6 004	(42.2)
Dyslipidemia	1 264 939	(26.9)	8 136	(46.2)	6 965	(49.0)
Cardiovascular Disorders	336 047	(7.1)	5 194	(29.5)	4 628	(32.6)
Respiratory Disorders	197 722	(4.2)	5 059	(28.7)	4 865	(34.2)
<i>Health risk group</i>						
Healthy	2 356 569	(50.0)	2 212	(12.6)	1 099	(7.7)
Low Risk	1 411 953	(30.0)	3 861	(21.9)	2 462	(17.3)
Moderate Risk	705 072	(15.0)	5 744	(32.6)	5 066	(35.6)
High Risk	235 255	(5.0)	5 791	(32.9)	5 587	(39.3)
<i>Urbanicity</i>						
Cities	2 925 072	(62.1)	11 384	(64.7)	9 602	(67.6)
Towns and Suburbs	1 374 400	(29.2)	4 792	(27.2)	3 509	(24.7)
Rural Area	409 377	(8.7)	1 432	(8.1)	1 103	(7.8)

^a excluding influenza and pneumonia.

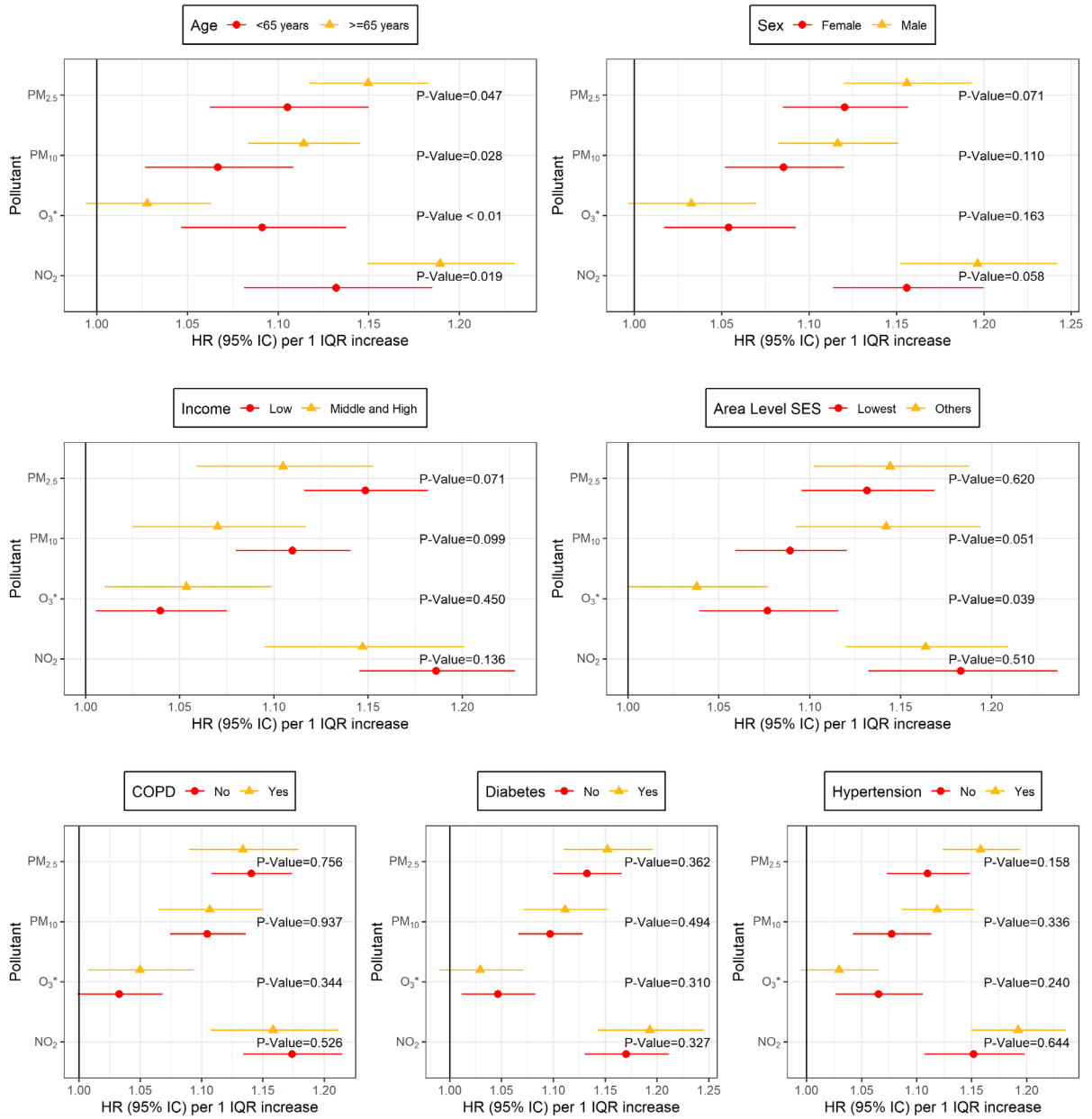


Figure A10. Associations between long-term exposure to air pollution and hospital admission for lower respiratory infections according to vulnerability indicators. P-values for interaction between continuous air pollution exposures and vulnerability indicator.

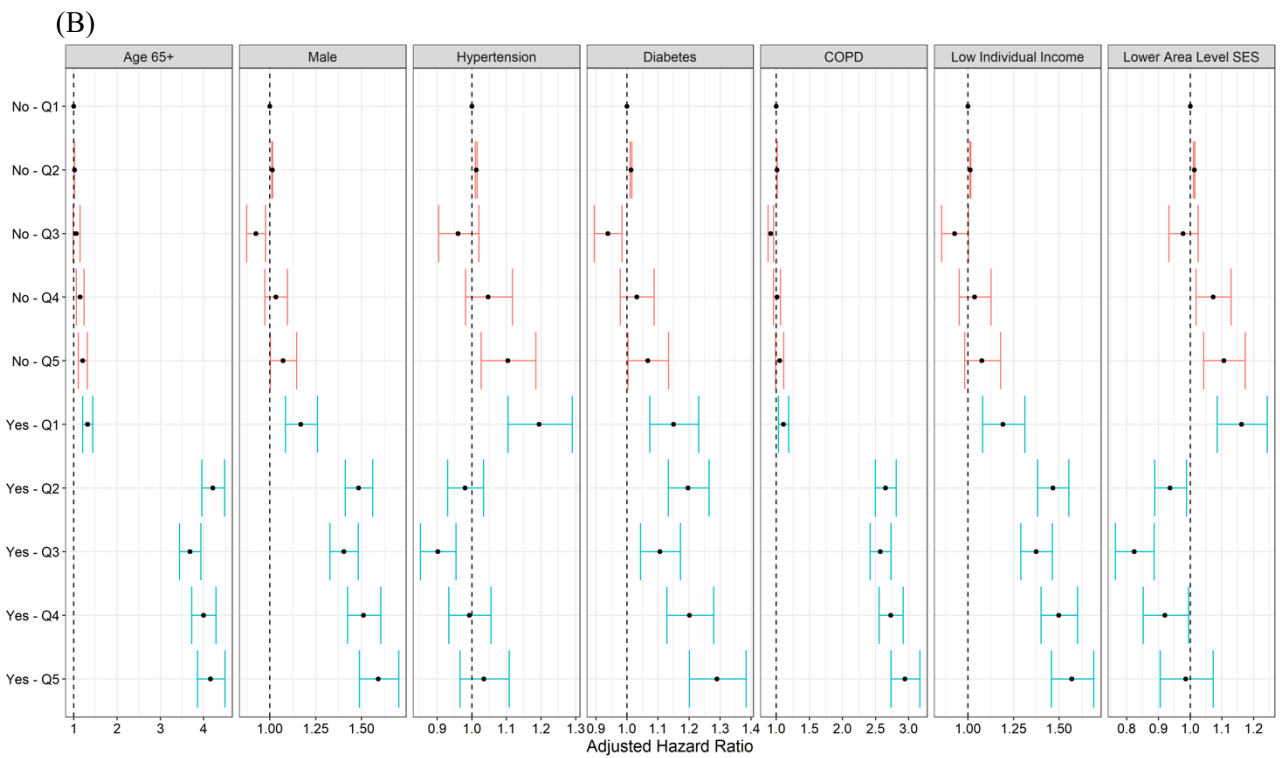
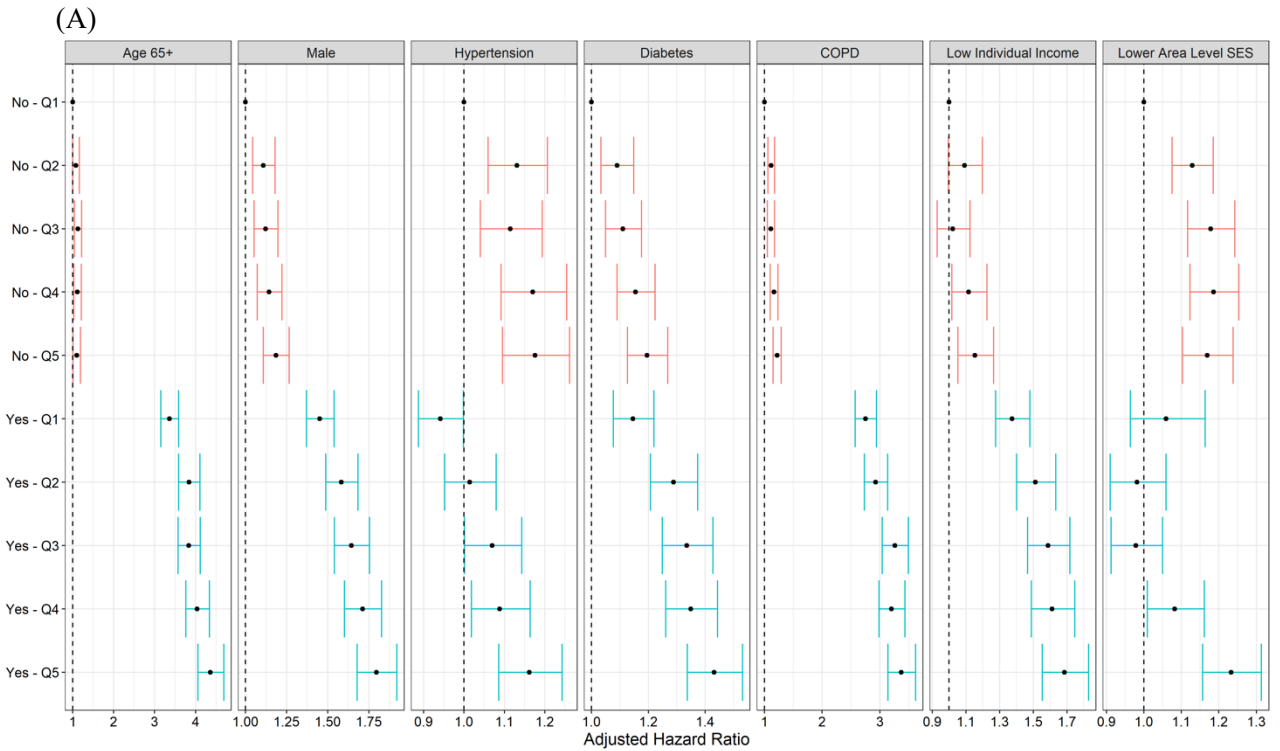


Figure A11. Combined effects of long-term ambient (A) PM₁₀ and (B) O₃ and vulnerability indicators on the risk of hospital admission for lower respiratory infections.

Table A16. Association Between NO₂ and Hospital Admission for Lower Respiratory Infections by Vulnerability Indicators and Their Interaction on Additive and Multiplicative Scales

	NO ₂ ^a		Interaction in Multiplicative Scale	Interaction in Additive Scale	Type of interaction
	Low	High	HR (95% CI)	RERI ^b (95% CI)	
Age, years					
22-64	1.00 (Reference)	1.03 (0.97 to 1.09)	1.09 (1.03 to 1.15)	0.38 (0.24 to 0.52)	Positive multiplicative positive additive
65+	3.43 (3.29 to 3.58)	3.84 (3.65 to 4.05)			
Male					
No	1.00 (Reference)	1.06 (1.01 to 1.11)	1.02 (0.98 to 1.07)	0.06 (0.00 to 0.12)	No multiplicative zero additive
Yes	1.45 (1.40 to 1.51)	1.58 (1.50 to 1.65)			
Hypertension					
No	1.00 (Reference)	1.06 (1.01 to 1.11)	1.02 (0.98 to 1.07)	0.02 (-0.03 to 0.07)	No multiplicative zero additive
Yes	0.93 (0.90 to 0.97)	1.01 (0.96 to 1.06)			
Diabetes					
No	1.00 (Reference)	1.08 (1.03 to 1.12)	0.99 (0.94 to 1.04)	0.00 (-0.06 to 0.06)	No multiplicative zero additive
Yes	1.19 (1.14 to 1.23)	1.27 (1.21 to 1.33)			
Chronic Obstructive Pulmonary Disease					
No	1.00 (Reference)	1.08 (1.04 to 1.13)	0.97 (0.92 to 1.02)	0.04 (-0.10 to 0.19)	No multiplicative zero additive
Yes	2.81 (2.70 to 2.93)	2.94 (2.79 to 3.09)			

Low individual income					
No	1.00 (Reference)	1.04 (0.98 to 1.11)	1.04 (0.98 to 1.10)	0.07 (0.00 to 0.14)	No multiplicative positive additive
Yes	1.41 (1.35 to 1.47)	1.53 (1.45 to 1.62)			
Lower area-level SES					
No	1.00 (Reference)	1.06 (1.02 to 1.11)	1.05 (0.98 to 1.11)	0.04 (-0.02 to 0.10)	No multiplicative zero additive
Yes	0.92 (0.87 to 0.97)	1.02 (0.97 to 1.07)			

^acategories defined by the median value (27.1), the low category has a mean of 17.1 (SD=6) while the high category has a mean of 33.6 (SD=6).

^bRERI = relative excess risk due to interaction.

Table A17. Association Between PM_{2.5} and Hospital Admission for Lower Respiratory Infections by Vulnerability Indicators and Their Interaction on Additive and Multiplicative Scales

	PM _{2.5} ^a		Interaction in Multiplicative Scale	Interaction in Additive Scale	Type of Interaction
	Low	High	HR (95% CI)	RERI ^b (95% CI)	
Age, years					
22-64	1.00 (Reference)	1.03 (0.98 to 1.09)	1.06 (1.00 to 1.12)	0.30 (0.17 to 0.42)	Positive multiplicative positive additive
65+	3.48 (3.34 to 3.63)	3.81 (3.63 to 3.99)			
Male					
No	1.00 (Reference)	1.06 (1.01 to 1.10)	1.04 (0.99 to 1.09)	0.08 (0.02 to 0.15)	No multiplicative positive additive
Yes	1.44 (1.39 to 1.50)	1.58 (1.52 to 1.65)			
Hypertension					
No	1.00 (Reference)	1.07 (1.02 to 1.11)	1.02 (0.97 to 1.07)	0.01 (-0.03 to 0.06)	No multiplicative zero additive
Yes	0.93 (0.90 to 0.97)	1.01 (0.97 to 1.06)			
Diabetes					
No	1.00 (Reference)	1.07 (1.03 to 1.11)	1.02 (0.96 to 1.07)	0.03 (-0.03 to 0.09)	No multiplicative zero additive
Yes	1.17 (1.13 to 1.22)	1.27 (1.22 to 1.33)			
Chronic Obstructive Pulmonary Disease					
No	1.00 (Reference)	1.08 (1.04 to 1.13)	1.00 (0.95 to 1.06)	0.15 (0.01 to 0.29)	No multiplicative positive additive

Yes	2.75 (2.64 to 2.879)	2.98 (2.85 to 3.12)			
Low individual income					
No	1.00 (Reference)	1.05 (1.00 to 1.12)	1.03 (0.97 to 1.09)	0.07 (0.00 to 0.13)	No multiplicative positive additive
Yes	1.42 (1.36 to 1.49)	1.54 (1.47 to 1.62)			
Lower area-level SES					
No	1.00 (Reference)	1.07 (1.03 to 1.11)	1.03 (0.97 to 1.09)	0.03 (-0.03 to 0.08)	No multiplicative zero additive
Yes	0.93 (0.88 to 0.98)	1.03 (0.98 to 1.07)			

^a PM_{2.5} categories defined by the median value (13.8), the low category has a mean of 12.3 (SD=1) while the high category has a mean of 14.9 (SD=1).

^b Relative Excess Risk due to Interaction.

Table A18. Association Between PM₁₀ and Hospital Admission for Lower Respiratory Infections by Vulnerability Indicators and Their Interaction on Additive and Multiplicative Scales

	PM ₁₀ ^a		Interaction in Multiplicative Scale	Interaction in Additive Scale	Type of Interaction
	Low	High	HR (95% CI)	RERI ^b (95% CI)	
Age, years					
22-64	1.00 (Reference)	1.02 (0.97 to 1.07)	1.08 (1.02 to 1.14)	0.32 (0.20 to 0.44)	Positive multiplicative positive additive
65+	3.45 (3.30 to 3.59)	3.78 (3.62 to 3.96)			
Male					
No	1.00 (Reference)	1.04 (1.00 to 1.08)	1.05 (1.00 to 1.10)	0.10 (0.04 to 0.16)	Positive multiplicative positive additive
Yes	1.43 (1.38 to 1.48)	1.57 (1.51 to 1.63)			
Hypertension					
No	1.00 (Reference)	1.05 (1.00 to 1.09)	1.04 (0.99 to 1.09)	0.03 (-0.01 to 0.08)	No multiplicative zero additive
Yes	0.92 (0.89 to 0.96)	1.00 (0.96 to 1.05)			
Diabetes					
No	1.00 (Reference)	1.07 (1.03 to 1.10)	1.01 (0.96 to 1.06)	0.02 (-0.03 to 0.08)	No multiplicative zero additive

Yes	1.17 (1.13 to 1.22)	1.26 (1.21 to 1.32)			
Chronic Obstructive Pulmonary Disease					
No	1.00 (Reference)	1.07 (1.04 to 1.11)	1.00 (0.95 to 1.06)	0.13 (-0.01 to 0.26)	No multiplicative zero additive
Yes	2.76 (2.64 to 2.87)	2.95 (2.83 to 3.09)			
Low individual income					
No	1.00 (Reference)	1.05 (0.99 to 1.11)	1.02 (0.96 to 1.08)	0.05 (-0.01 to 0.12)	No multiplicative zero additive
Yes	1.43 (1.36 to 1.49)	1.53 (1.46 to 1.61)			
Lower area-level SES					
No	1.00 (Reference)	1.06 (1.02 to 1.09)	1.06 (1.00 to 1.12)	0.05 (-0.01 to 0.11)	Positive multiplicative zero additive
Yes	0.91 (0.87 to 0.96)	1.02 (0.98 to 1.06)			

^a PM₁₀ categories defined by the median value (22.8), the low category has a mean of 20.5 (SD=2) while the high category has a mean of 24.4 (SD=1).

^b Relative Excess Risk due to Interaction.

Table A19. Association Between O₃ and Hospital Admission for Lower Respiratory Infections by Vulnerability Indicators and Their Interaction on Additive and Multiplicative Scales

	O ₃ ^a		Interaction in Additive Scale	Interaction in Multiplicative Scale	Type of Interaction
	Low	High	RERI ^b (95% CI)	HR (95% CI)	
Age, years					
22-64	1.00 (Reference)	1.16 (1.10 to 1.22)	0.07 (-0.07 to 0.21)	0.92 (0.87 to 0.97)	No multiplicative positive additive
65+	3.74 (3.58 to 3.89)	3.96 (3.76 to 4.17)			
Male					
No	1.00 (Reference)	1.12 (1.07 to 1.17)	0.00 (-0.07 to 0.06)	0.96 (0.92 to 1.01)	No multiplicative zero additive
Yes	1.50 (1.45 to 1.55)	1.62 (1.55 to 1.70)			
Hypertension					
No	1.00 (Reference)	1.13 (1.08 to 1.19)	-0.05 (-0.10 to 0.00)	0.96 (0.91 to 1.00)	No multiplicative zero additive
Yes	0.96 (0.93 to 1.00)	1.04 (0.99 to 1.09)			
Diabetes					
No	1.00 (Reference)	1.10 (1.06 to 1.14)	0.02 (-0.04 to 0.08)	1.00 (0.95 to 1.05)	No multiplicative zero additive
Yes	1.18 (1.14 to 1.22)	1.30 (1.24 to 1.36)			
Chronic Obstructive Pulmonary Disease					
No	1.00 (Reference)	1.09 (1.05 to 1.14)	0.22 (0.08 to 0.37)	1.02 (0.97 to 1.08)	Positive multiplicative zero additive
Yes	2.73 (2.63 to 2.84)	3.04 (2.90 to 3.20)			

Low individual income					
No	1.00 (Reference)	1.13 (1.06 to 1.20)	0.01 (-0.06 to 0.08)	0.97 (0.91 to 1.03)	No multiplicative zero additive
Yes	1.47 (1.41 to 1.53)	1.61 (1.53 to 1.69)			
Lower area-level SES					
No	1.00 (Reference)	1.09 (1.04 to 1.13)	0.05 (-0.01 to 0.11)	1.06 (1.00 to 1.13)	No multiplicative positive additive
Yes	0.89 (0.86 to 0.92)	1.03 (0.97 to 1.08)			

^a O₃ categories defined by the median value (94.2), the low category has a mean of 88.9 (SD=7) while the high category has a mean of 99.2 (SD=3).

^b Relative Excess Risk due to Interaction.

Table A20. Summary of Individual-Level Cohort Studies of Long-Term Air Pollution Exposure and Severe COVID-19 Outcomes

Population	Exposures	Outcomes	Reference increase	Findings
COVID-19 positive				
1,128 COVID-19 patients diagnosed at University of Cincinnati healthcare system (UC Health) (Mendy, Resp Med 2021) ²	PM _{2.5}	COVID-19 hospitalization	OR per 1µg/m ³ in average and maximal PM _{2.5}	0.99 (0.79-1.23) for average PM _{2.5} 0.95 (0.81-1.11) for maximal PM _{2.5}
2,112 COVID-19 hospitalized patients in Catalonia, Spain (Marquès, EI 2022) ³	PM ₁₀ NO ₂	Severe COVID-19 Death	OR for categorical (High vs Low) exposure to pollutants according to WHO: ≥20 for PM ₁₀ and ≥40 for NO ₂	1.65 (1.32-2.06) for Severe COVID PM ₁₀ 2.37 (1.71-3.32) for Death PM ₁₀ 0.75 (0.57-0.99) for Severe COVID NO ₂ 0.77 (0.54-1.10) for Death NO ₂
169K COVID-19 diagnosed US Veterans (Bowe, Environ Int 2021) ⁴	PM _{2.5}	COVID-19 hospital admission	RR per IQR (1.9 µg/m ³) annual avg PM _{2.5}	1.10 (1.08, 1.12)
6,524 COVID hospitalized individuals in NYC (Bozack, AJRCCM 2021) ⁴	PM _{2.5} , NO ₂ , BC	Mortality, ICU admission and Intubation	RR per 1 µg/m ³ annual avg PM _{2.5}	1.11 (1.02, 1.21) mortality 1.13 (1.00, 1.28) ICU 1.05 (0.91, 1.20) Intubation No associations for NO ₂ or BC
75,000 COVID diagnosed individuals in Kaiser Permanente, California (Chen, AJRCCM 2022) ⁵	PM _{2.5} , NO ₂ , O ₃	COVID hospital admission ICU admission Ventilation (IRS) Mortality	RR per SD (1.5 µg/m ³) in 1 yr PM _{2.5}	1.24 (1.16, 1.32) hospital admis (30d) 1.33 (1.20,1.47) IRS 1.32 (1.16, 1.51) ICU 1.14 (1.02, 1.27) Mortality (60d) Null association with NO ₂
150,000 COVID-diagnosed individuals in Ontario	PM _{2.5} , NO ₂ , O ₃	COVID hospital	RR per IQR (1.7	1.06 (1.01, 1.12) hospital admis

Population	Exposures	Outcomes	Reference increase	Findings
(Chen, CMAJ 2022) ⁶		admission ICU admission Mortality	$\mu\text{g}/\text{m}^3$ PM _{2.5}	1.09 (0.98, 1.21) ICU 1.00 (0.90, 1.11) Mortality Null association with NO ₂ Positive association with O ₃
3,139,804 individuals with COVID-19 in California (English, EA 2022) ⁷	PM _{2.5}	Death	RR for 1-unit PM _{2.5} RR for PM quintiles	1.04 (1.03-1.05) per 1-unit 1.18 (1.11-1.25) for lowest quintile (9.9-11.2 μg) 1.56 (1.43-1.71) for highest quintile (16.2-18.8 μg)
Non-COVID cohort				
Selected population				
9,605 individuals in Catalonia (Kogevinas, EHP 2021) ⁸	PM _{2.5} , NO ₂ , BC, O ₃	Severe COVID (Hospital admission/ ICU/ Oxygen)	RRR per IQR PM _{2.5} RRR per IQR NO ₂	1.51 (1.06, 2.16) for PM _{2.5} 1.26 (0.89, 1.79) for NO ₂
424,721 individuals in England (UK-Biobank) (Sheridan, EP 2022) ⁹	PM _{2.5} , PM ₁₀ , NO ₂	COVID-19 hospitalization COVID-19 deaths	OR per IQR PM _{2.5} (1.27) OR per IQR PM ₁₀ (1.75) OR per IQR NO ₂ (9.93)	1.01 (0.95-1.09) Hosp for PM _{2.5} 1.02 (0.94-1.11) Hosp for NO ₂ 1.00 (0.89-1.11) Death for PM _{2.5} 1.03 (0.90-1.16) Death for NO ₂ Similar results for PM ₁₀
General population				
1,594,308 aged 30+ residents in Rome (Nobile F, ERJ 2022) ¹⁰	PM _{2.5} , NO ₂	COVID-19 death	HR per IQR PM _{2.5} (0.92) HR per IQR NO ₂ (9.22)	1.08 (1.03, 1.13) for PM _{2.5} 1.09 (1.02, 1.16) for NO ₂

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