Concawe

Environmental Science for European Fuel Manufacturing

Appendix

Report no. 8/26 A

Impact of Sea Shipping Emissions on Future Urban Air Quality in Major European Ports: A 2030 Scenario Analysis

ISBN 978-2-87567-217-9

Impact of Sea Shipping Emissions on Future Urban Air Quality in Major European Ports: A 2030 Scenario Analysis

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At the request of:

Concawe Air Quality Management Group (AQMG)

Thanks for their contribution to:

Members of AQMG

Concawe/FuelsEurope Secretariat Members

KEYWORDS

air quality; shipping; atmospheric modelling; emission inventories; emission scenarios; emissions

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1. INTRODUCTION

This document is the Appendix of the study 'Impact of Sea Shipping Emissions on Future Urban Air Quality in Major European Ports: A 2030 Scenario Analysis' and should be read in conjunction with the main report.

This Appendix comprises of:

- Appendix A: Emissions Appendix; and
- Appendix B: Modelling Appendix.

APPENDIX A EMISSIONS APPENDIX

A1 SUPPLEMENTARY DATA ON SEA SHIPPING EMISSIONS

This section presents supplementary information and data on the sea shipping emissions.

Fuel usage

Table 1 presents the fuel usage for different ship categories for each of the sensitivity scenarios assessed in this study, while Table 2 to Table 5 present the total annual fuel consumption by ship type category.

Table 1 *Fuel usage for different ship type categories under the different sensitivity scenarios assessed in this study*

Ship type	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
RoPax vessels	-	LNG	LNG	LNG
RoRo vessels	-	-	LNG	-
Vehicle carriers	-	Methanol	Methanol	Methanol
General cargo ships	-	Methanol	Methanol	Methanol
Bulk carriers	-	-	-	-
Container ships	-	-	-	-
Refrigerated cargo ships	-	-	-	-
Tankers	-	-	-	-
Gas tankers	-	-	LNG	-
Oil tankers	-	-	-	-
Passenger ships	-	-	LNG	-
Other	-	-	-	-

Notes: The main engines of each ship type have been set to use the fuel specified in this table. For ship types marked with "-", no fuel scenario is implemented. Ships with an LNG engine are assumed to use LNG as a fuel regardless of the fuel scenario.

Table 2 *Total annual fuel consumption [in kt] (including all engines and operational modes) by ship type category in the 2023 base case*

Ship type	HFO	VLSFO	MDO	MGO	Methanol	LNG
RoPax vessels	1,007	1,436	940	1,259	0	240
RoRo vessels	852	612	336	459	0	131
Vehicle carriers	224	685	236	281	0	34
General cargo ships	118	1,026	2,364	1,824	0	14
Bulk carriers	877	3,936	1,860	1,596	0	7
Container ships	3,637	5,496	5,067	2,912	0	133
Refrigerated cargo ships	52	116	107	137	0	0
Tankers	348	1,827	1,785	1,864	0	53
Gas tankers	28	772	534	420	0	1,585
Oil tankers	1,632	2,832	1,387	1,432	0	207
Passenger ships	1,069	414	742	520	0	156
Other	3	328	4,060	4,339	0	39

Table 3 *Total annual fuel consumption [in kt] (including all engines and operational modes) by ship type category in the 2030 BAU scenario*

Ship type	HFO	VLSFO	MDO	MGO	Methanol	LNG
RoPax vessels	23	1	139	620	0	3,850
RoRo vessels	1,035	193	269	833	0	138
Vehicle carriers	6	8	147	212	2,222	36
General cargo ships	2	20	695	1,355	7,149	15
Bulk carriers	918	1,783	1,068	4,666	0	7
Container ships	4,315	2,536	3,493	8,450	0	175
Refrigerated cargo ships	53	94	76	201	0	0
Tankers	313	737	913	3,274	0	49
Gas tankers	48	458	395	1,813	0	2,540
Oil tankers	1,501	1,100	847	3,106	0	197
Passenger ships	1,156	117	441	1,307	0	175
Other	3	206	2,080	6,726	0	41

Table 4 *Total annual fuel consumption [in kt] (including all engines and operational modes) by ship type category in the 2030 LNG scenario*

Ship type	HFO	VLSFO	MDO	MGO	Methanol	LNG
RoPax vessels	23	1	139	620	0	3,850
RoRo vessels	24	2	217	202	0	1,816
Vehicle carriers	6	8	147	212	2,222	36
General cargo ships	2	20	695	1,355	7,149	15
Bulk carriers	918	1,783	1,068	4,666	0	7
Container ships	4,315	2,536	3,492	8,450	0	175
Refrigerated cargo ships	53	94	76	201	0	0
Tankers	313	737	913	3,274	0	49
Gas tankers	0	37	319	832	0	3,974
Oil tankers	1,501	1,100	847	3,106	0	197
Passenger ships	36	2	179	421	0	2,322
Other	3	206	2,080	6,726	0	41

Table 5 *Total annual fuel consumption [in kt] (including all engines and operational modes) by ship type category in the 2030 all-EU ECA scenario*

Ship type	HFO	VLSFO	MDO	MGO	Methanol	LNG
RoPax vessels	23	0	105	654	0	3,850
RoRo vessels	1,035	44	232	1,006	0	138
Vehicle carriers	6	4	98	264	2,222	36
General cargo ships	2	13	595	1,461	7,149	15
Bulk carriers	918	963	859	5,622	0	7
Container ships	4,316	1,285	2,996	10,086	0	175
Refrigerated cargo ships	53	57	53	257	0	0
Tankers	313	372	689	3,830	0	49
Gas tankers	48	214	225	2,205	0	2,540
Oil tankers	1,501	507	717	3,778	0	197
Passenger ships	1,157	51	358	1,451	0	175
Other	3	141	1,231	7,630	0	41

Total annual shipping emissions

Figure 1 *Total annual emissions of NMVOCs from shipping in the European domain in 2023 base case and in the 2030 scenarios*

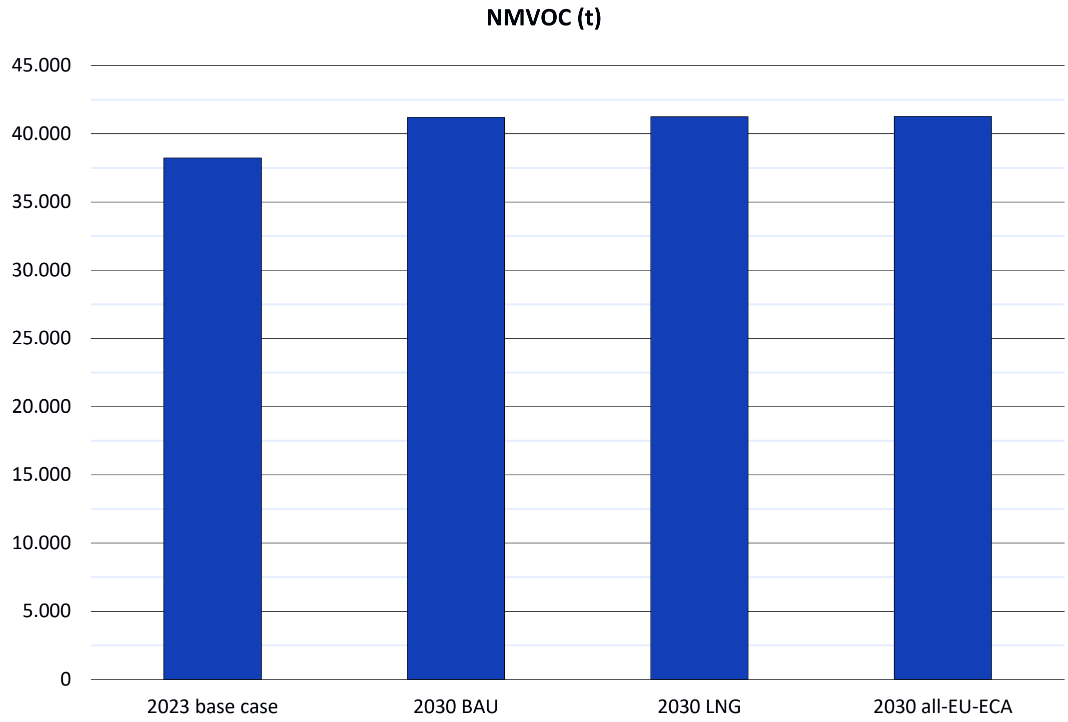
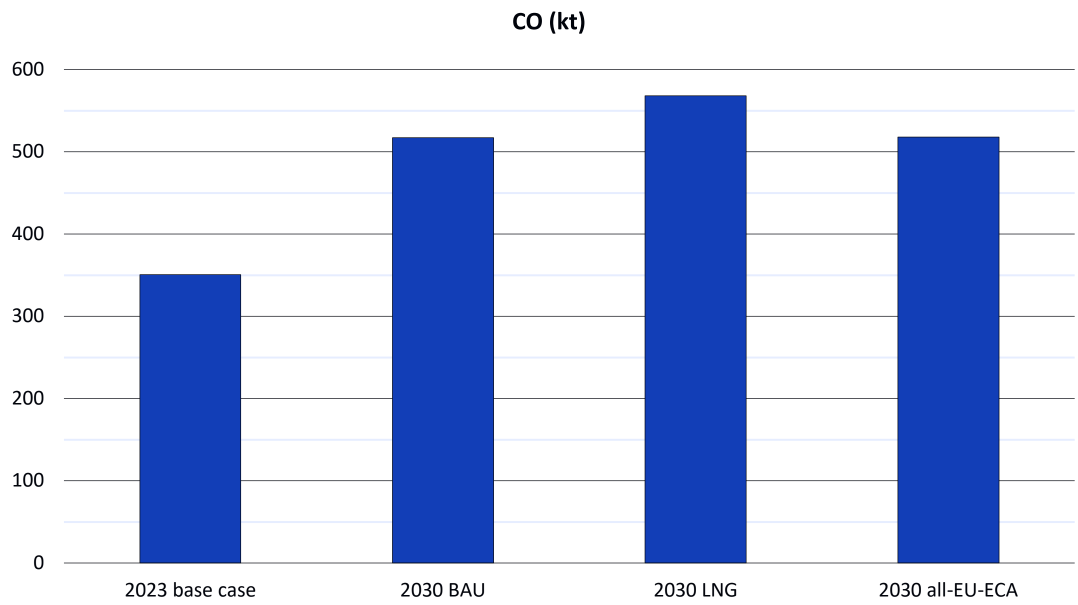
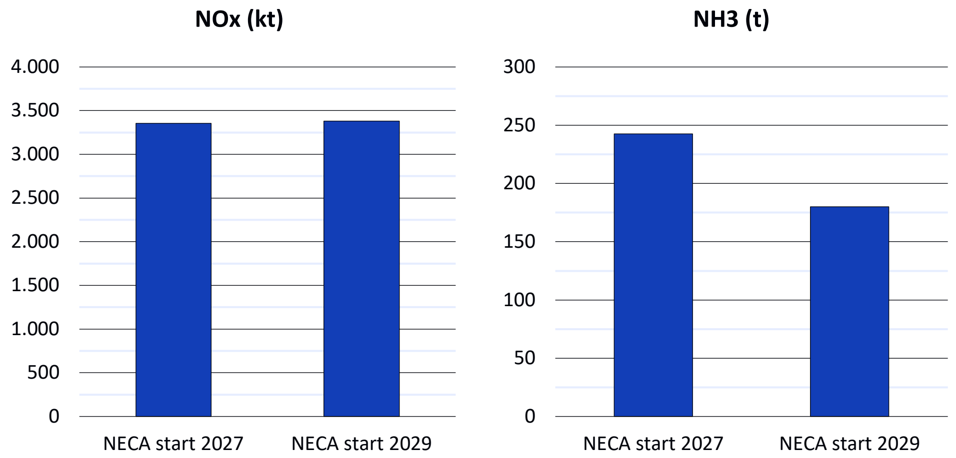


Figure 2 *Total annual emissions of CO from shipping in the European domain in 2023 base case and in the 2030 scenarios*



Effect of the NECA start date

Figure 3 *Total annual emissions of NOx and NH_3 from shipping in the European domain in 2030 with two different assumptions of NECA start date*



Annual shipping emissions in sea regions

Table 6 *Total annual SOx emissions (tonnes) from shipping in the sea regions of the European domain in 2023 base case and in the 2030 future scenarios*

Sea region	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Arctic Ocean	3,139	2,469	2,455	2,469
Atlantic Ocean	75,888	73,845	68,296	42,486
Baltic Sea	8,911	7,148	6,436	7,148
Bay of Biscay	4,136	3,804	3,545	882
Black Sea	13,264	12,036	11,729	12,036
English Channel	6,222	5,879	5,537	5,249
Greenland Sea	382	388	303	101
Irish & British Seas	16,746	14,246	12,456	3,349
Mediterranean Sea	213,592	56,630	51,835	56,595
North Sea	16,776	15,742	14,667	15,742
Norwegian Sea	9,160	3,992	3,436	3,639
Other/Inland	21,685	19,305	18,482	19,083
Red Sea	64	66	64	66
Sea of Azov	1,475	1,153	1,147	1,153

Table 7 *Total annual NOx emissions (tonnes) from shipping in the sea regions of the European domain in 2023 base case and in the 2030 scenarios*

Sea region	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Arctic Ocean	19,489	18,324	18,122	18,324
Atlantic Ocean	651,618	637,037	601,689	624,852
Baltic Sea	287,260	198,857	183,423	198,858
Bay of Biscay	28,762	26,213	24,417	25,382
Black Sea	90,213	80,436	78,756	80,437
English Channel	189,560	140,455	133,528	140,846
Greenland Sea	2,718	2,719	2,033	2,621
Irish & British Seas	132,162	117,536	106,759	113,984
Mediterranean Sea	1,707,444	1,560,713	1,437,298	1,560,544
North Sea	519,355	388,148	362,210	388,148
Norwegian Sea	66,458	54,642	49,760	54,557
Other/Inland	180,874	163,495	158,818	163,456
Red Sea	450	452	441	452
Sea of Azov	7,666	6,916	6,888	6,916

Table 8 *Total annual $PM_{2.5}$ emissions (tonnes) from shipping in the sea regions of the European domain in 2023 base case and in the 2030 scenarios*

Sea region	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Arctic Ocean	555	485	481	485
Atlantic Ocean	16,398	16,271	15,043	12,516
Baltic Sea	4,573	3,743	3,365	3,743
Bay of Biscay	763	710	651	471
Black Sea	2,401	2,237	2,181	2,237
English Channel	3,054	2,930	2,745	2,863
Greenland Sea	69	72	52	51
Irish & British Seas	3,429	3,001	2,607	1,798
Mediterranean Sea	43,986	25,253	22,776	25,248
North Sea	8,715	8,368	7,679	8,368
Norwegian Sea	1,723	1,232	1,065	1,198
Other/Inland	4,489	4,188	4,044	4,174
Red Sea	15	16	15	16
Sea of Azov	209	166	165	166

Table 9 *Total annual CO emissions (tonnes) from shipping in the sea regions of the European domain in 2023 base case and in the 2030 scenarios*

Sea region	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Arctic Ocean	3,085	4,224	4,261	4,224
Atlantic Ocean	50,765	76,981	83,948	76,898
Baltic Sea	29,086	46,425	50,111	46,425
Bay of Biscay	3,685	5,385	5,761	5,380
Black Sea	7,992	11,805	12,161	11,805
English Channel	16,970	25,144	27,006	25,149
Greenland Sea	322	401	536	402
Irish & British Seas	11,998	19,143	21,330	19,117
Mediterranean Sea	137,997	205,219	229,454	205,218
North Sea	54,223	74,967	82,573	74,967
Norwegian Sea	9,761	13,920	15,450	13,920
Other/Inland	22,595	32,440	33,720	32,440
Red Sea	45	55	59	55
Sea of Azov	877	1,721	1,729	1,721

A2 LAND-BASED AND SEA SHIPPING EMISSIONS FROM ALL SECTORS

Annual emissions from all sectors

Table 10 *Annual NOx emissions (in ktons) from all sectors in the European domain in 2023 base case and in the 2030 scenarios*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Public Power	2,654	2,227	2,227	2,227
Industry	326	326	326	326
Industry – refineries	240	247	247	247
Industry – other	1,625	1,772	1,772	1,772
Other Stationary Combustion	980	701	701	701
Fugitives	45	43	43	43
Solvents	3	3	3	3
Road Transport - exhaust	4,280	3,062	3,062	3,062
Road Transport - non-exhaust	0	0	0	0
Inland Shipping	149	120	120	120
Aviation	86	85	85	85
Off-Road	916	639	639	639
Waste	90	90	90	90
Agriculture – livestock	11	11	11	11
Agriculture – other	98	97	97	97
Sea Shipping	3,584	3,131	2,906	3,090

Table 11 *Annual SOx emissions (in ktons) from all sectors in the European domain in 2023 base case and in the 2030 scenarios*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Public Power	4,059	3,633	3,633	3,633
Industry	742	742	742	742
Industry - refineries	542	565	565	565
Industry - other	1,217	1,353	1,353	1,353
Other Stationary Combustion	879	589	589	589
Fugitives	95	101	101	101
Solvents	2	2	2	2
Road Transport - exhaust	78	77	77	77
Road Transport - non-exhaust	0	0	0	0
Inland Shipping	11	10	10	10
Aviation	6	7	7	7
Off-Road	25	27	27	27
Waste	6	6	6	6
Agriculture - livestock	0	0	0	0
Agriculture - other	6	6	6	6
Sea Shipping	361	192	175	146

Table 12 *Annual $PM_{2.5}$ emissions (in ktons) from all sectors in the European domain in 2023 base case and in the 2030 scenarios*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Public Power	133	114	114	114
Industry	115	115	115	115
Industry - refineries	15	14	14	14
Industry - other	779	881	881	881
Other Stationary Combustion	1,307	811	811	811
Fugitives	79	72	72	72
Solvents	20	21	21	21
Road Transport - exhaust	70	56	56	56
Road Transport - non-exhaust	119	127	127	127
Inland Shipping	9	8	8	8
Aviation	3	3	3	3
Off-Road	82	61	61	61
Waste	195	189	189	189
Agriculture - livestock	59	59	59	59
Agriculture - other	147	144	144	144
Sea Shipping	83	62	57	57

Table 13 *Annual PM_{10} emissions (in ktons) from all sectors in the European domain in 2023 base case and in the 2030 scenarios*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Public Power	235	202	202	202
Industry	182	182	182	182
Industry - refineries	23	20	20	20
Industry - other	1,352	1,554	1,554	1,554
Other Stationary Combustion	1,464	930	930	930
Fugitives	141	121	121	121
Solvents	24	26	26	26
Road Transport - exhaust	71	56	56	56
Road Transport - non-exhaust	211	227	227	227
Inland Shipping	9	8	8	8
Aviation	3	3	3	3
Off-Road	95	68	68	68
Waste	207	200	200	200
Agriculture - livestock	290	296	296	296
Agriculture - other	464	458	458	458
Sea Shipping	83	62	57	57

Table 14 — *Annual CO emissions (in ktons) from all sectors in the European domain in 2023 base case and in the 2030 scenarios*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Public Power	911	894	894	894
Industry	783	783	783	783
Industry - refineries	228	278	278	278
Industry - other	7,178	8,676	8,676	8,676
Other Stationary Combustion	12,494	8,316	8,316	8,316
Fugitives	393	418	418	418
Solvents	49	0	0	0
Road Transport - exhaust	16,635	16,392	16,392	16,392
Road Transport - non-exhaust	0	0	0	0
Inland Shipping	20	14	14	14
Aviation	115	0	0	0
Off-Road	2,811	2,328	2,328	2,328
Waste	907	912	912	912
Agriculture - livestock	0	0	0	0
Agriculture - other	1,350	1,311	1,311	1,311
Sea Shipping	311	467	515	467

Table 15 *Annual NMVOC emissions (in ktons) from all sectors in the European domain in 2023 base case and in the 2030 scenarios*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Public Power	110	93	93	93
Industry	315	315	315	315
Industry – refineries	248	244	244	244
Industry – other	890	910	910	910
Other Stationary Combustion	1,678	1,045	1,045	1,045
Fugitives	1,968	1,873	1,873	1,873
Solvents	5,079	4,941	4,941	4,941
Road Transport - exhaust	3,325	3,338	3,338	3,338
Road Transport - non-exhaust	311	286	286	286
Inland Shipping	6	5	5	5
Aviation	22	31	31	31
Off-Road	431	424	424	424
Waste	277	271	271	271
Agriculture – livestock	2,146	2,144	2,144	2,144
Agriculture – other	545	535	535	535
Sea Shipping	35	38	38	38

Table 16 *Annual NH_3 emissions (in ktons) from all sectors in the European domain in 2023 base case and in the 2030 scenarios*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Public Power	17	17	17	17
Industry	20	20	20	20
Industry - refineries	1	1	1	1
Industry - other	81	91	91	91
Other Stationary Combustion	84	78	78	78
Fugitives	2	2	2	2
Solvents	37	36	36	36
Road Transport - exhaust	65	69	69	69
Road Transport - non-exhaust	0	0	0	0
Inland Shipping	0	0	0	0
Aviation	0	0	0	0
Off-Road	18	21	21	21
Waste	56	55	55	55
Agriculture - livestock	3,083	3,172	3,172	3,172
Agriculture - other	2,883	2,777	2,777	2,777
Sea Shipping	0	0	0	0

Definition of port-cities areas

This section presents the domains for the port-cities areas that have been used in the calculation of total emissions.

Figure 4 *Port-city area of Rotterdam*

Figure 5 *Port-city area of Antwerp*

Figure 6 *Port-city area of Marseille*

Figure 7 *Port-city area of Athens*

APPENDIX B MODELLING APPENDIX

B1 COMPARISON AGAINST OBSERVATIONS (MODEL VALIDATION)

Validation against EBAS background/rural stations

In this section the performance of the model is assessed with comparisons from rural sites from the EBAS database. The EBAS sites are used to evaluate the PM ($PM_{2.5}$ and PM_{10}) speciation derived from the model since PM speciation is not provided by the EEA database on urban locations. Figure 8 presents the location of EBAS background/rural stations across Europe that were included in the model validation.

LOTOS-EUROS captures well (R^2 ~ 0.75) the daily and seasonal variability of the measured NO_2 concentrations based on EBAS data (total of 70 stations), with high concentrations in the winter and low concentrations in the summer. A small underestimation is observed in late spring - early summer, possibly attributed to excess daytime removal and mixing in the planetary boundary layer. On the contrary, a slight overestimation of the measured data is observed in late-autumn and winter periods likely attributed to excessive surface build-up due to mixing, leading eventually to higher NOx lifetimes. Nevertheless, the model data is, overall, consistent with the observations, falling close to the 1:1 line (Figure 10), indicating a good model representation over rural areas.

Based on the EBAS data, LOTOS-EUROS captures the daily PM concentration well (R^2 ~ 0.6) over time (Figure 9). There is a general underestimation during summer due to a lack of secondary organic aerosol chemistry and meteorology in the model version that was used. The modelled data at all stations are fairly close to the magnitude observed, with slight underestimation among these rural background stations. Since PM is a composite term of all aerosol species, the error and variation are aggregated to the PM results. The modelled SIA (nitrate, sulphate, and ammonium) shows a fair correlation with EBAS data. Yet within the SIA species, ammonium nitrate is overestimated and sulphate is underestimated. The total sodium (mainly sea salt) is also slightly overestimated.

Figure 8 Location of EBAS stations used in the model validation

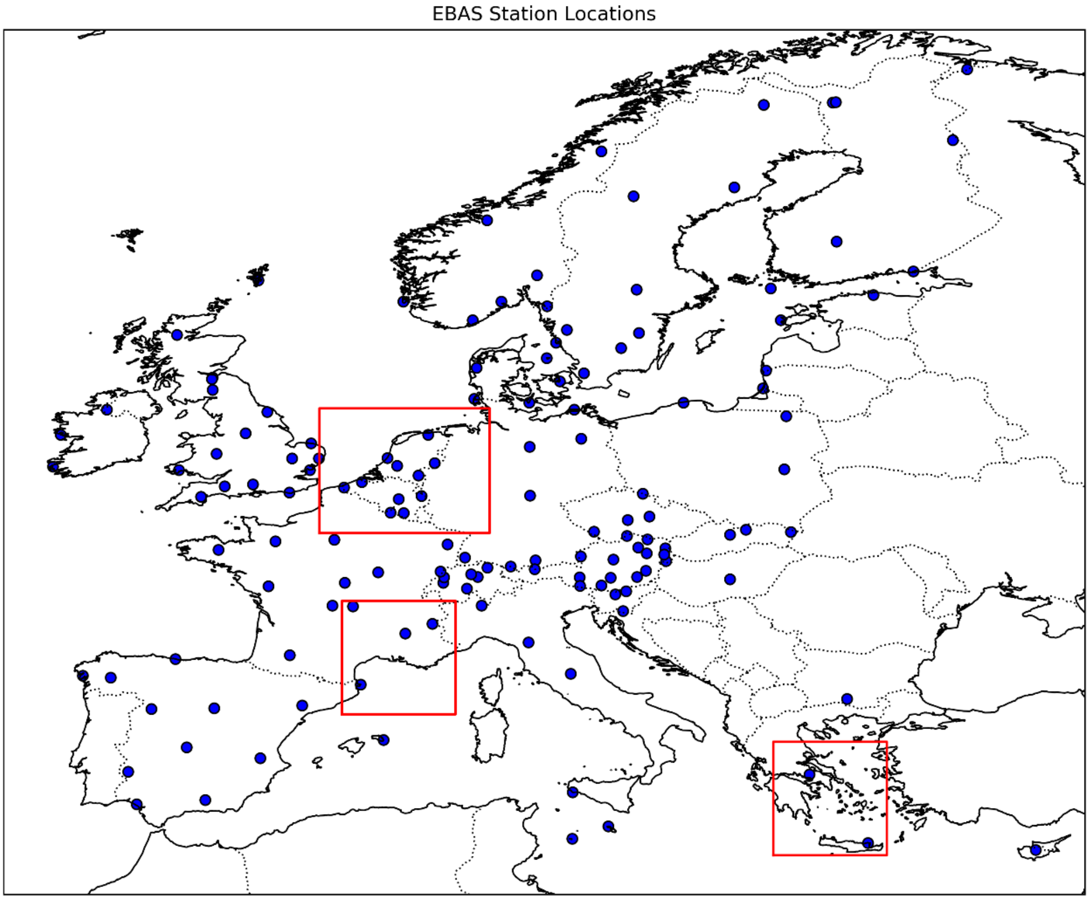


Figure 9 *Daily average modelled (line) and EBAS observed (points) concentrations of NO_2 (top) and $PM_{2.5}$ (bottom) in the EU domain for 2023*

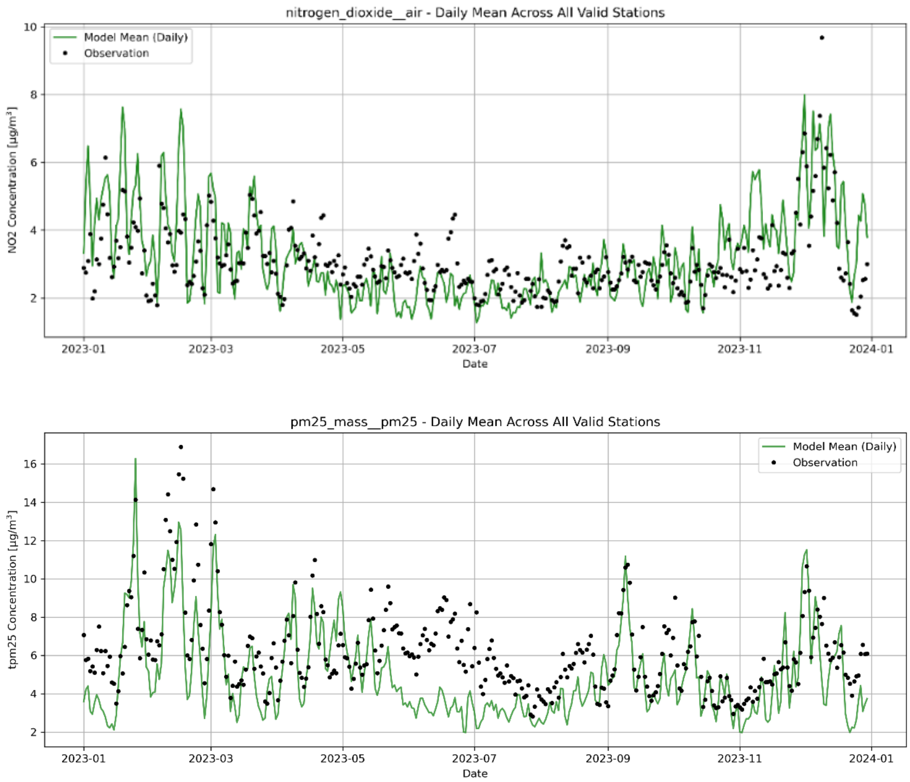
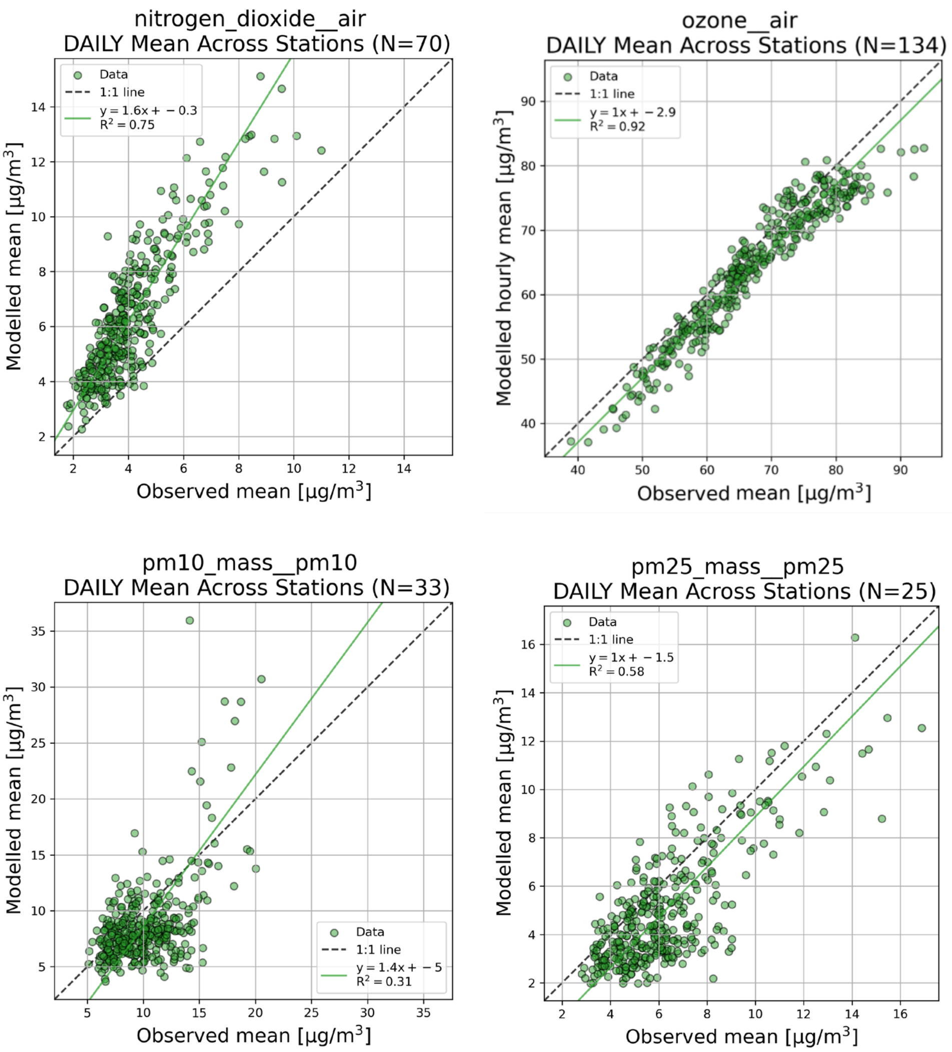
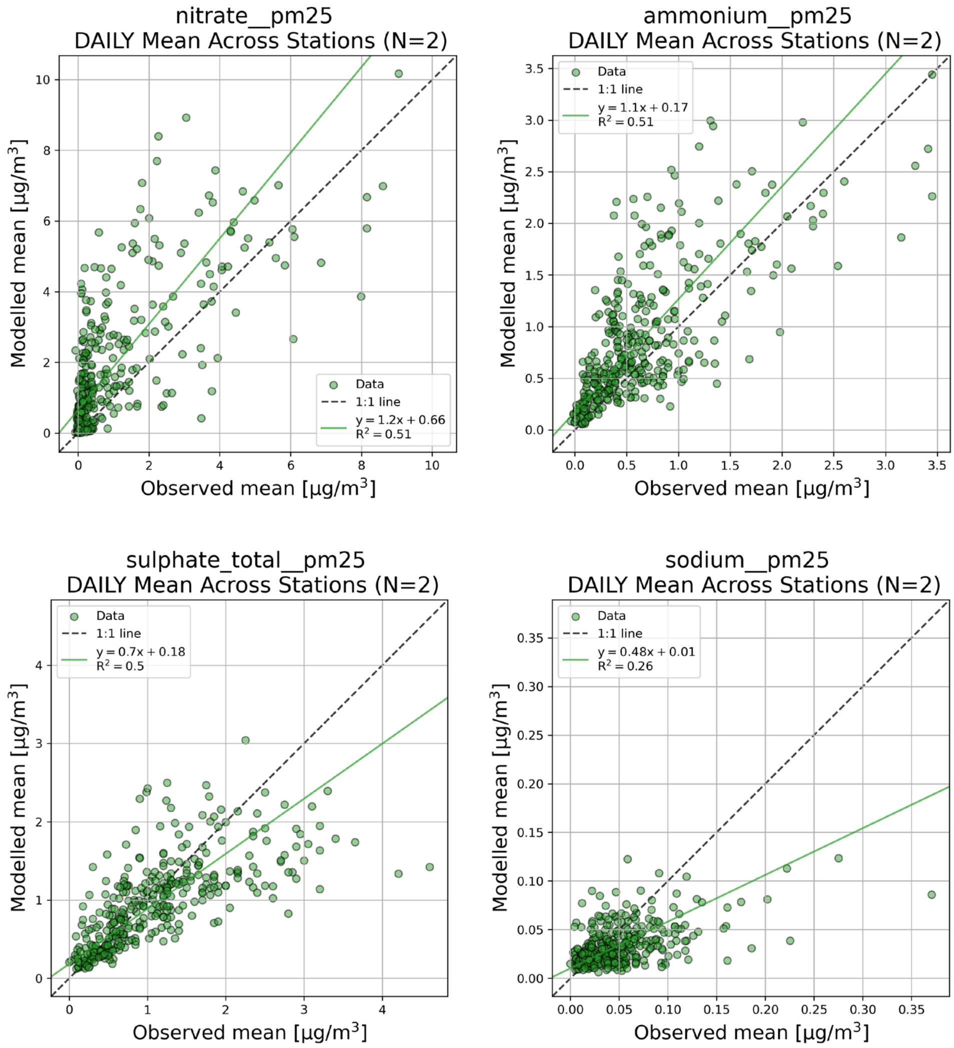


Figure 10 *Validation across EBAS stations in the EU domain for NO_2, O_3, PM_{10} and $PM_{2.5}$ for 2023*



Comparisons show the daily average values of surface concentrations across all stations. N responds to the valid number of stations.

Figure 11 *Validation across EBAS stations in the EU domain for $PM_{2.5}$ species for 2023*



Comparisons show the daily average values of surface concentrations across all stations. N responds to the valid number of stations.

Validation against EEA stations - EU and nested domains

In this section the evaluation of the performance of the model is provided for the parent and the nested domains and at specific stations at the port and city locations in the four examined cities. First, the analysis of the EU parent domain is shown for NO_2 and PM, followed by comparisons across all stations in the nested domains and finally at port/city specific station locations.

EU domain

In the EU, an overall underestimation of the observed NO_2 and PM concentrations is shown across all stations likely due to the coarse resolution used in the model simulations of the parent domain. The underestimation is higher for NO_2 throughout the whole year, since the coarse resolution cannot provide an accurate estimation of localised emission sources (combustion, traffic, etc.). $PM_{2.5}$ and PM_{10} show a better co-variability with the observed concentrations in winter, but an underestimation in summer attributed likely due to missing secondary organic aerosol formation.

Figure 12 *Daily average modelled (line) and EEA observed (points) concentrations of NO_2 (top), $PM_{2.5}$ (middle) and PM_{10} (bottom) in the EU domain for 2023*

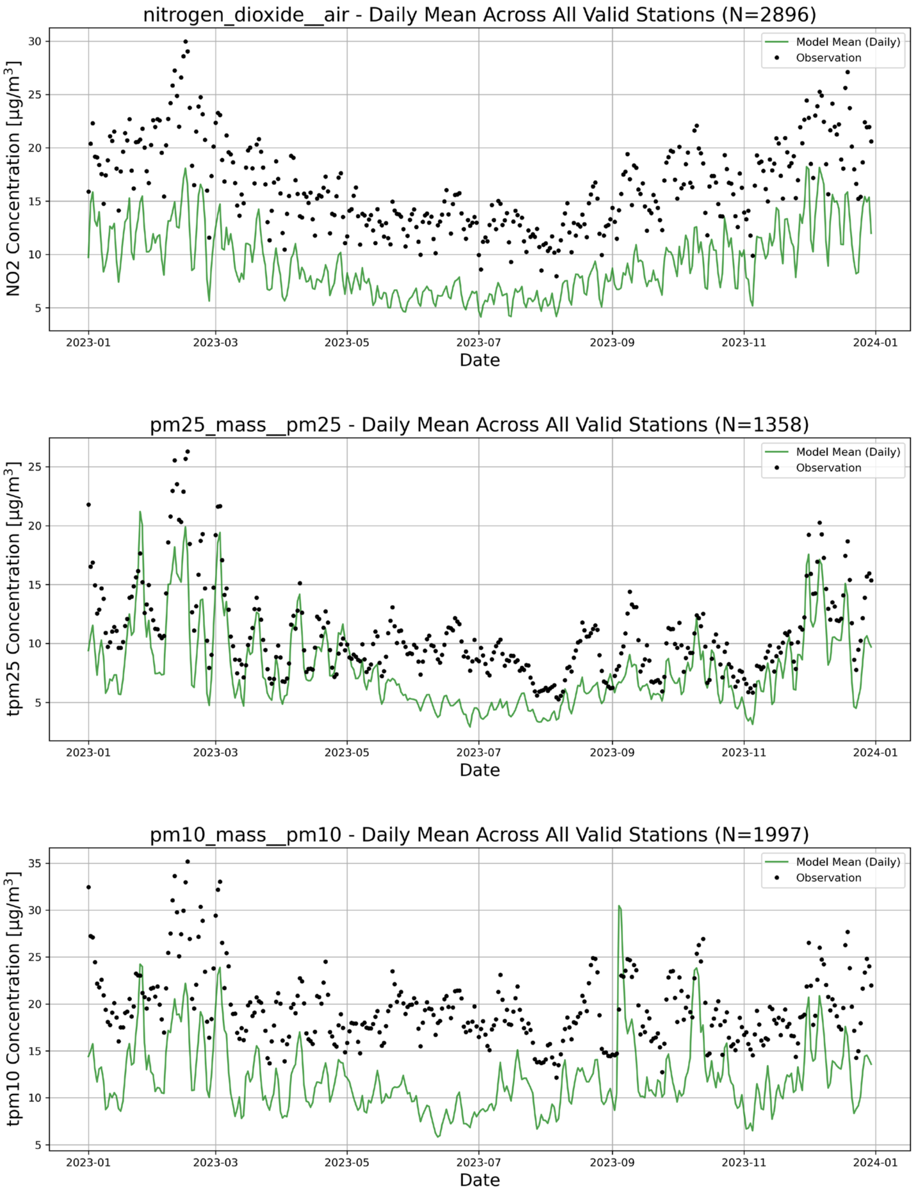
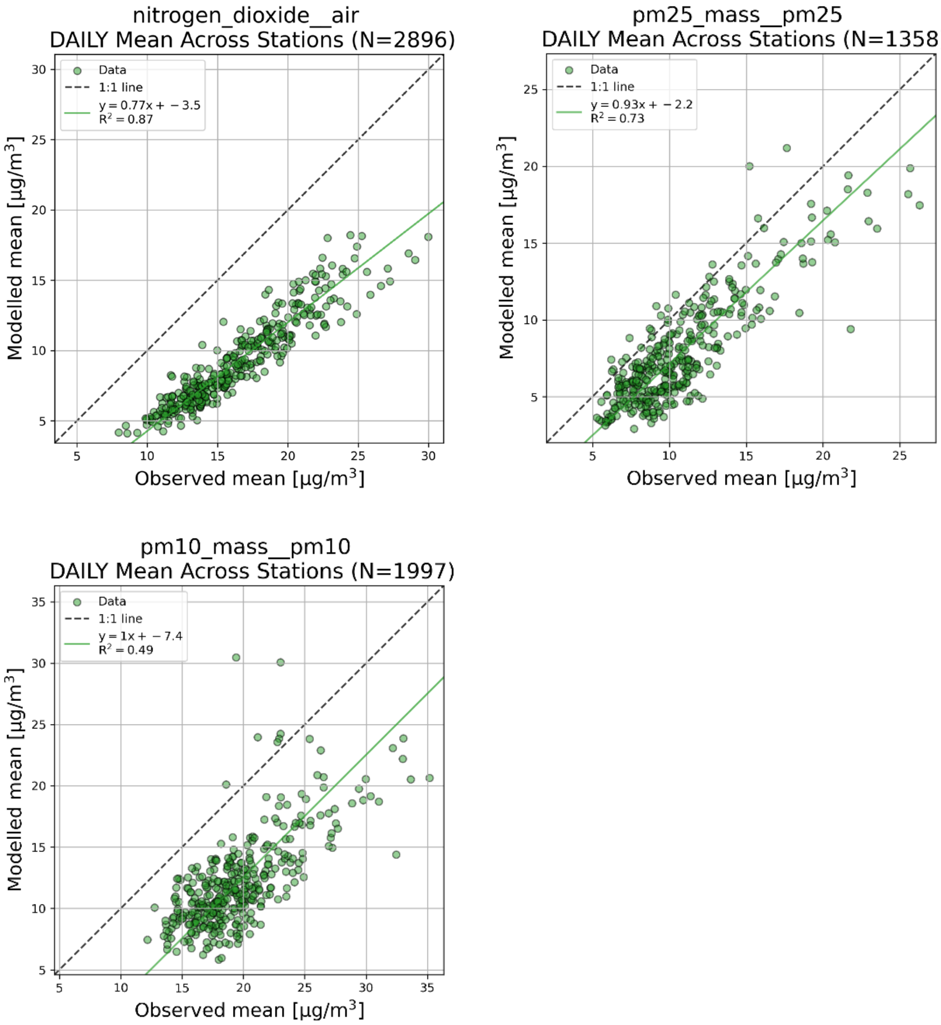


Figure 13 *Validation across EEA stations for NO_2, $PM_{2.5}$ and PM_{10} in the EU domain for 2023*



Comparisons show the daily average values of surface concentrations across all stations. N is the number of valid stations.

BENELUX nested domain

In the BENELUX nested domain, the discrepancies between the modelled and the observed surface concentrations are, overall, lower for all the examined species. NO_2 simulations show a strong correlation with the observations (R^2 ~0.8) following the 1:1 line and displaying a similar seasonal variability with the observations. Similarly, both $PM_{2.5}$ and PM_{10} show a strong agreement with the observations with a slight underestimation in summer attributed likely to missing secondary organic aerosol formation.

Figure 14 *Daily average modelled (line) and EEA observed (points) concentrations of NO_2 (top), $PM_{2.5}$ (middle) and PM_{10} (bottom) in the BENELUX nested domain for 2023*

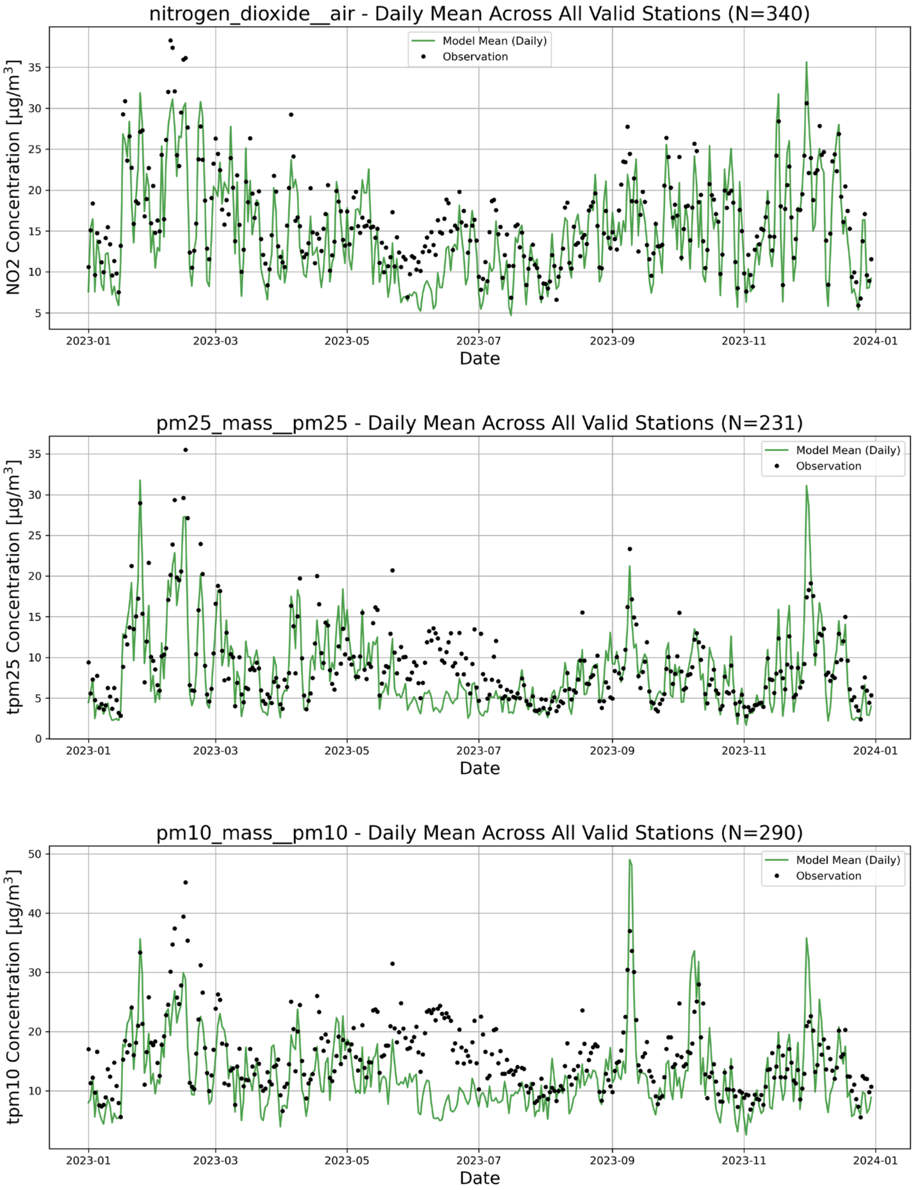
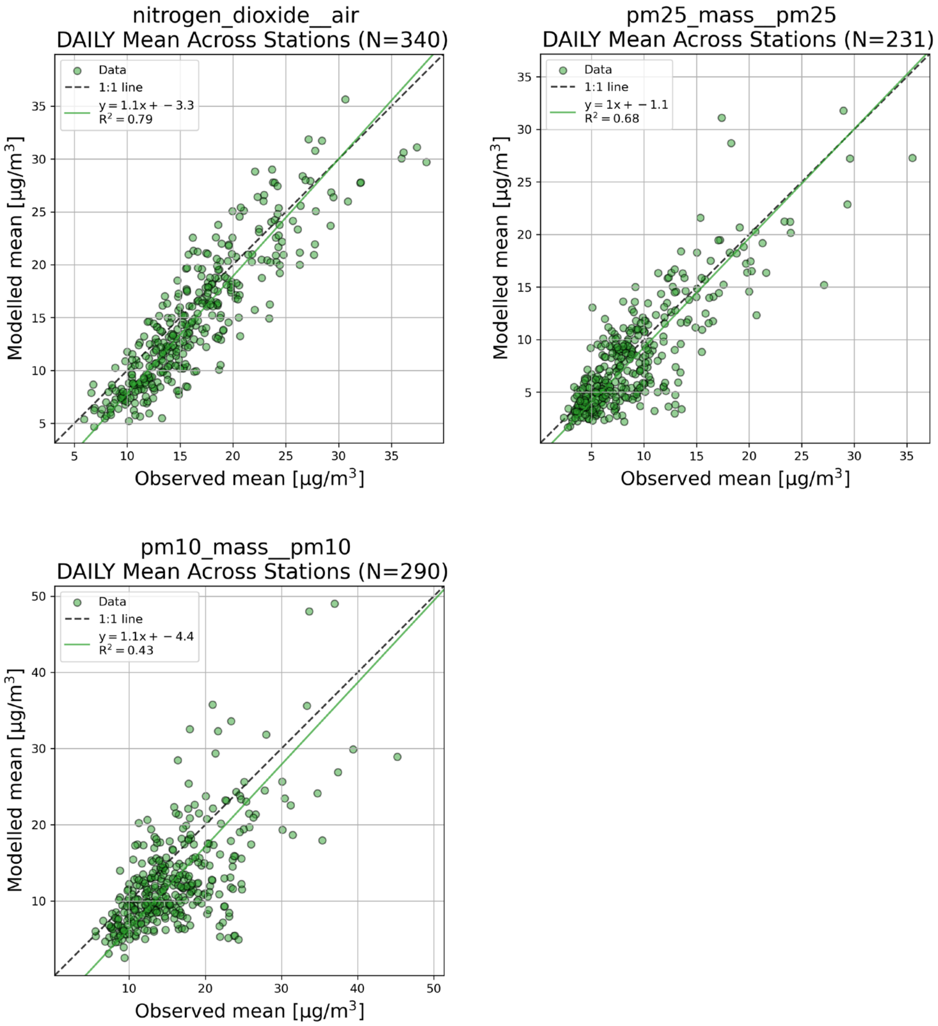


Figure 15 *Validation across EEA stations for NO_2, $PM_{2.5}$ and PM_{10} in the BENELUX nested domain for 2023*



Mediterranean/France nested domain

The model showcases a strong performance in the Mediterranean/France nested domain for all the examined species. NO_2 shows a strong correlation (R^2 ~0.8) with the in-situ measurements and captures well the seasonal variability but slightly underestimates the observed concentrations, especially in summer. The model accurately simulates PM concentrations, showing strong correlations for both $PM_{2.5}$ (R^2 ~0.75) and PM_{10} (R^2 ~0.7), following well the seasonal variability and capturing all the peaks likely linked to air pollution episodes (e.g., dust transport for PM_{10}). A slight underestimation is observed in $PM_{2.5}$ concentrations in summer, a common picture in all domains, attributed to missing secondary organic aerosol formation.

Figure 16 *Daily average modelled (line) and EEA observed (points) concentrations of NO_2 (top), $PM_{2.5}$ (middle) and PM_{10} (bottom) in the Mediterranean/France nested domain for 2023*

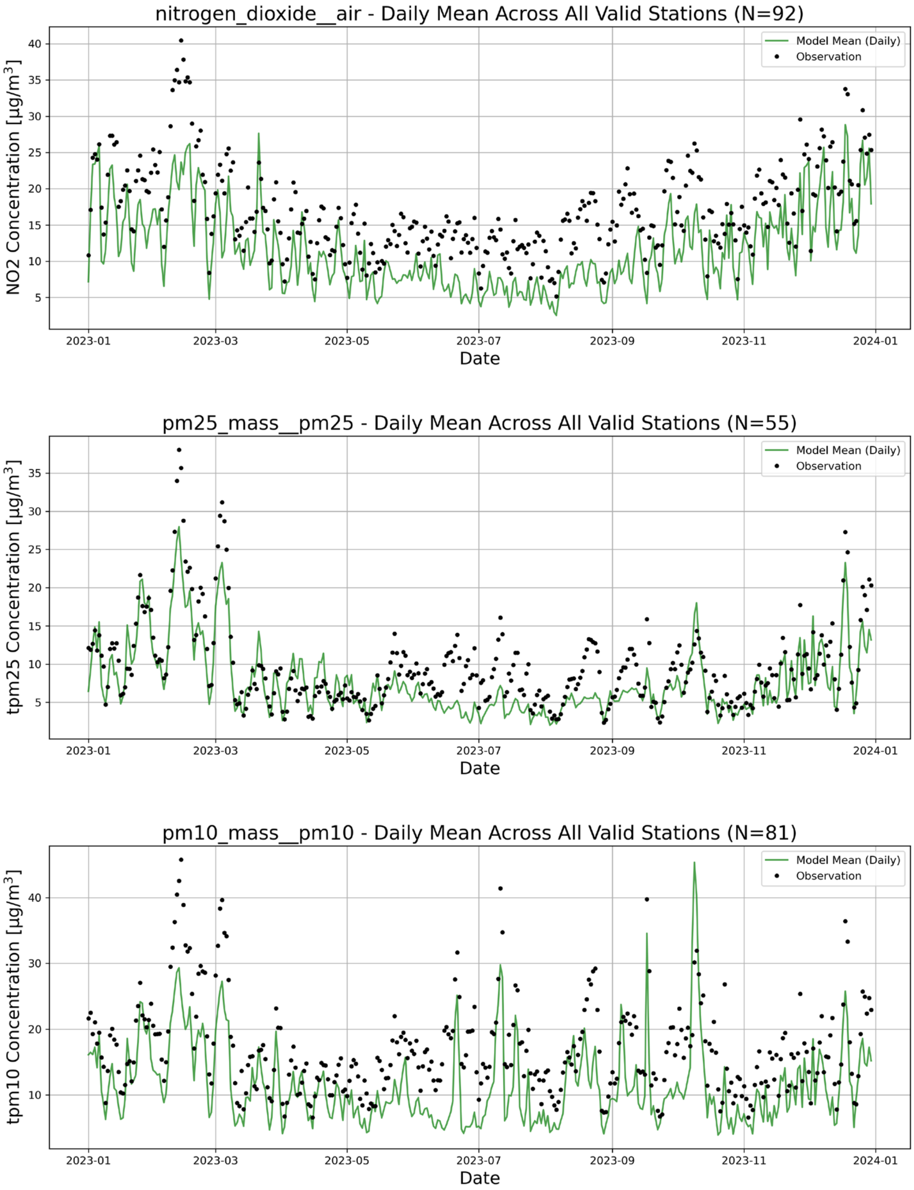
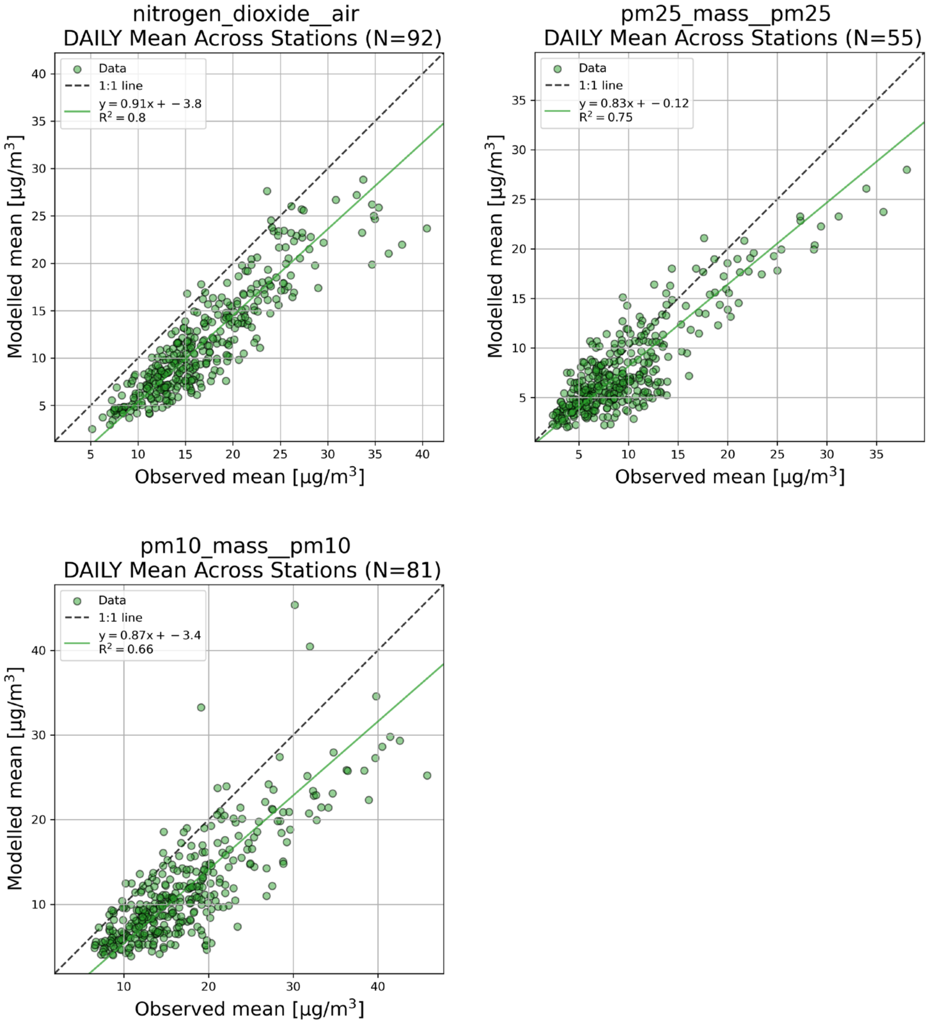


Figure 17 *Validation across EEA stations for NO_2, $PM_{2.5}$ and PM_{10} in the Mediterranean/France nested domain for 2023*



Mediterranean/Greece nested domain

In the Mediterranean/Greece domain, the model shows a strong agreement between simulated and measured NO_2 surface concentrations (R^2 ~0.8), falling well in line with the 1:1 line. The simulated PM concentrations show, overall, similar co-variability with the measurements but an underestimation for both the fine and the coarse fractions of the particles. For $PM_{2.5}$ the underestimation is higher in summer, linked to missing secondary organic aerosol formation. For PM_{10}, measurements are slightly underpredicted likely due to under-representation of sea-salt emissions. However, the model is slightly overpredicting the peaks attributed likely to the overestimation of dust emissions transported to the area. Nevertheless, both PM fractions show a moderate correlation (R^2 ~0.52), managing to capture well the seasonal variability and the peaks of air pollutant concentrations.

Figure 18 *Daily average modelled (line) and EEA observed (points) concentrations of NO_2 (top), $PM_{2.5}$ (middle) and PM_{10} (bottom) in the Mediterranean/Greece nested domain for 2023*

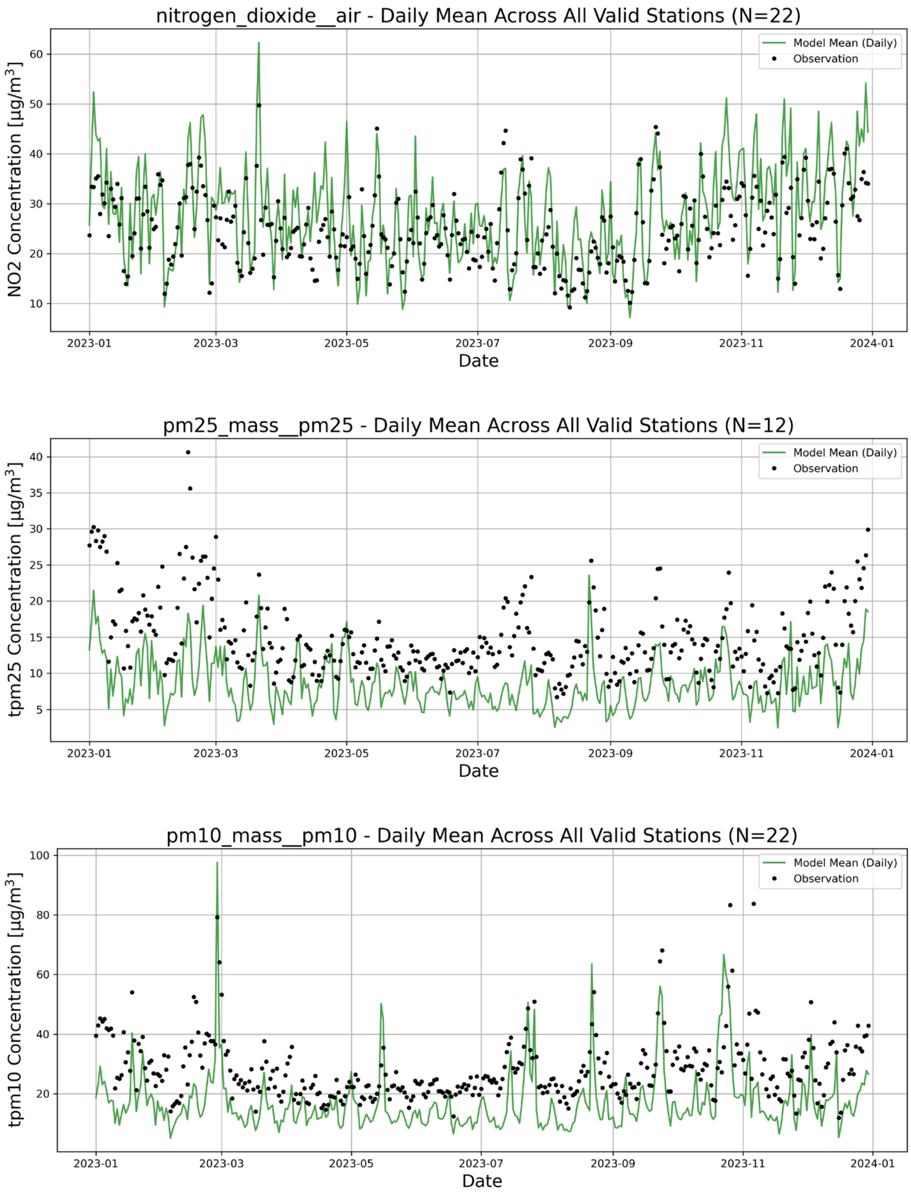
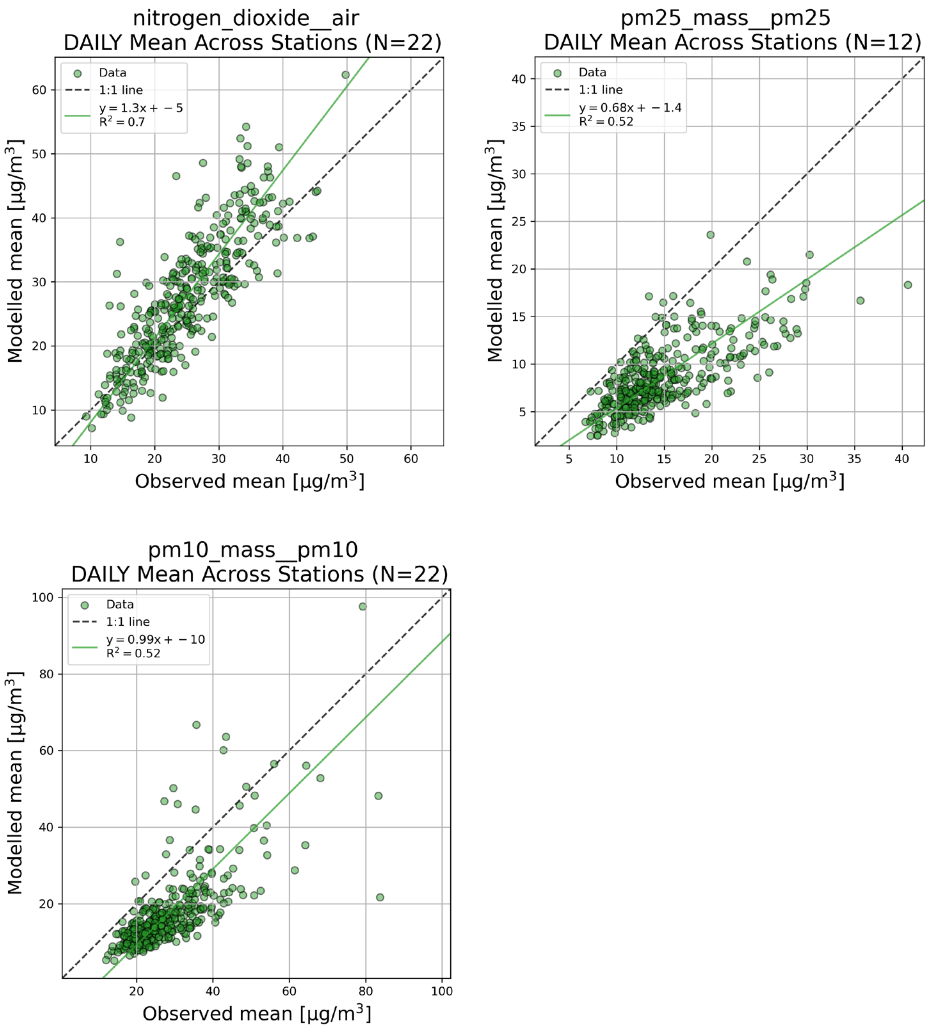


Figure 19 *Validation across EEA stations for NO_2, $PM_{2.5}$ and PM_{10} in the Mediterranean/Greece nested domain for 2023*



Antwerp

The 2023 base case simulation from LOTOS-EUROS accurately captures the daily concentrations of NO_2 compared to measurements at EEA station BETR817 in the city of Antwerp. Overall, a slight overestimation in Antwerp is observed. Both the model and observations agree that February sees the highest NO_2 concentrations in Antwerp. The nested run at Antwerp with higher resolution did not improve the simulation. Since both runs share the same resolution of emissions and meteorology as well as a relatively flat topography, the higher resolution here has not improved the modelled accuracy.

In relation to $PM_{2.5}$, the modelled daily surface concentrations show a slight underestimation compared to observations but closely follow the 1:1 line at station BETR817. The seasonal time series indicate that the model captures most seasonal variations well, except for an underestimation of concentrations from May to July, likely due to missing secondary organic aerosol formation. Without speciated results in Antwerp, it is difficult to determine whether this is caused by meteorological factors like vertical mixing or by emissions.

EU run

Figure 20 *Daily average modelled (line) and observed (points) concentrations at BETR817 EEA station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Antwerp for 2023 using the EU parent domain model configuration*

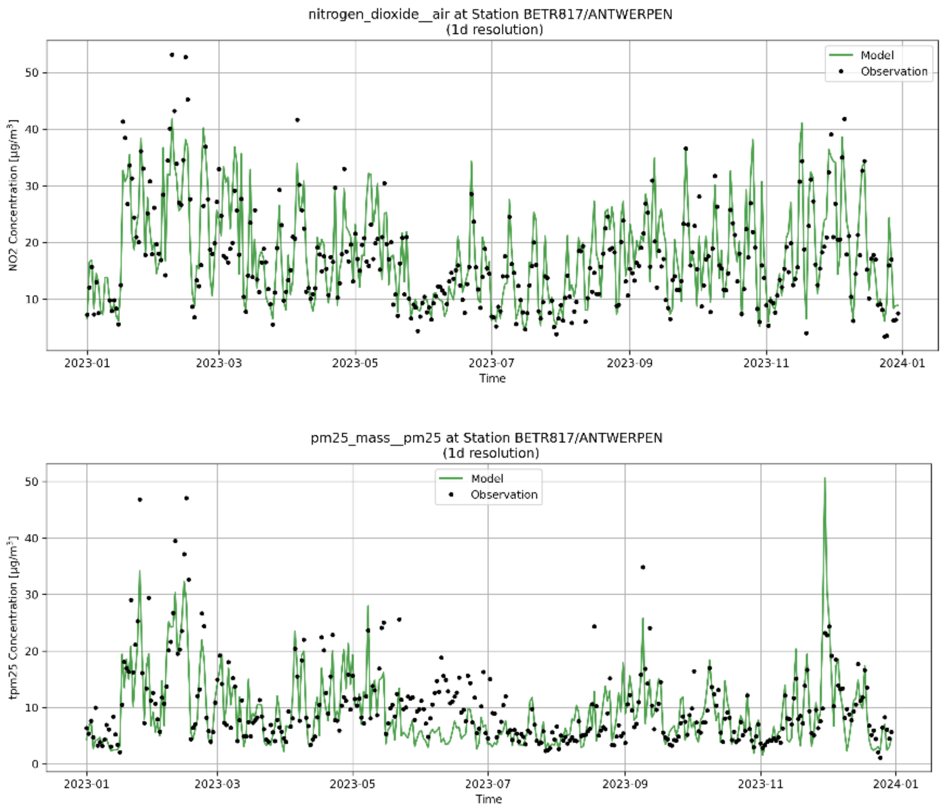
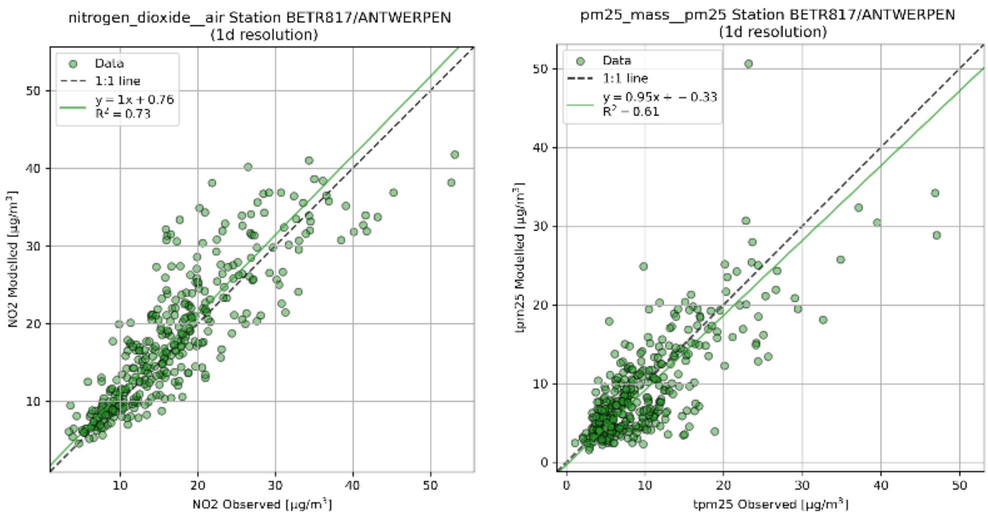


Figure 21 *Validation at BETR817 EEA station for NO_2 and $PM_{2.5}$ in the city of Antwerp for 2023 using the EU parent domain model configuration*



Nested run

Figure 22 *Daily average modelled (line) and observed (points) concentrations at BETR817 EEA station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Antwerp for 2023 using the BENELUX nested domain model configuration*

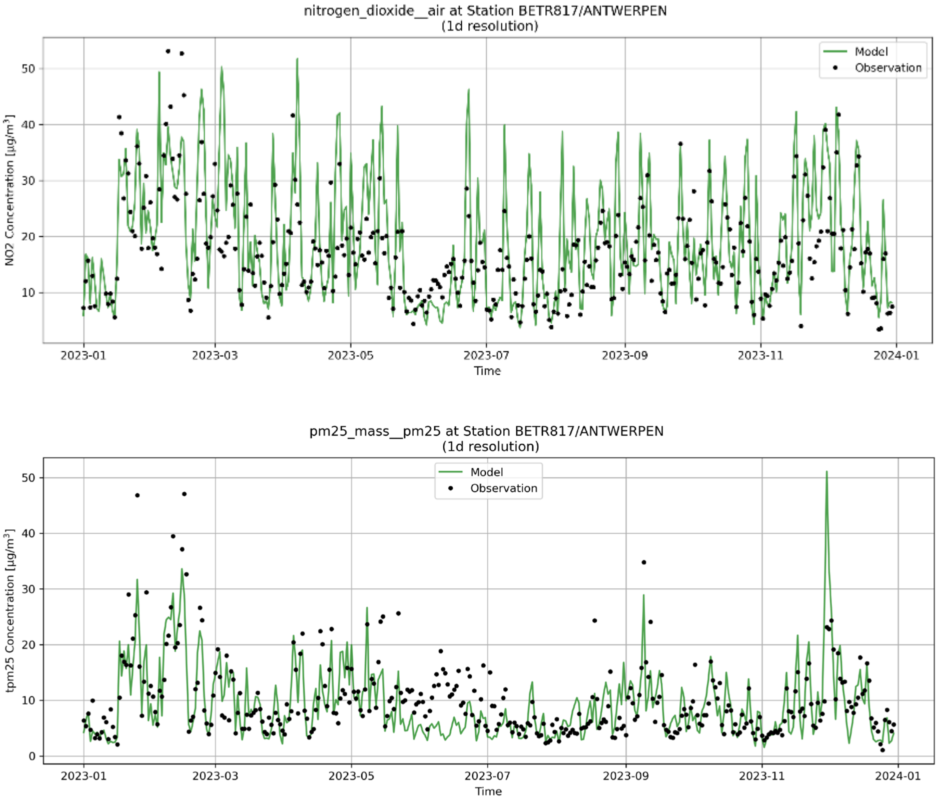
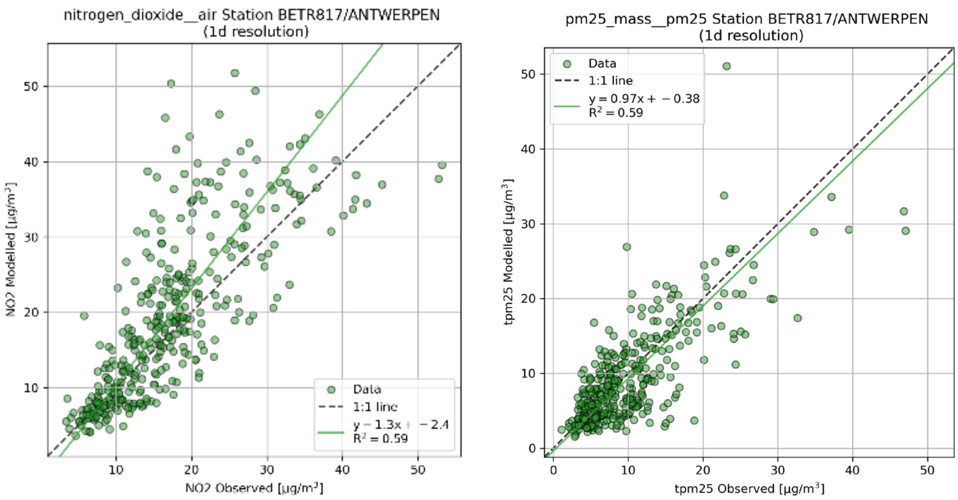


Figure 23 *Validation at BETR817 EEA station for NO_2 and $PM_{2.5}$ in the city of Antwerp for 2023 using the BENELUX nested domain model configuration*

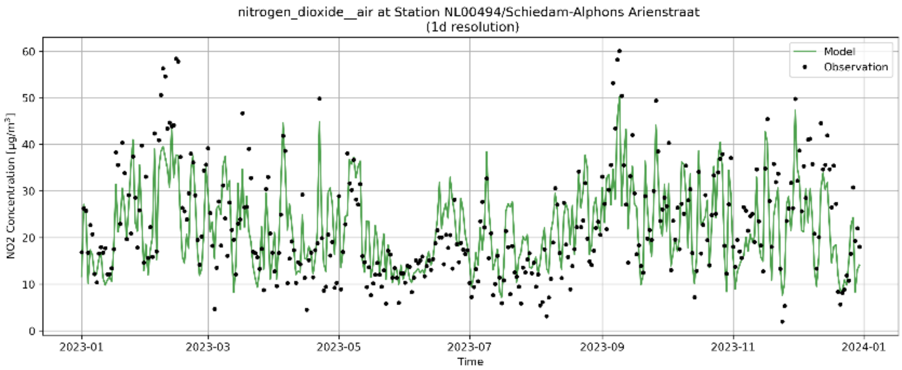


Rotterdam

The base run in Rotterdam performs well ($PM_{2.5}$ R^2 >0.6; NO_2 R^2 >0.5) in the city urban area compared to the EEA station NL00494 (city centre). The finer resolution leads to a slight overestimation of the measured concentrations compared to the coarse resolution used in the parent domain. Nevertheless, the modelled NO_2 concentration stays well within the range of observations. Simulated $PM_{2.5}$ concentrations in Rotterdam are well in line with the observations (R^2 ~0.7), following the seasonal variability and capturing well the low and high concentrations.

EU run

Figure 24 *Daily average modelled (line) and observed (points) concentrations at NL00494 station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Rotterdam for 2023 using the EU parent domain model configuration*



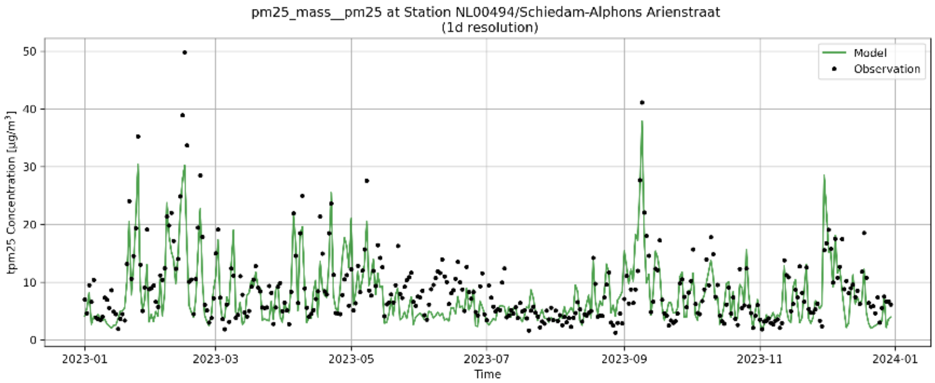
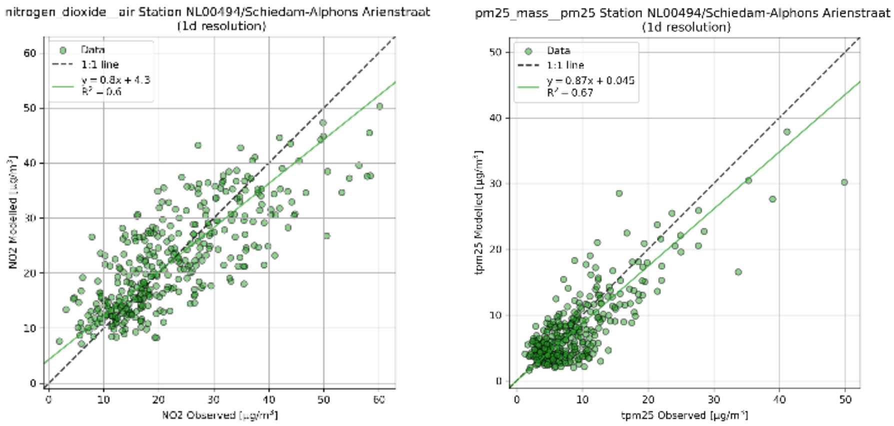


Figure 25 *Validation at NL00494 station for NO_2 and $PM_{2.5}$ in the city of Rotterdam for 2023 using the EU parent domain model configuration*



Nested run

Figure 26 *Daily average modelled (line) and observed (points) concentrations at NL00494 station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Rotterdam for 2023 using the BENELUX nested domain model configuration*

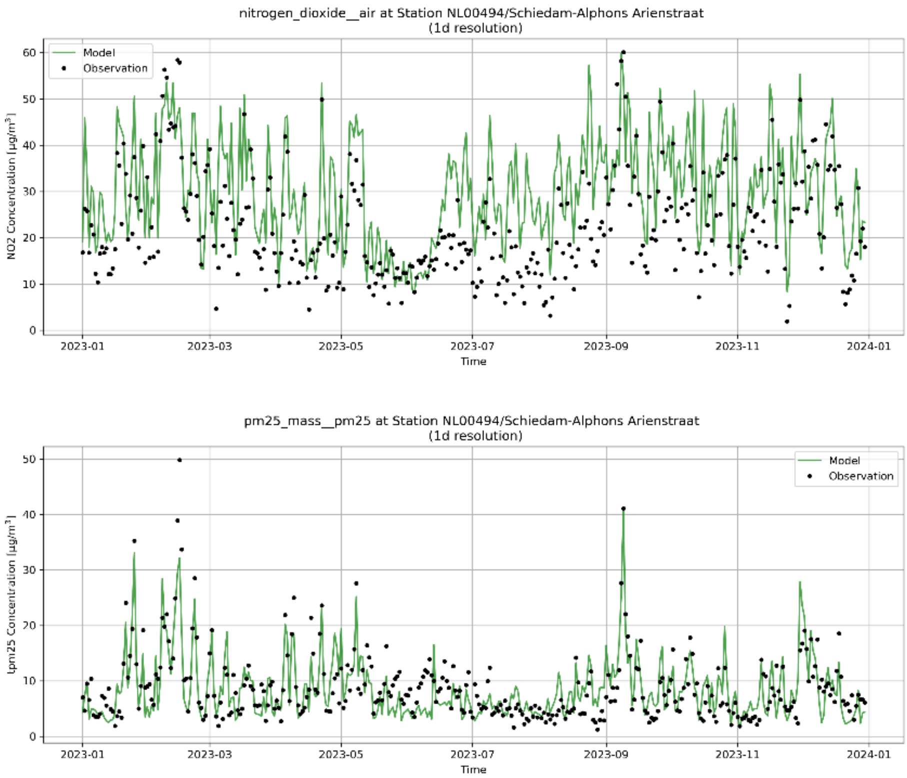
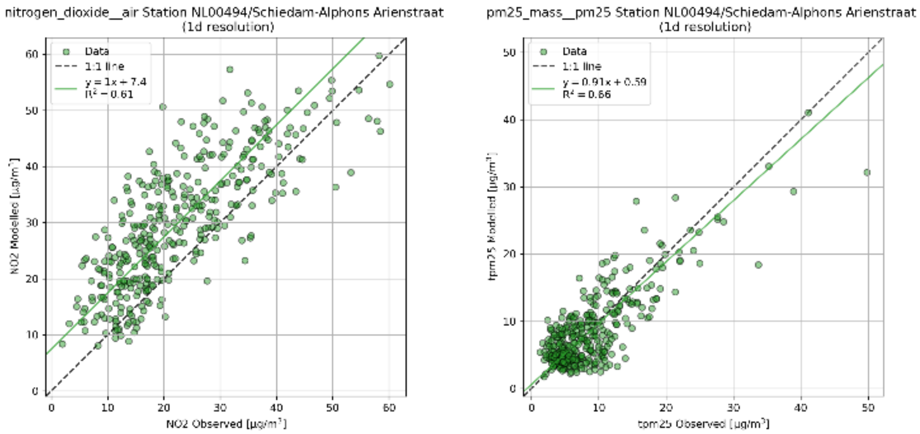


Figure 27 *Validation at NL00494 station for NO_2 and $PM_{2.5}$ in the city of Rotterdam for 2023 using the BENELUX nested domain model configuration*



Athens

The base EU run shows a moderate performance in the city centre of Athens (R^2 ~0.45) with an underestimation of the NO_2 and $PM_{2.5}$ surface concentrations. Nevertheless, the model accurately captures the temporal variability of the concentrations. The performance of the model is improved in the higher resolution nested run for both NO_2 and $PM_{2.5}$ concentrations (R^2 ~0.52). A slight overestimation in the NO_2 concentrations is observed, with the model accurately capturing the observed peaks. The discrepancies between the modelled and observed $PM_{2.5}$ concentrations in the EU run are reduced in the nested higher resolution, indicating a better representation of the emission sources and physiochemical processes in urban areas.

EU run

Figure 28 *Daily average modelled (line) and observed (points) concentrations at GR0003A station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Athens for 2023 using the EU parent domain model configuration*

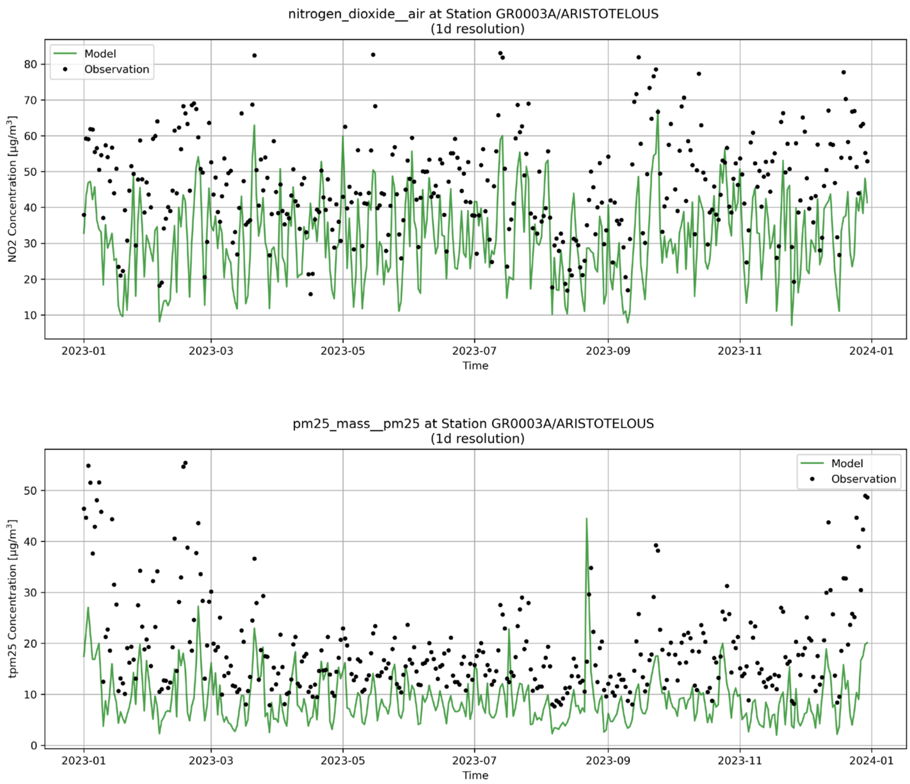
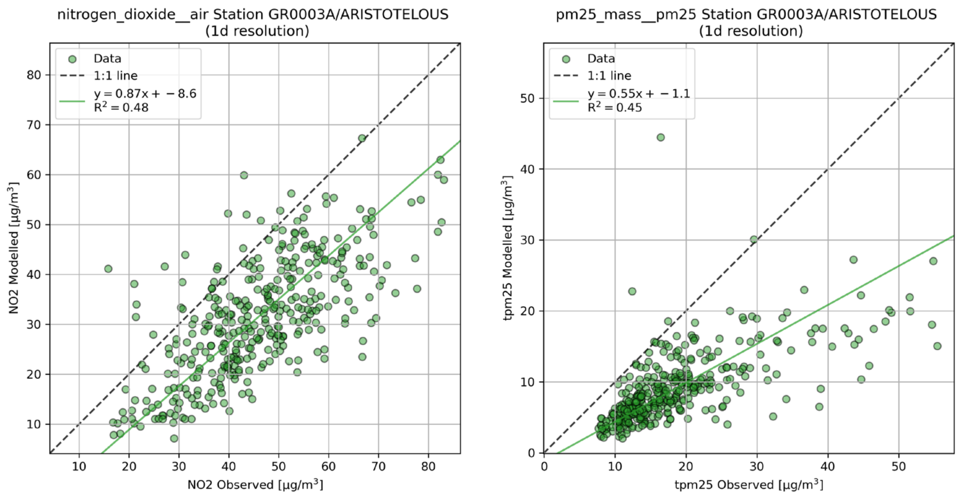


Figure 29 *Validation at GR0003A station for NO_2 and $PM_{2.5}$ in the city of Athens for 2023 using the EU parent domain model configuration*



Nested run

Figure 30 *Daily average modelled (line) and observed (points) concentrations at GR0003A station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Athens for 2023 using the Mediterranean/Greece nested domain model configuration*

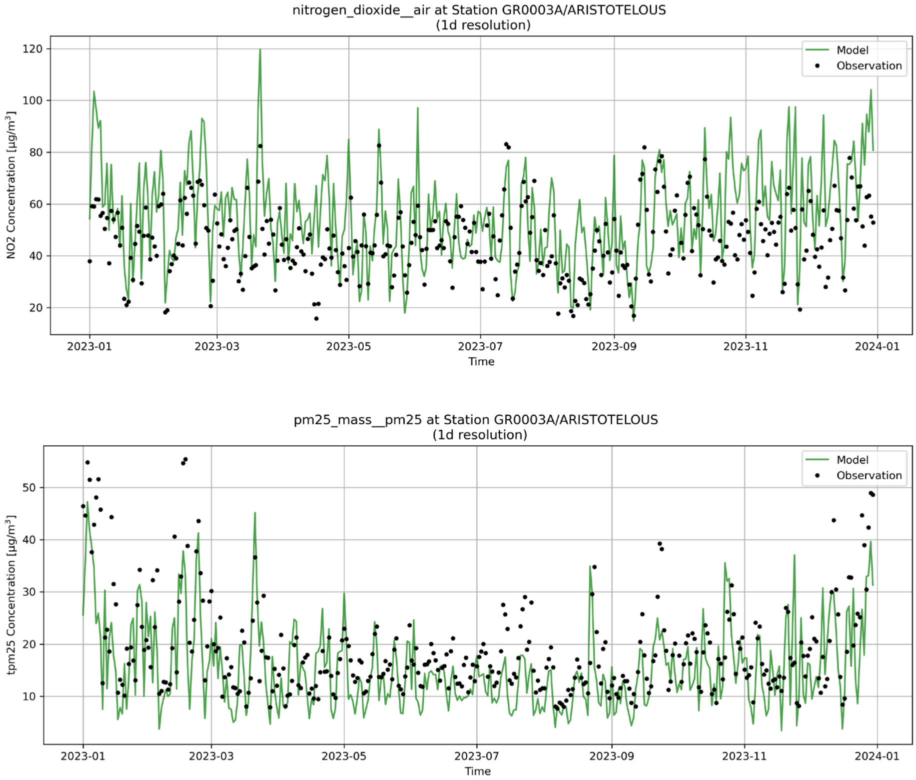
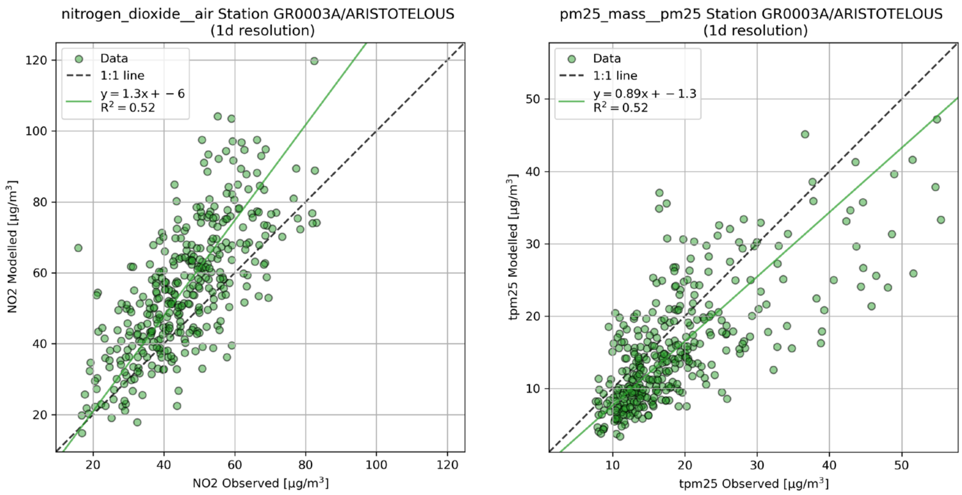


Figure 31 *Validation at GR0003A station for NO_2 and $PM_{2.5}$ in the city of Athens for 2023 using the Mediterranean/Greece nested domain model configuration*



Marseille

The base EU run shows a moderate performance regarding NO_2 surface concentrations (R^2 ~0.5) with an underestimation occurring mainly during the cold periods of the year, indicating a possible underrepresentation of combustion and road traffic emissions due to the coarse model resolution. The offset from the 1:1 line is reduced in the nested higher resolution run and the model shows an overall better performance, capturing the winter peaks.

The modelled $PM_{2.5}$ surface concentrations show a strong agreement with the observations (R^2 ~0.7) and the simulations capture well the seasonal variability. An underestimation of the observed concentrations is taking place in late spring/summer due to missing SIA formation. The higher resolution simulations show an improvement of the slope and a reduced bias.

EU run

Figure 32 *Daily average modelled (line) and observed (points) concentrations at FR03043 station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Marseille for 2023 using the EU parent domain model configuration*

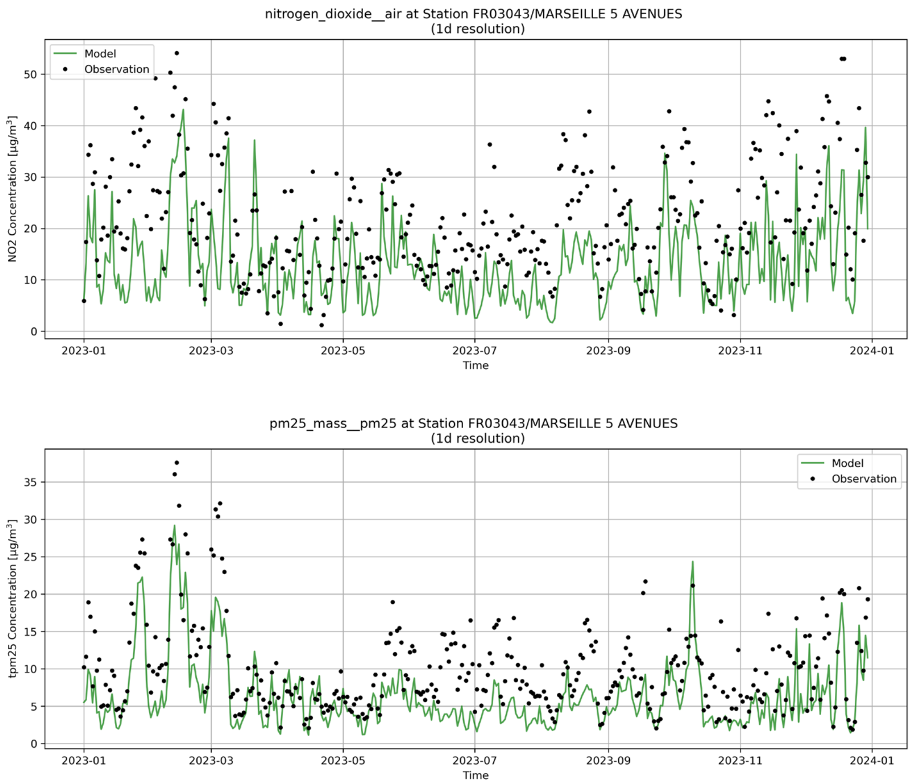
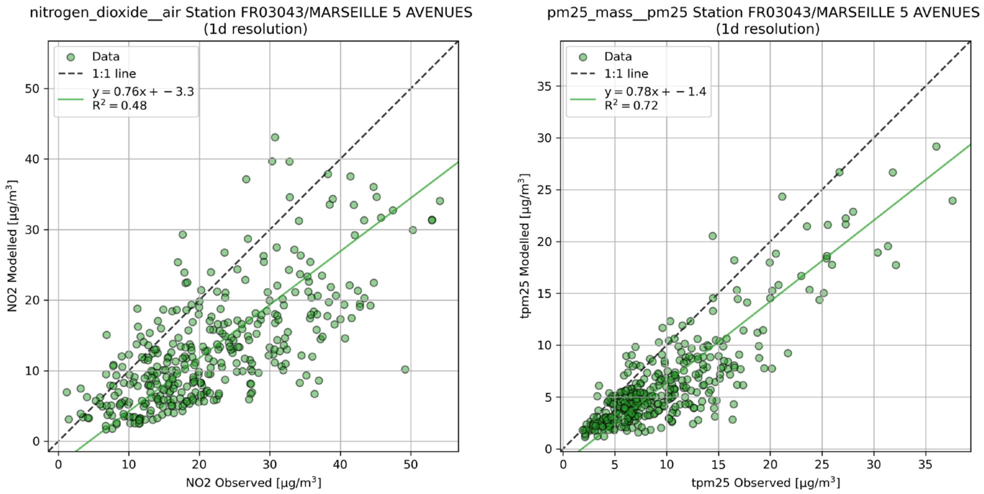


Figure 33 *Validation at FR03043 station for NO_2 and $PM_{2.5}$ in the city of Marseille for 2023 using the EU parent domain model configuration*



Nested run

Figure 34 *Daily average modelled (line) and observed (points) concentrations at FR03043 station for NO_2 (top) and $PM_{2.5}$ (bottom) in the in the city of Marseille for 2023 using the Mediterranean/France nested domain model configuration*

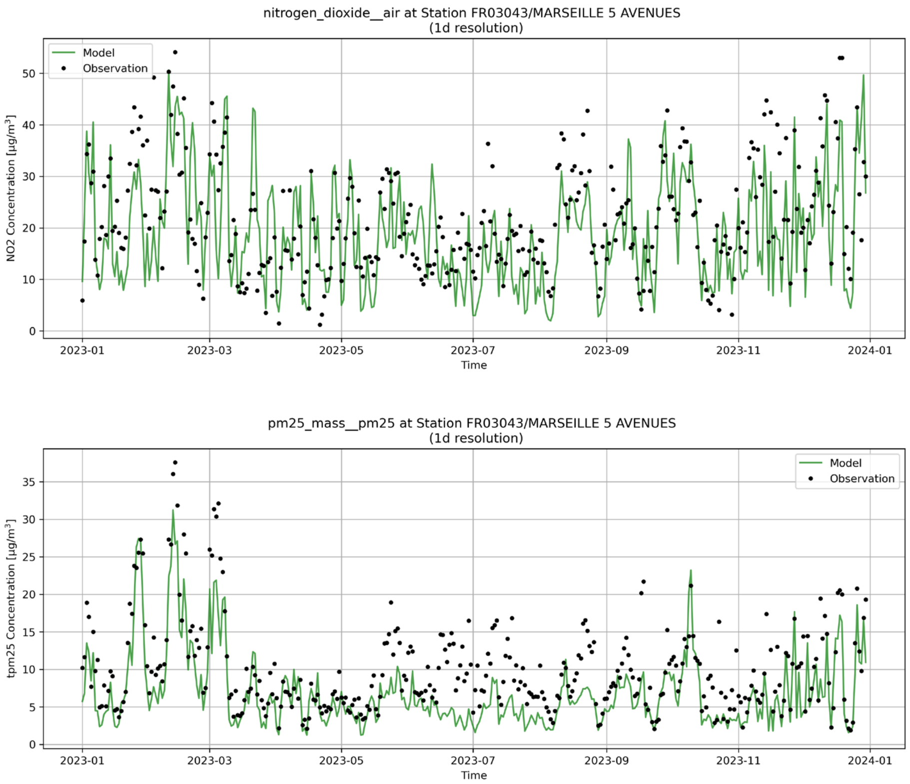
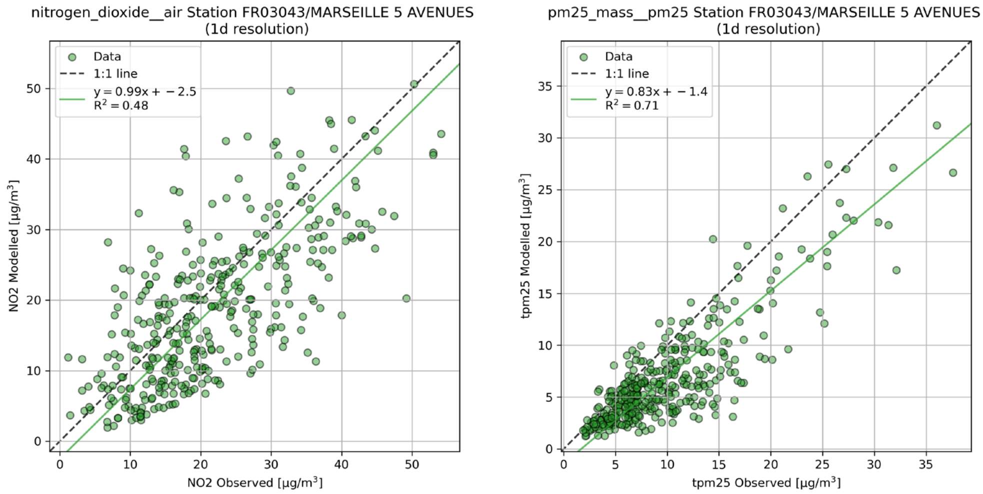


Figure 35 *Validation at FR03043 station for NO_2 and $PM_{2.5}$ in the city of Marseille for 2023 using the Mediterranean/France nested domain model configuration*



B2 SHIPPING CONTRIBUTION

EU source apportionment

This section presents the source apportionment across the European domain per assessed scenario and per pollutant.

Figure 36 *Predicted annual average NO_2 absolute concentration differences (in µg/m^3) attributed to shipping across the parent European domain between the 2030 all-EU ECA and 2023 base case (left) and the 2030 LNG and 2023 base (right) scenarios*

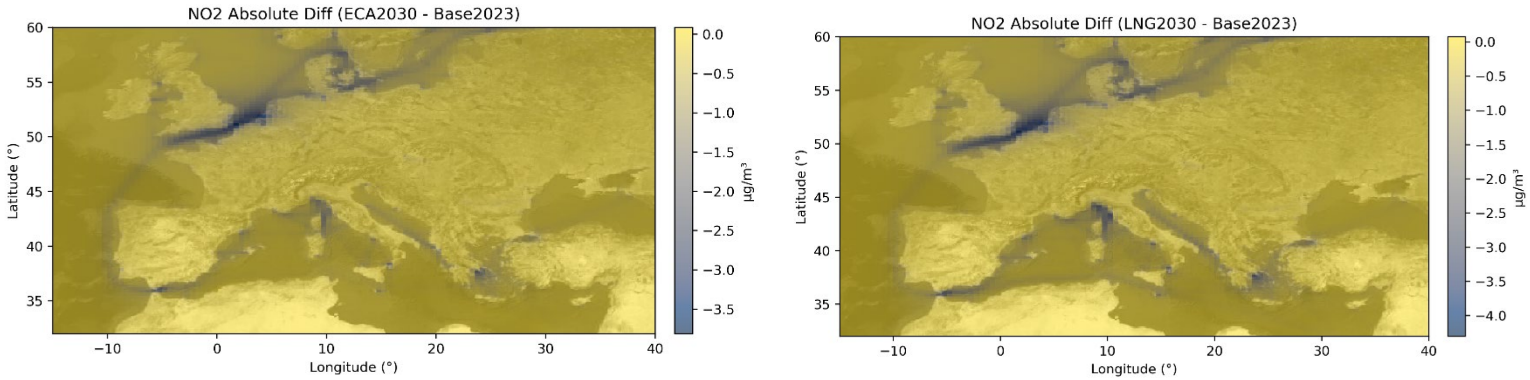


Figure 37 *Predicted annual average $PM_{2.5}$ absolute concentration differences (in μg/m³) attributed to shipping across the parent European domain between the 2030 all-EU ECA and 2023 base case (left) and the 2030 LNG and 2023 base (right) scenarios*

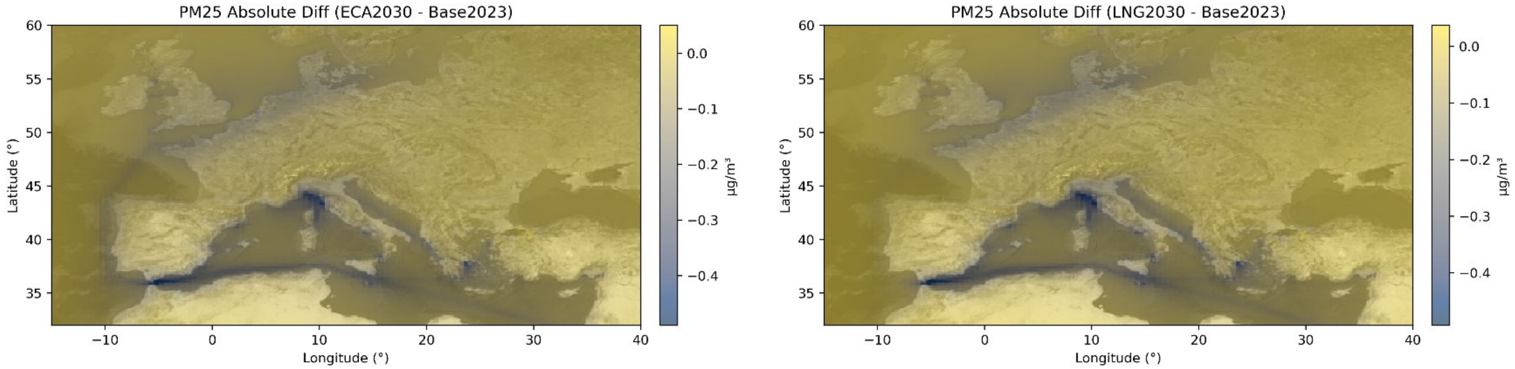


Figure 38 *Predicted annual average SO_2 absolute concentration differences (in μg/m³) attributed to shipping across the parent European domain between the 2030 all-EU ECA and 2023 base case (left) and the 2030 LNG and 2023 base (right) scenarios*

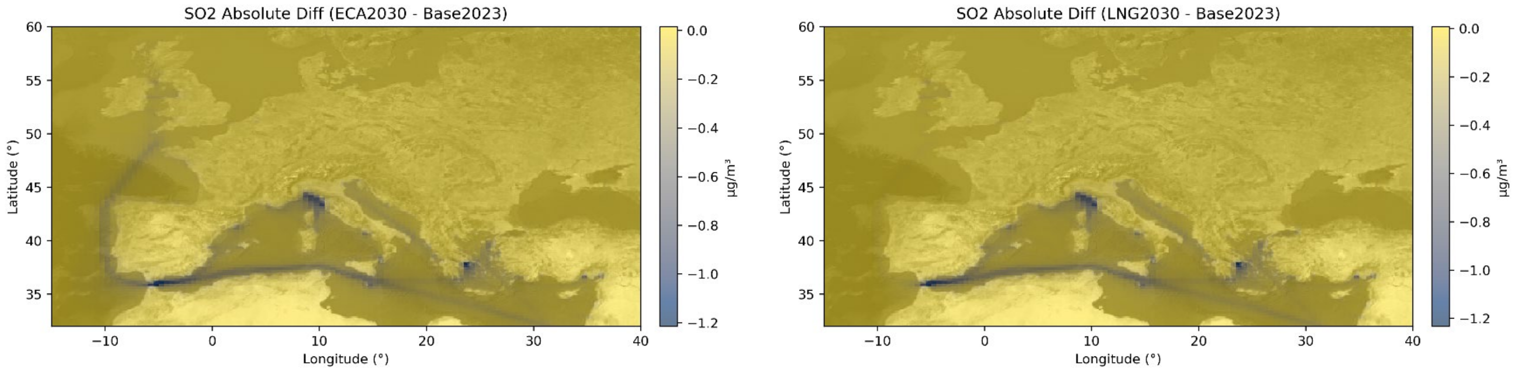


Figure 39 *Predicted $PM_{2.5}$ annual average concentrations (μg/m^3) over Europe, sector (left) and relative sectoral contribution (in %) (right) for all examined scenarios*

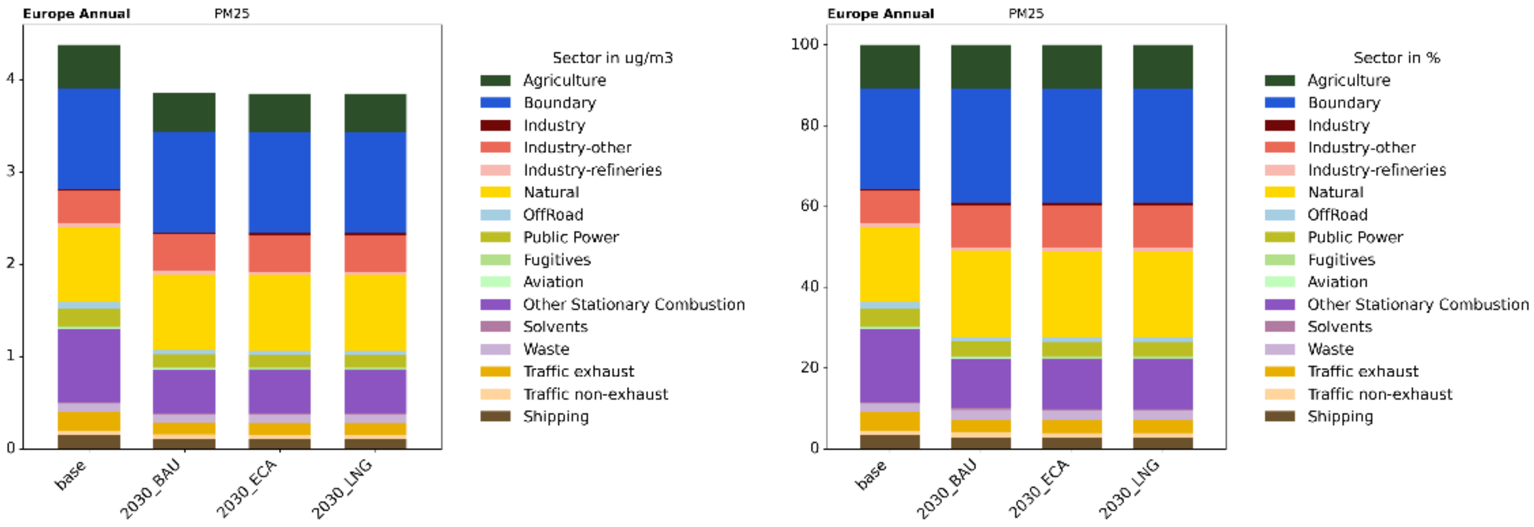
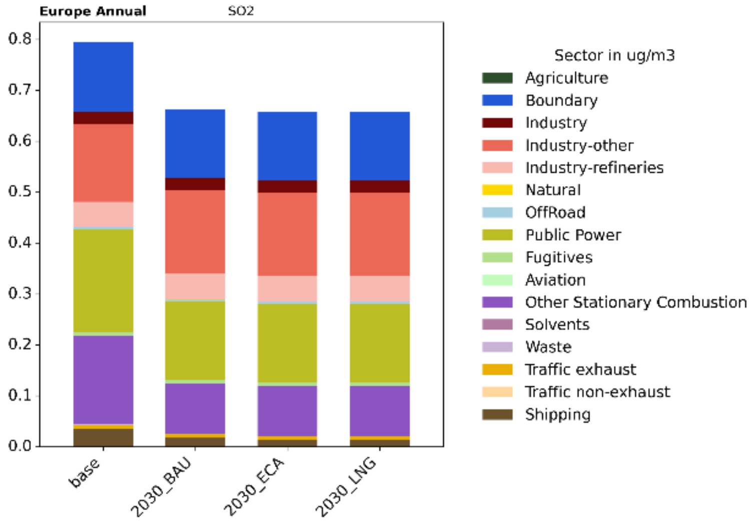
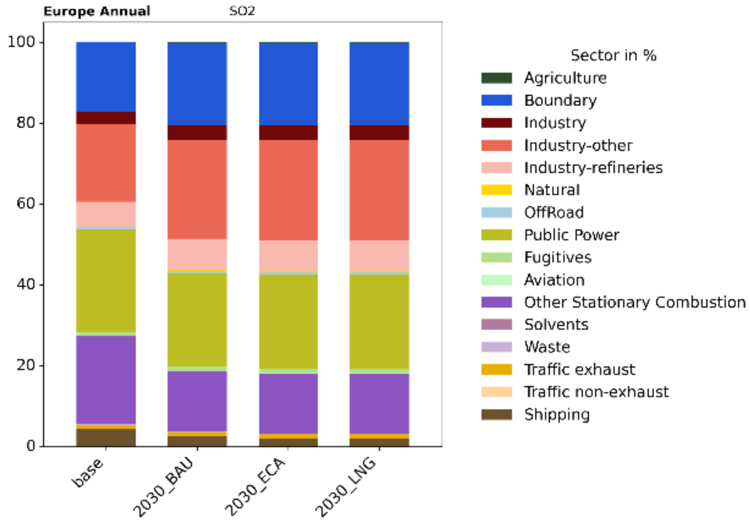


Figure 40 *Predicted SO_2 annual average concentrations (µg/m^3) over Europe, sector (left) and relative sectoral contribution (in %) (right) for all examined scenarios*





$PM_{2.5}$ source apportionment per port/city

Antwerp

Figure 41 *Annual averaged total $PM_{2.5}$ surface concentrations in [µg/m^3] within the Antwerp [Antwerpen] city core area in the 2023 base case (left) and 2030 BAU (right) scenarios*

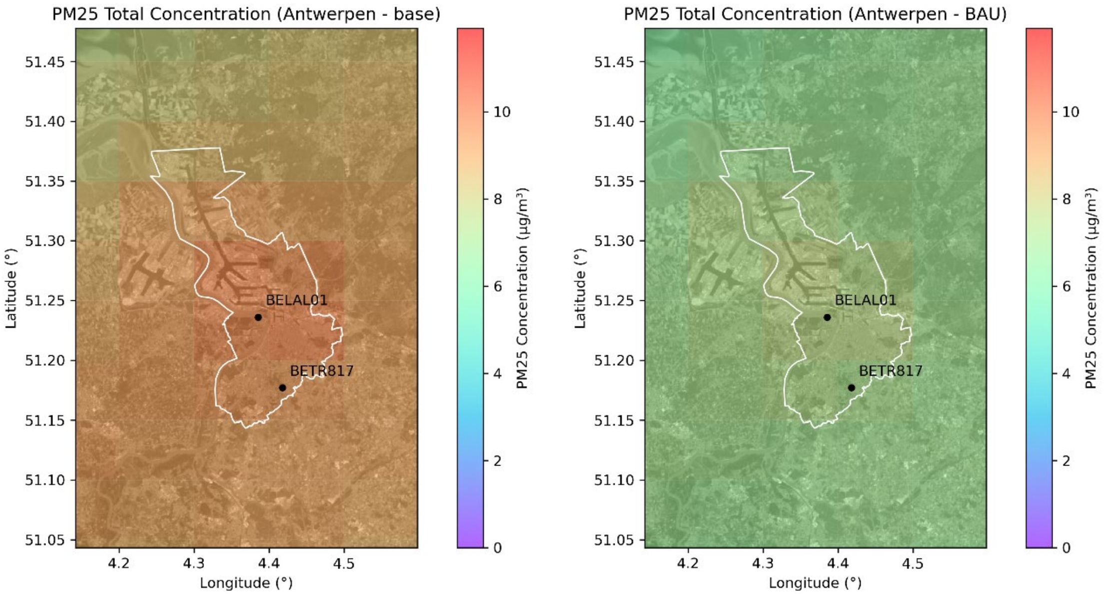


Figure 42 *Relative $PM_{2.5}$ shipping sector share [in %] within the Antwerp [Antwerpen] city core area in the 2023 base case (left) and 2030 BAU (middle) scenarios, and difference in the $PM_{2.5}$ concentrations attributed to shipping between the 2030 BAU and 2023 base case scenarios*

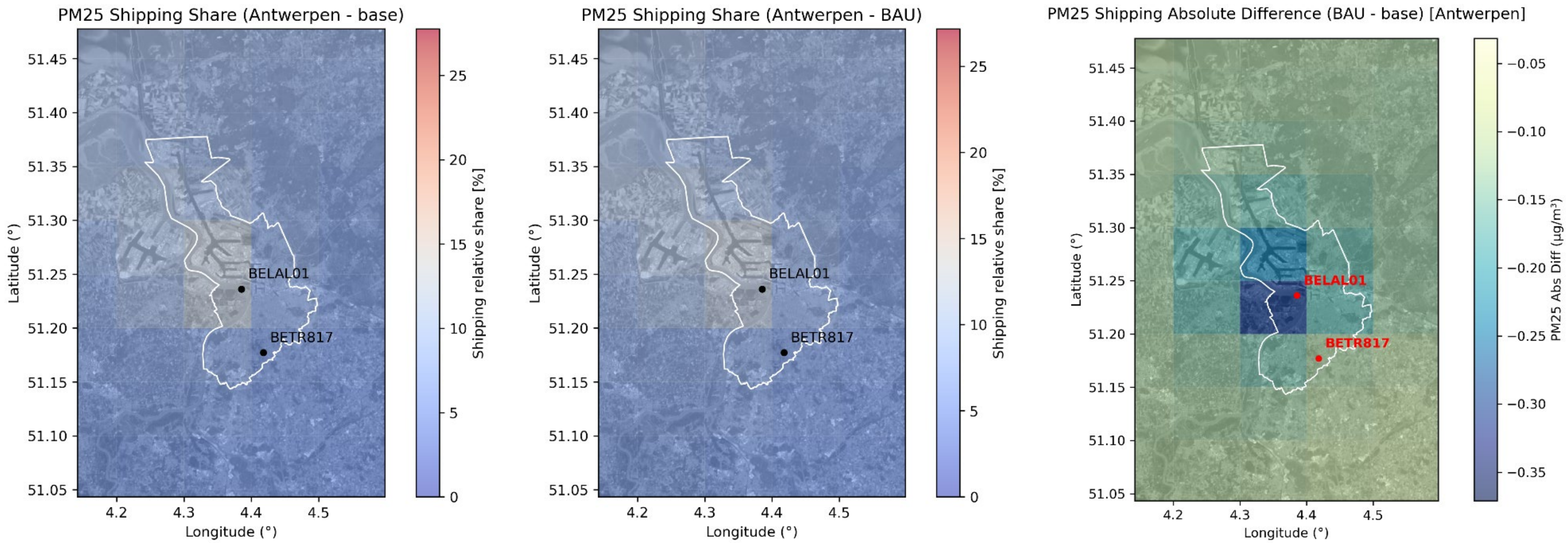
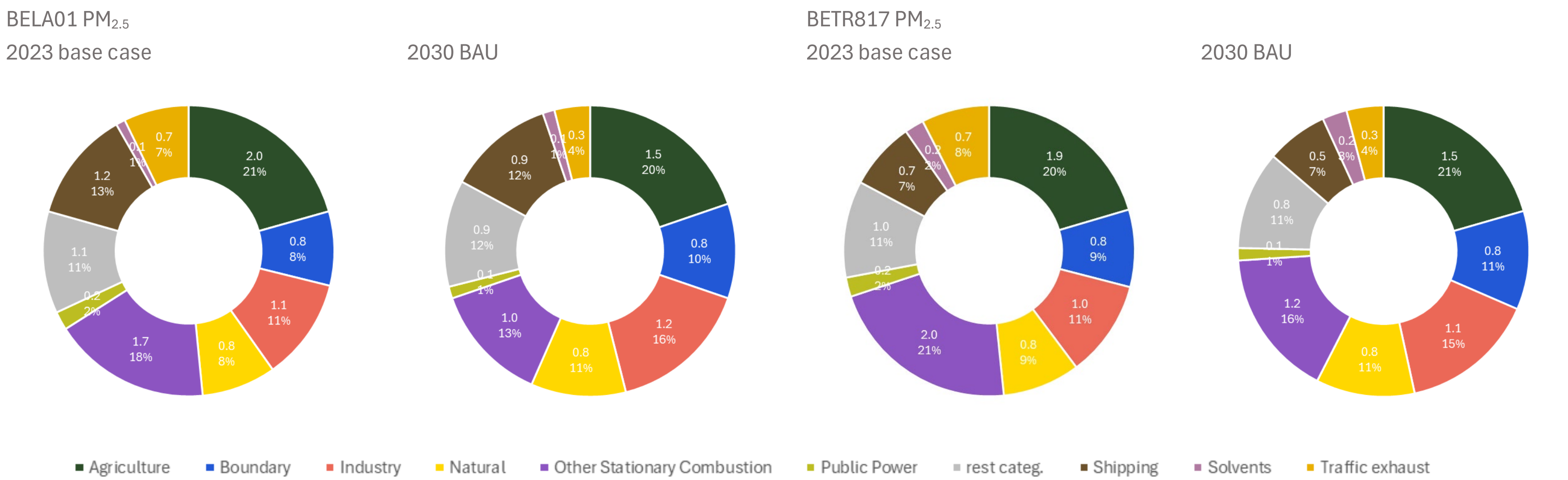
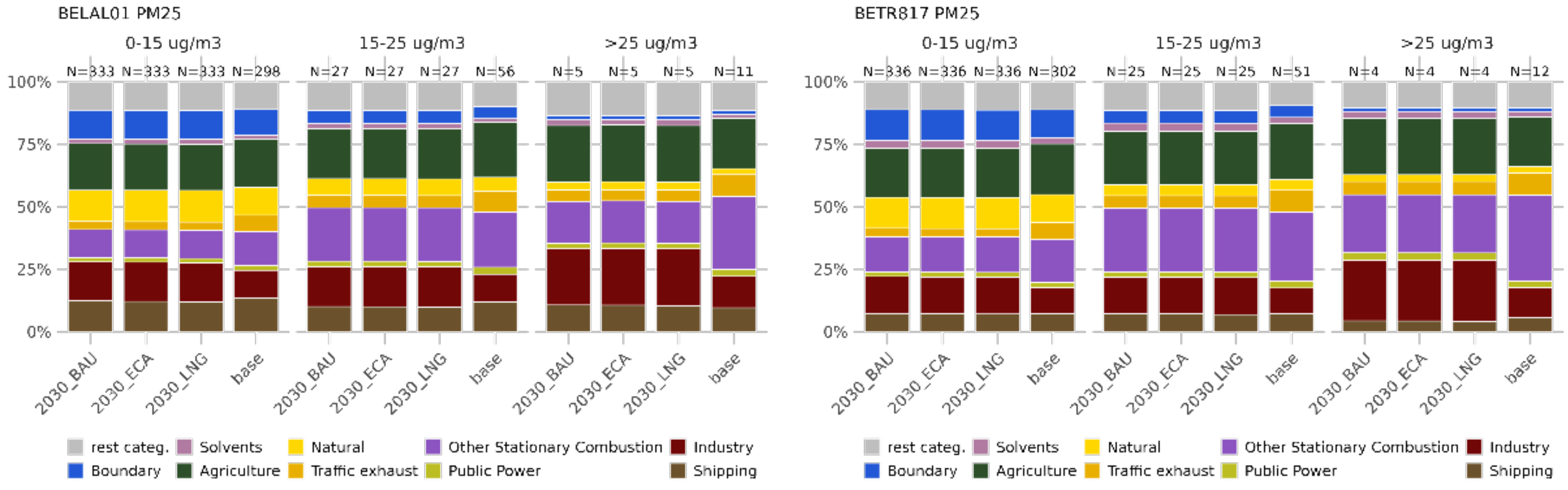


Figure 43 *Predicted $PM_{2.5}$ annual source apportionment results in Antwerp at observation sites BELAL01 (port) and BETR817 (city centre)*



The main contributing sectors are shown here, whereas the remaining sectors are grouped in the "rest categories". The top labels are relative contribution and lower labels are absolute contribution in $\mu g/m^3$.

Figure 44 *Relative contribution to daily surface $PM_{2.5}$ concentrations at 0-15 µg/m^3, 15-25 µg/m^3, and exceeding 25 µg/m^3 (2030 EU $PM_{2.5}$ daily limit) at stations BELAL01 (port) and BETR817 (city)*



"N" represents the number of days in each scenario within each concentration range.

Rotterdam

Figure 45 *Annual averaged total $PM_{2.5}$ surface concentrations in [µg/m^3] within the Rotterdam city core area in the 2023 base case (left) and 2030 BAU (right) scenarios*

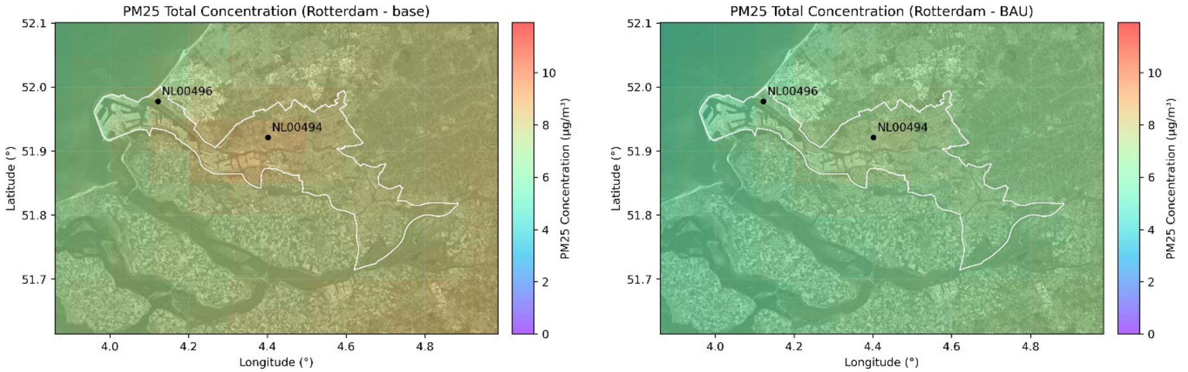


Figure 46 *Relative $PM_{2.5}$ shipping sector share [in %] within the Rotterdam city core area in the 2023 base case (left) and 2030 BAU (middle) scenarios, and difference in the $PM_{2.5}$ concentrations attributed to shipping between the 2030 BAU and 2023 base case scenarios*

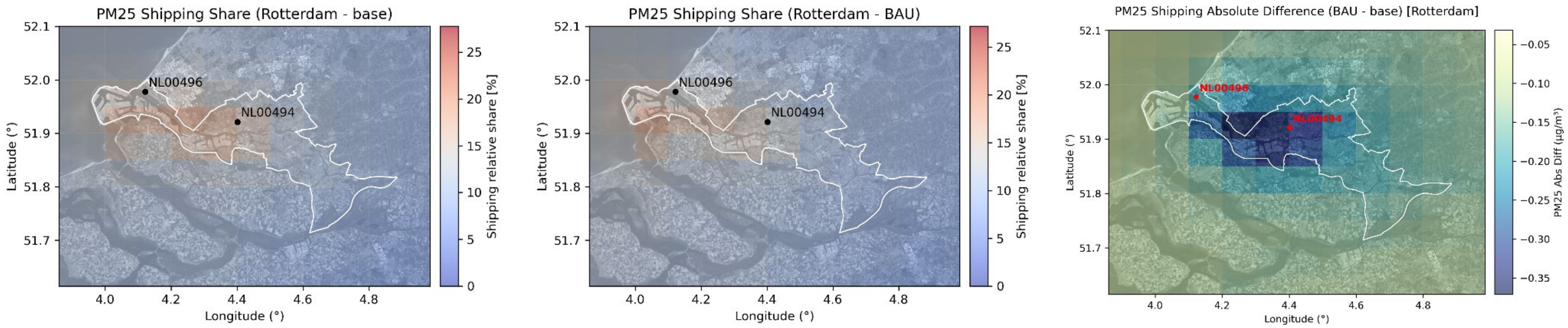
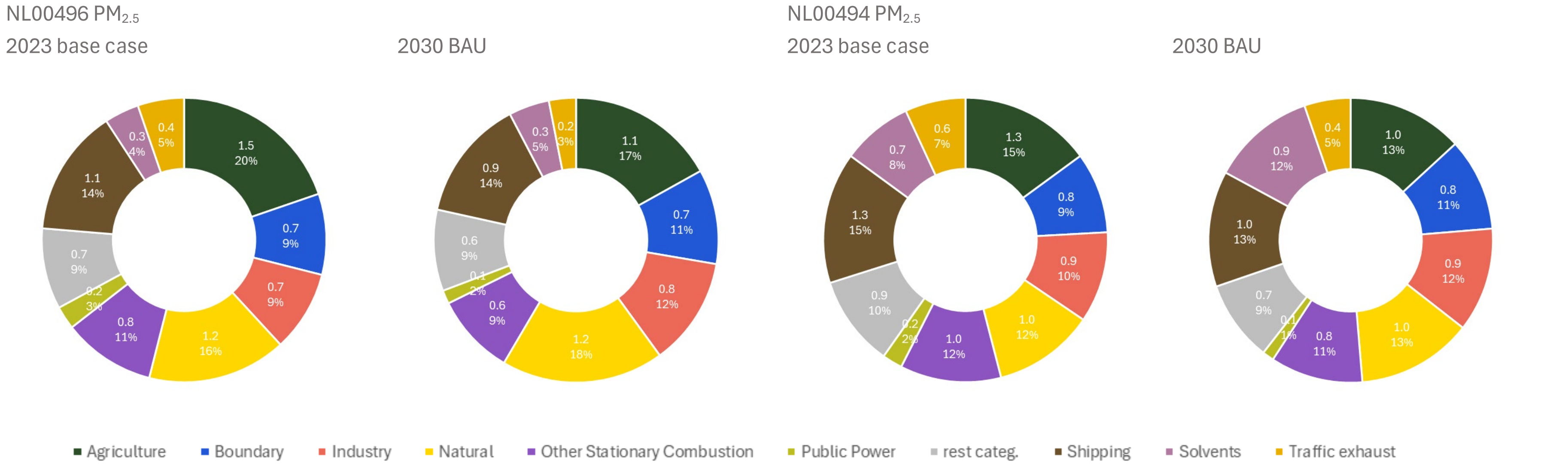
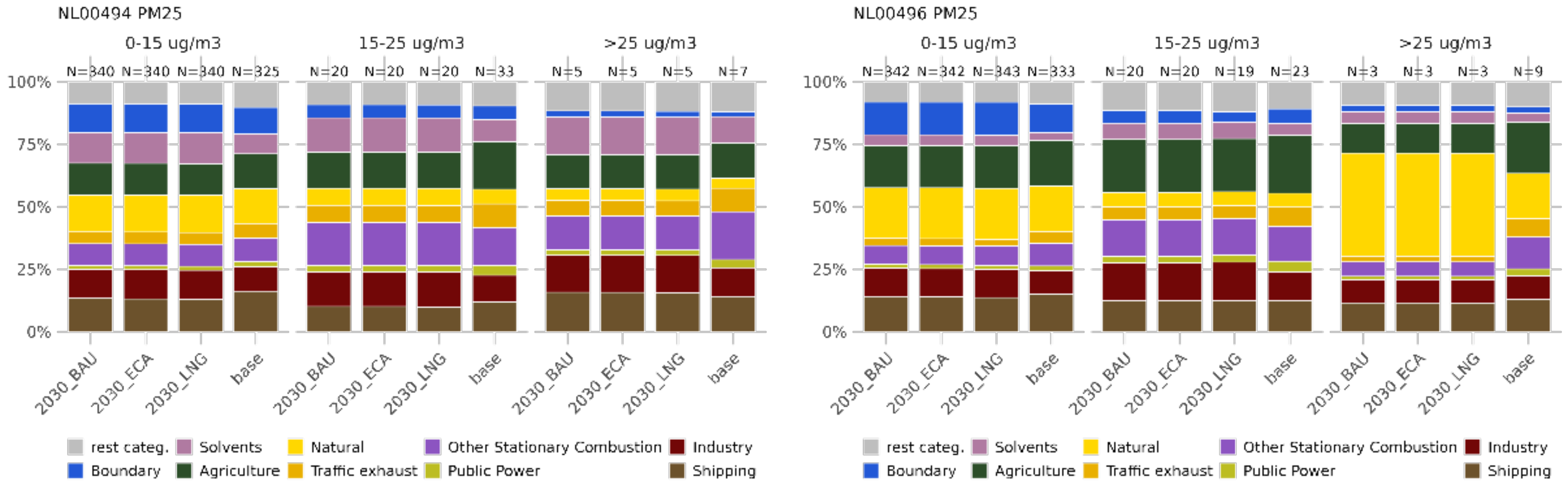


Figure 47 *Predicted $PM_{2.5}$ annual source apportionment results in Rotterdam at observation sites NL00496 (port) and NL00494 (city)*



The main contributing sectors are shown here, whereas the remaining sectors are grouped in the "rest categories". The top labels are relative contribution and the lower labels are absolute contribution in $\mu g/m^3$.

Figure 48 *Relative contribution to daily surface $PM_{2.5}$ concentrations at 0-15 µg/m^3, 15-25 µg/m^3, and exceeding 25 µg/m^3 (2030 EU $PM_{2.5}$ daily limit) at stations NL00494 (city) and NL00496 (port)*



"N" represents the number of days in each scenario within each concentration range.

Athens

Figure 49 *Annual averaged total $PM_{2.5}$ surface concentrations in [µg/m³] within the Athens [Athina] city core area in the 2023 base case (left) and 2030 BAU (right) scenarios*

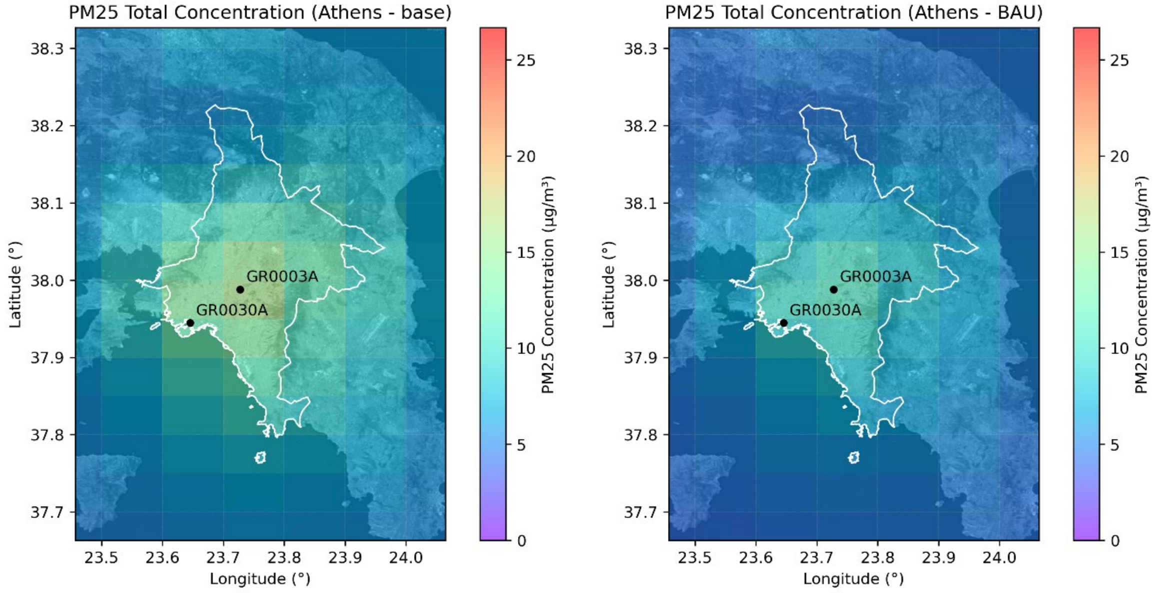


Figure 50 *Relative $PM_{2.5}$ shipping sector share [in %] within the Athens [Athina] city core area in the 2023 base case (left) and 2030 BAU (middle) scenarios, and difference in the $PM_{2.5}$ concentrations attributed to shipping between the 2030 BAU and 2023 base case scenarios*

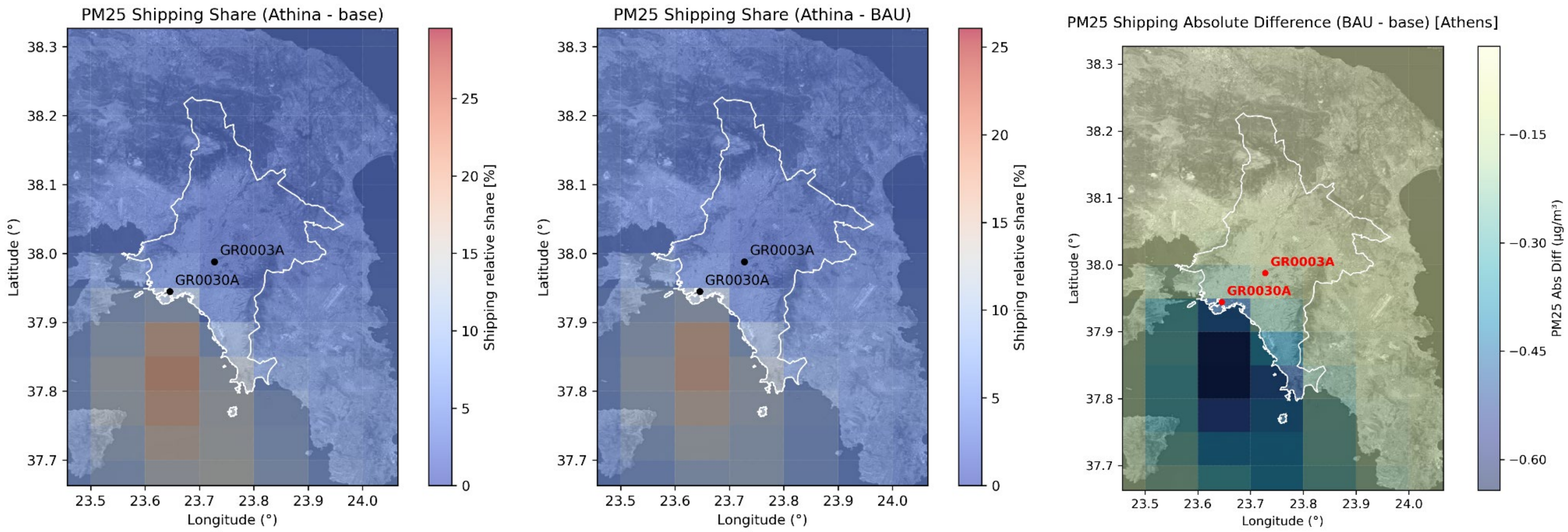
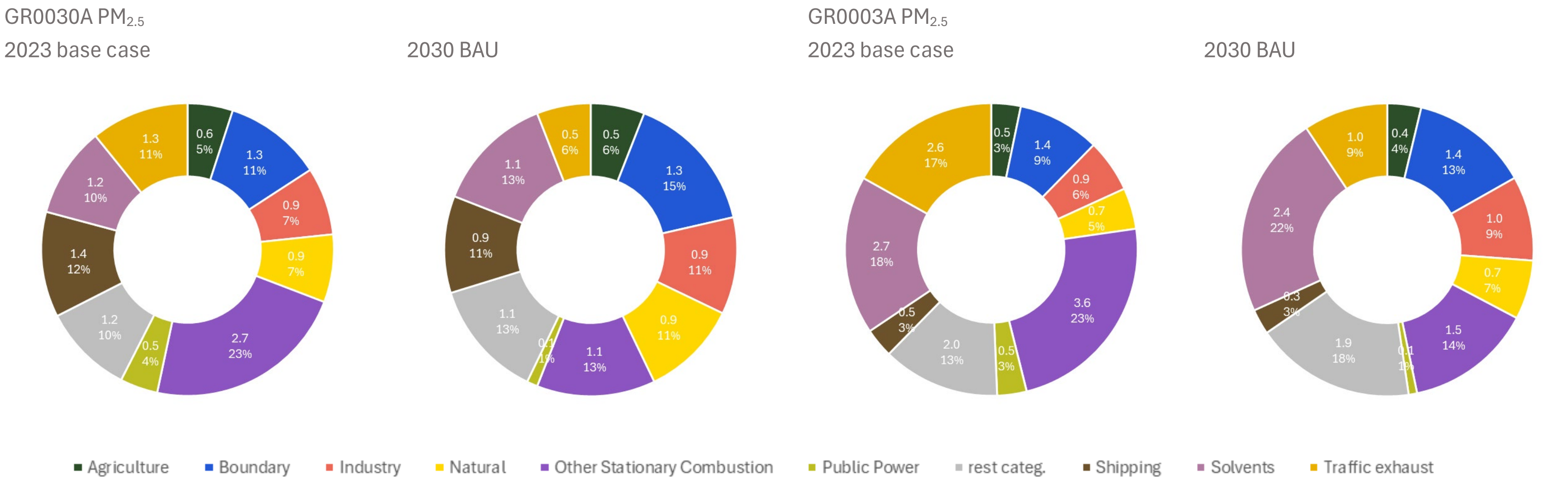
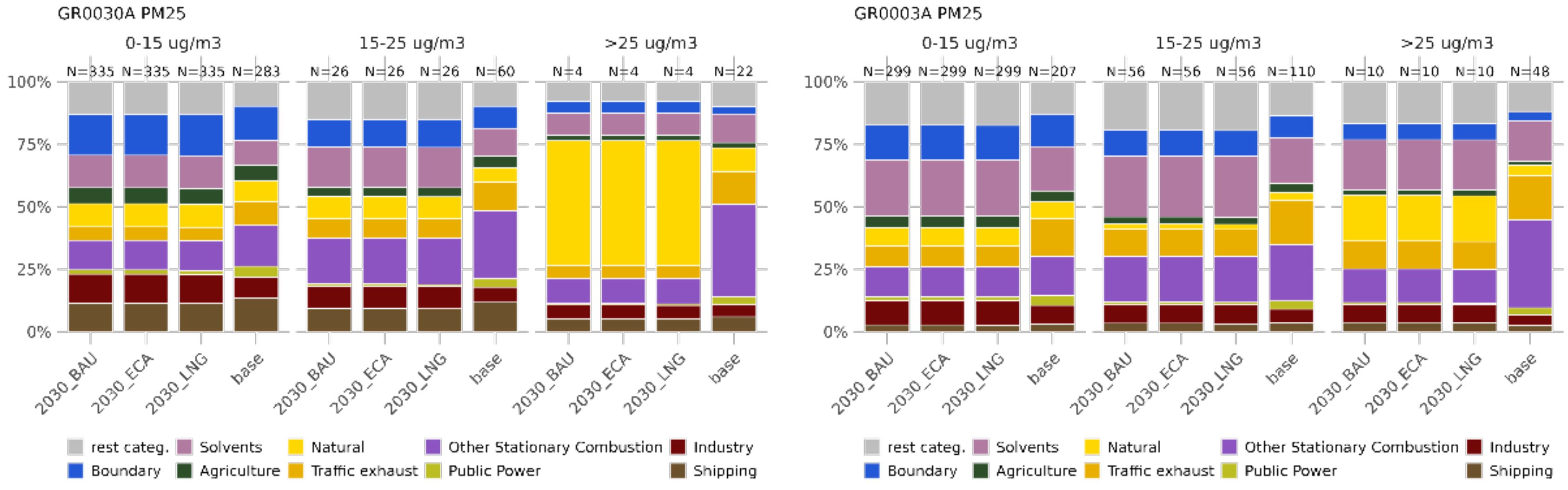


Figure 51 *Predicted annual $PM_{2.5}$ source apportionment results in Athens at observation sites GR0030A (port) and GR0003A (city centre)*



The main contributing sectors are shown here, whereas the remaining sectors are grouped in the "rest categories". The top labels are relative contribution and lower labels are absolute contribution in $\mu g/m^3$.

Figure 52 *Relative contribution to daily surface $PM_{2.5}$ concentrations at 0-15 µg/m^3, 15-25 µg/m^3, and exceeding 25 µg/m^3 (2030 EU $PM_{2.5}$ daily limit) at stations GR0030A (port) and GR0003A (city)*



"N" represents the number of days in each scenario within each concentration range.

Marseille

Figure 53 *Annual averaged total $PM_{2.5}$ surface concentrations in [µg/m^3] within the Marseille city core area in the 2023 base case (left) and 2030 BAU (right) scenarios*

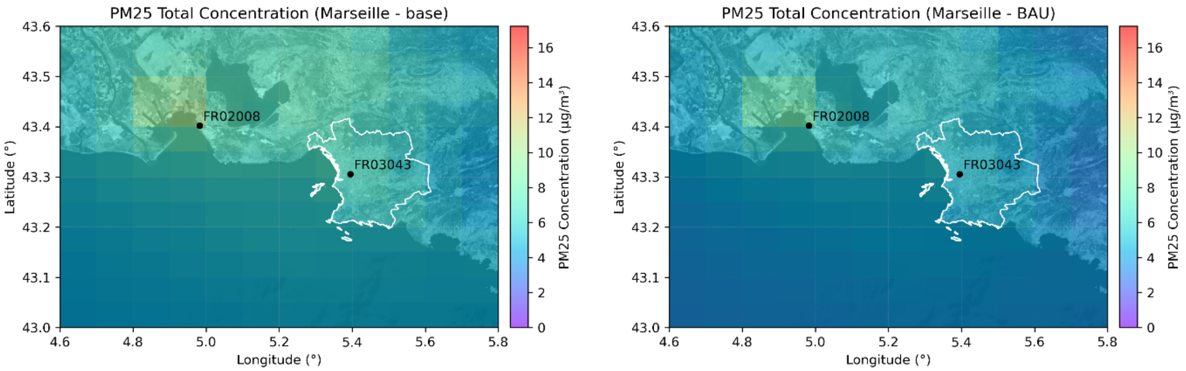


Figure 54 *Relative $PM_{2.5}$ shipping sector share [in %] within the Marseille city core area in the 2023 base case (left) and 2030 BAU (middle) scenarios, and difference in the $PM_{2.5}$ concentrations attributed to shipping between the 2030 BAU and 2023 base case scenarios*

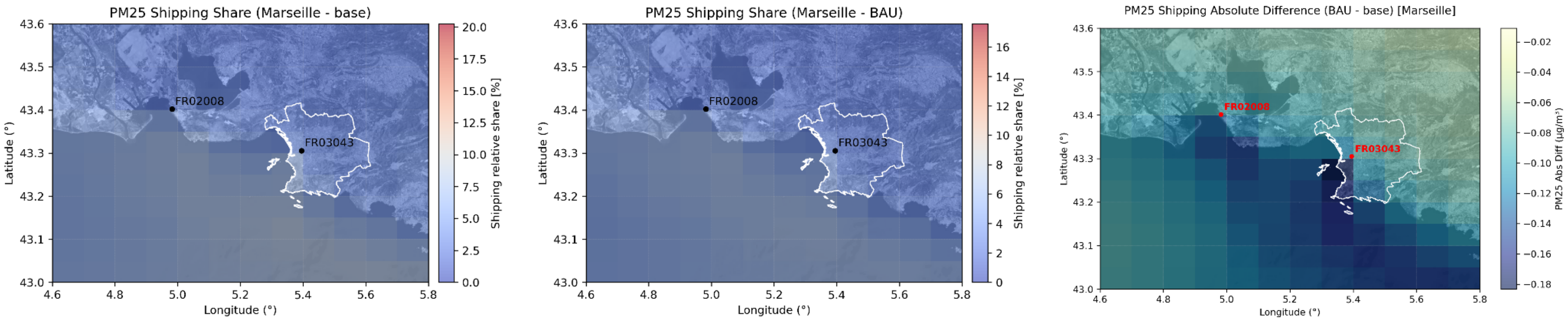
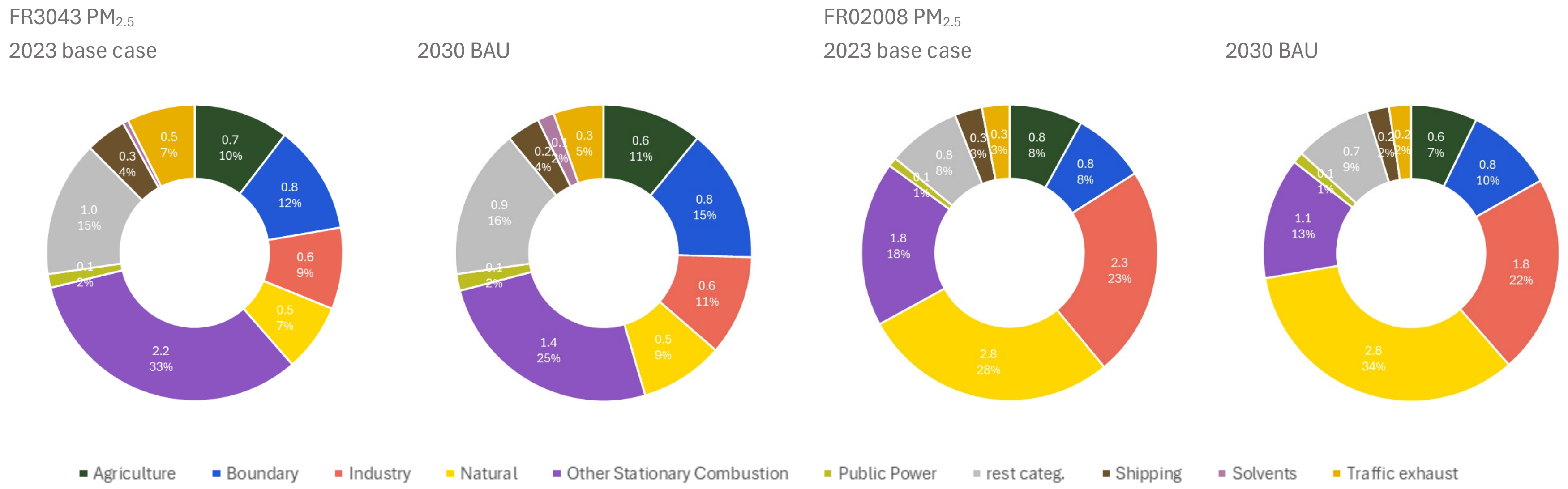
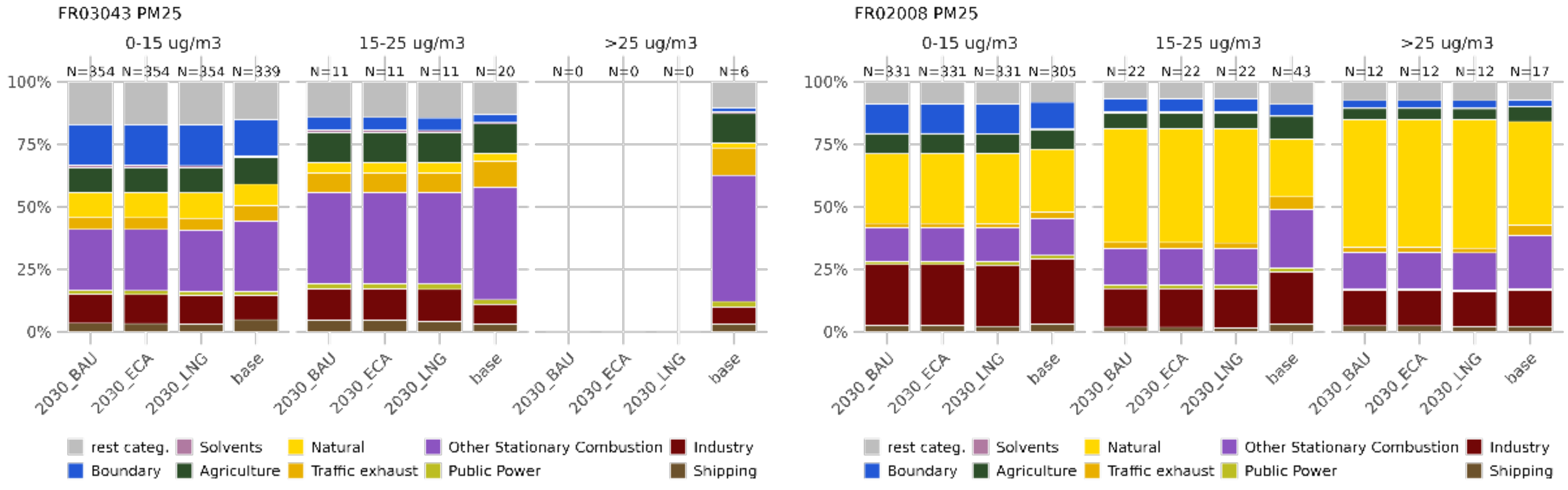


Figure 55 *Predicted $PM_{2.5}$ annual source apportionment results in Marseille at observation sites FR3043 (port) and FR02008 (city centre)*



The main contributing sectors are shown here, whereas the remaining sectors are grouped in the "rest categories". The top labels are relative contribution and lower labels are absolute contribution in µg/m^3.

Figure 56 *Relative contribution to daily surface $PM_{2.5}$ concentrations at 0-15 µg/m^3, 15-25 µg/m^3, and exceeding 25 µg/m^3 (2030 EU $PM_{2.5}$ daily limit) at stations FR03043 (port) and FR02008 (city)*

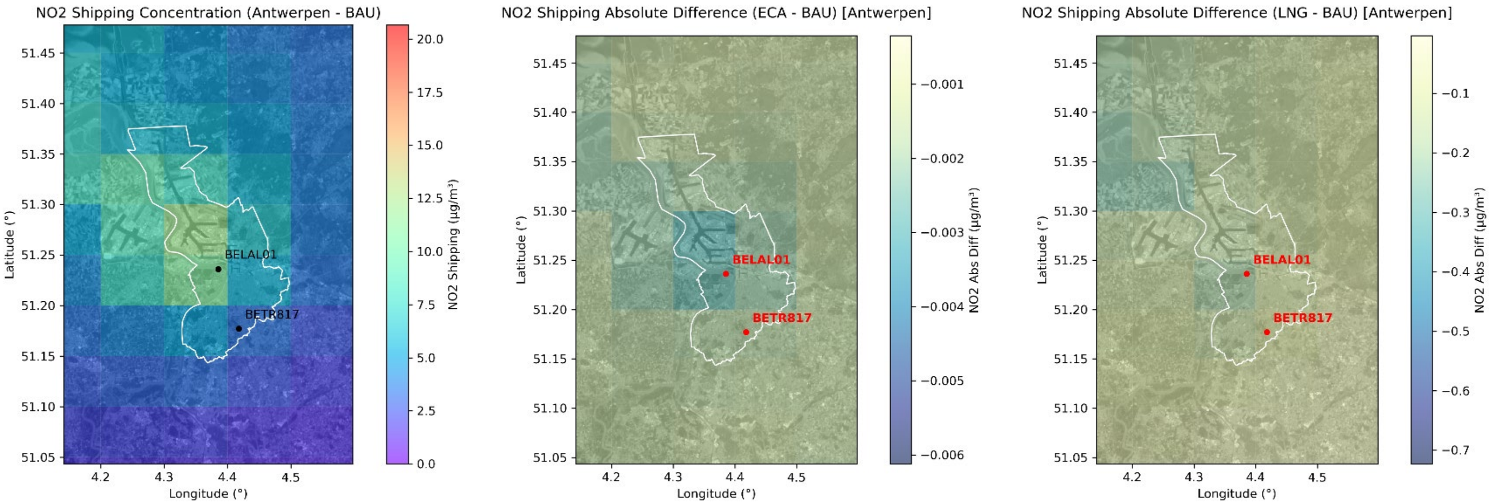


"N" represents the number of days in each scenario within each concentration range.

Differences between scenarios in each port city

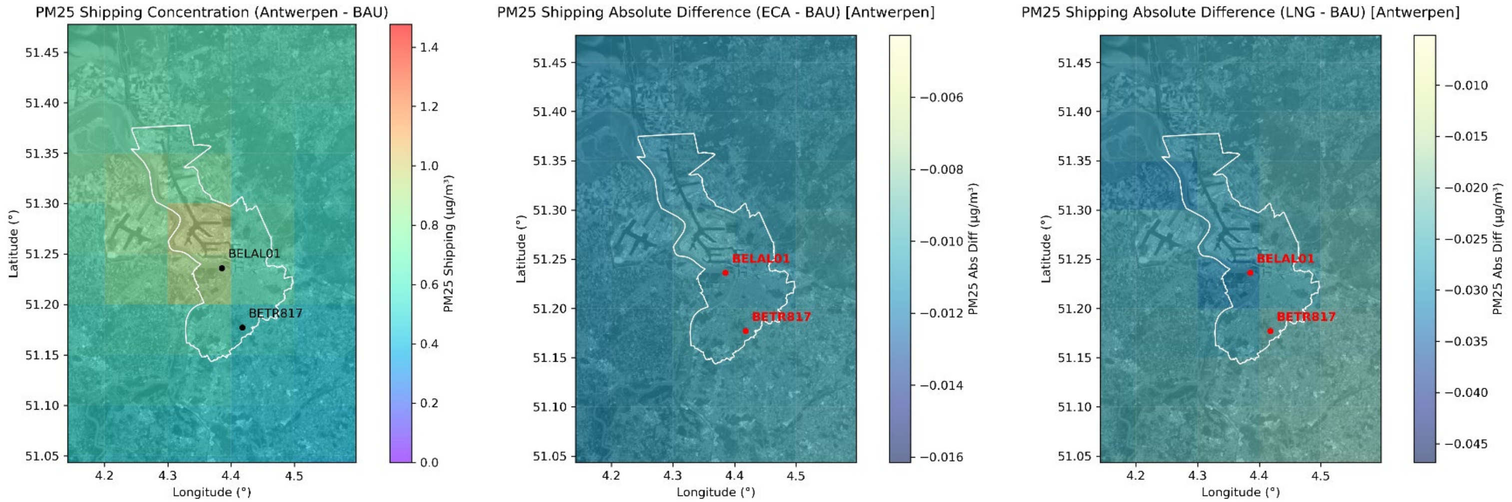
Antwerp

Figure 57 *Annual averaged shipping NO_2 surface concentrations in µg/m^3 (left) within the Antwerp city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



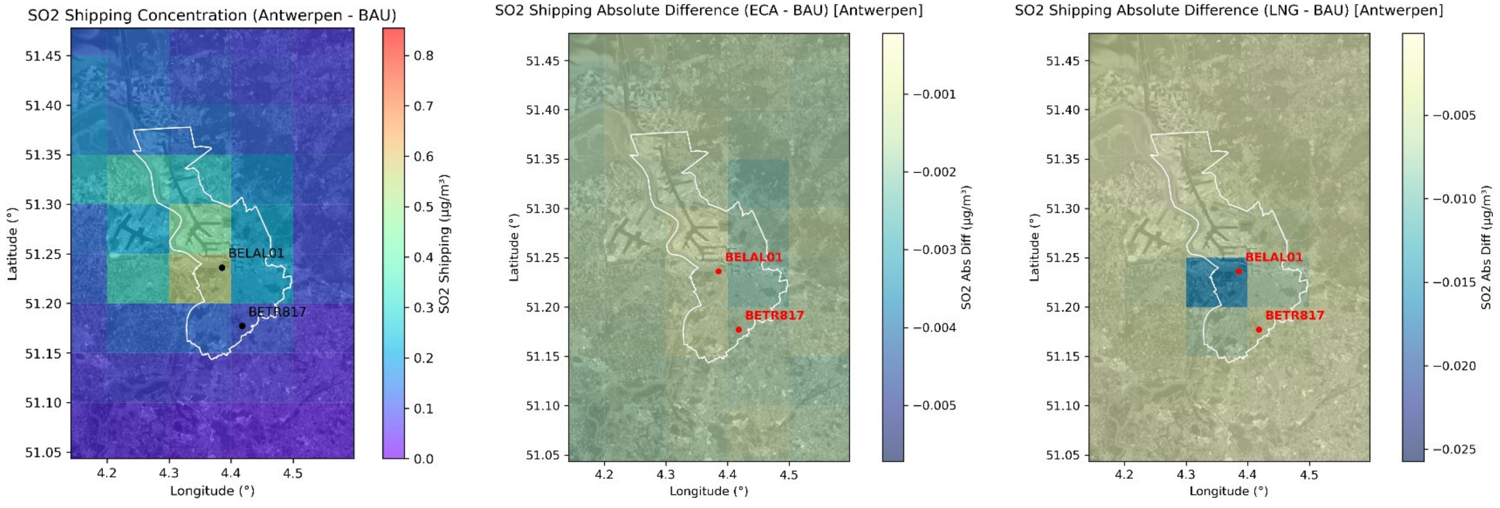
The city core area is highlighted in white. Observation stations marked as points.

Figure 58 *Annual averaged shipping $PM_{2.5}$ surface concentrations in µg/m³ (left) within the Antwerp city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

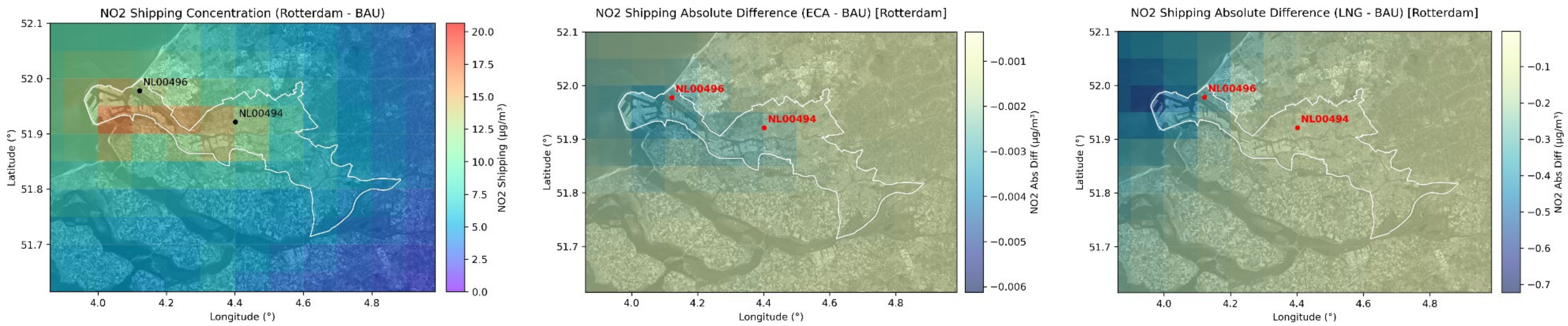
Figure 59 *Annual averaged shipping SO_2 surface concentrations in µg/m^3 (left) within the Antwerp city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

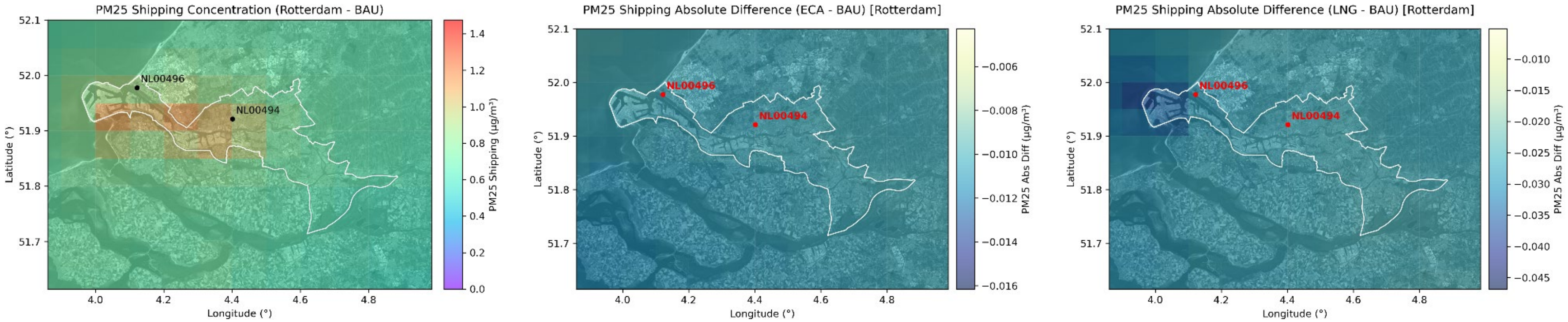
Rotterdam

Figure 60 *Annual averaged shipping NO_2 surface concentrations in µg/m^3 (left) within the Rotterdam city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



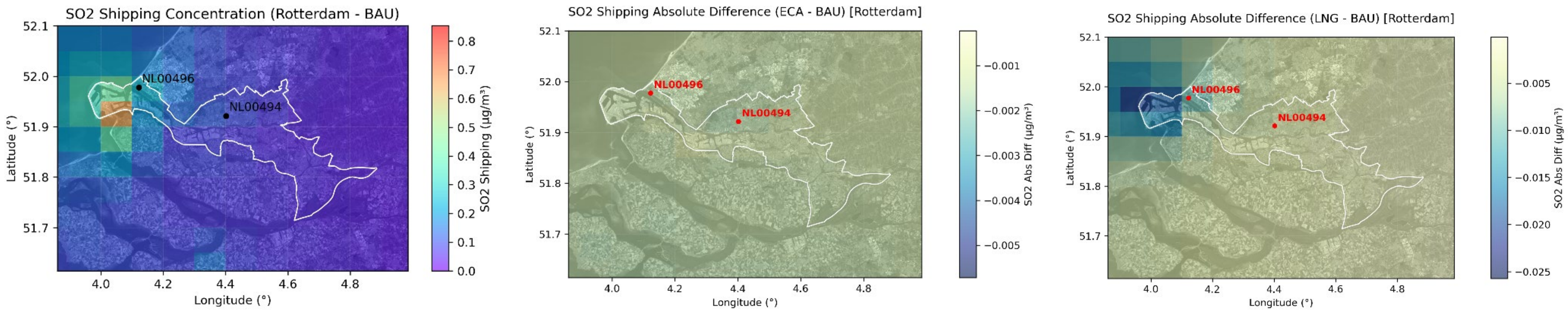
The city core area is highlighted in white. Observation stations marked as points.

Figure 61 *Annual averaged shipping $PM_{2.5}$ surface concentrations in µg/m^3 (left) within the Rotterdam city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

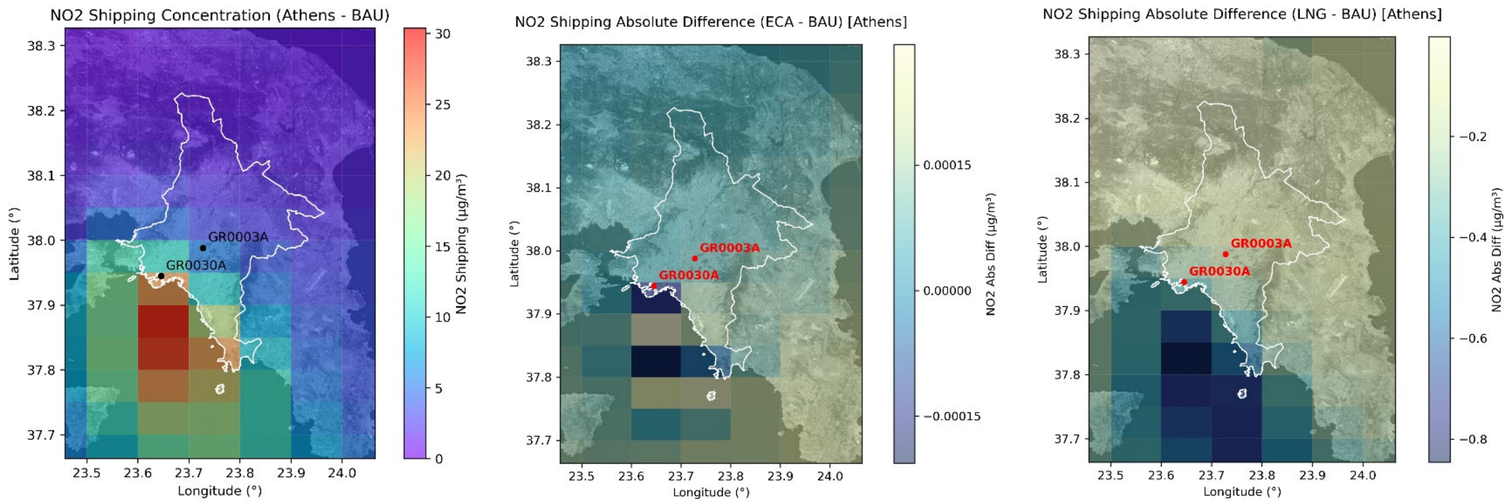
Figure 62 *Annual averaged shipping SO_2 surface concentrations in µg/m^3 (left) within the Rotterdam city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

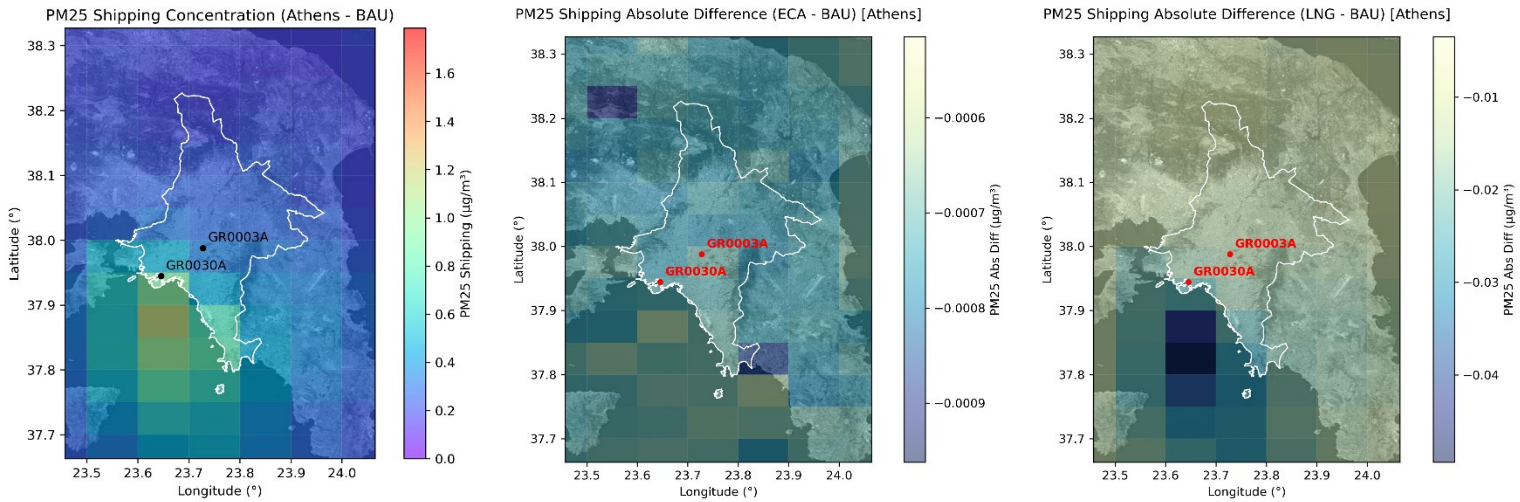
Athens

Figure 63 *Annual averaged shipping NO_2 surface concentrations in µg/m^3 (left) within the Athens city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



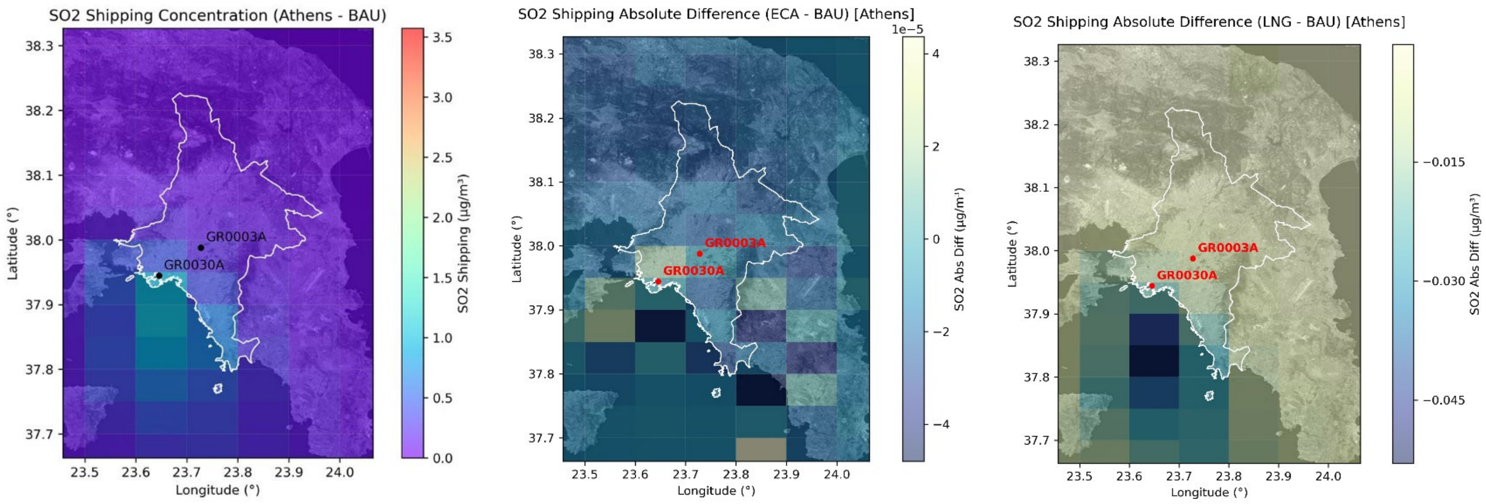
The city core area is highlighted in white. Observation stations marked as points.

Figure 64 *Annual averaged shipping $PM_{2.5}$ surface concentrations in µg/m^3 (left) within the Athens city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

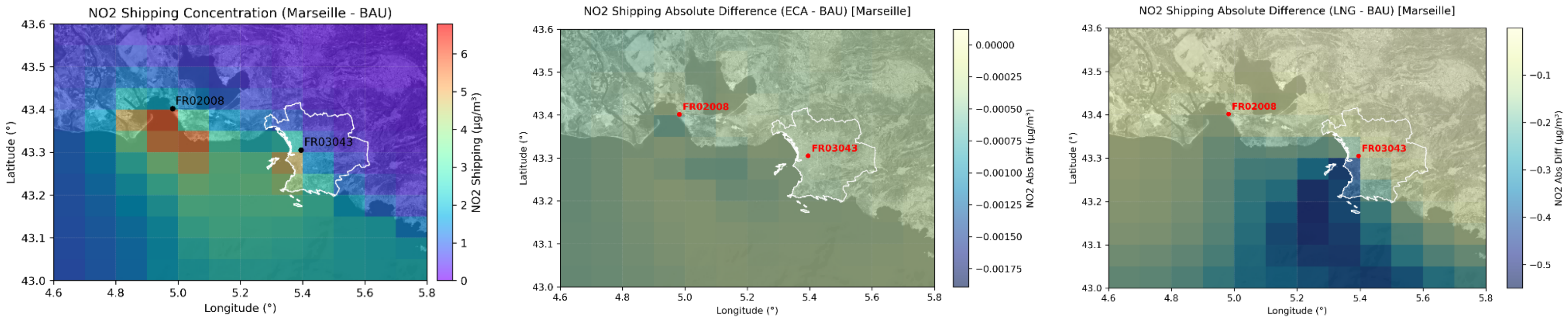
Figure 65 *Annual averaged shipping SO_2 surface concentrations in µg/m^3 (left) within the Athens city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

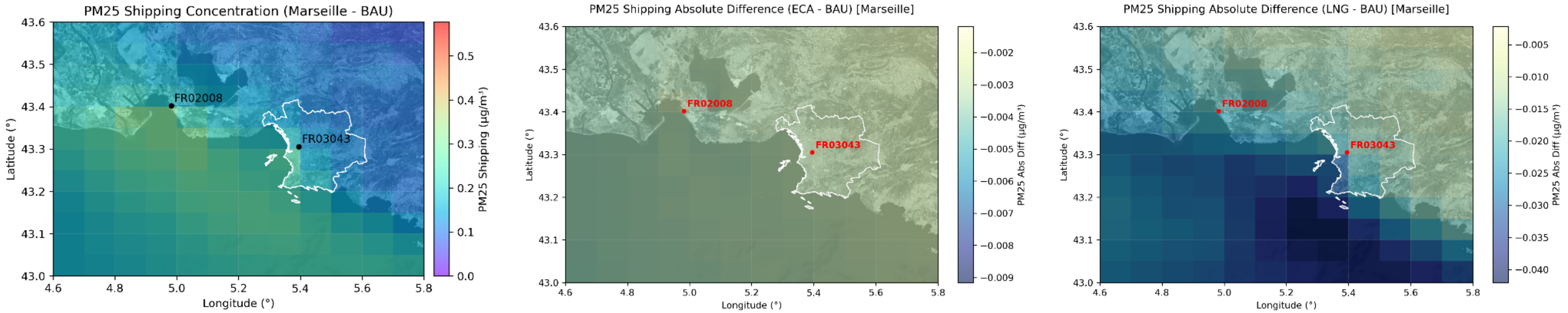
Marseille

Figure 66 *Annual averaged shipping NO_2 surface concentrations in µg/m^3 (left) within the Marseille city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



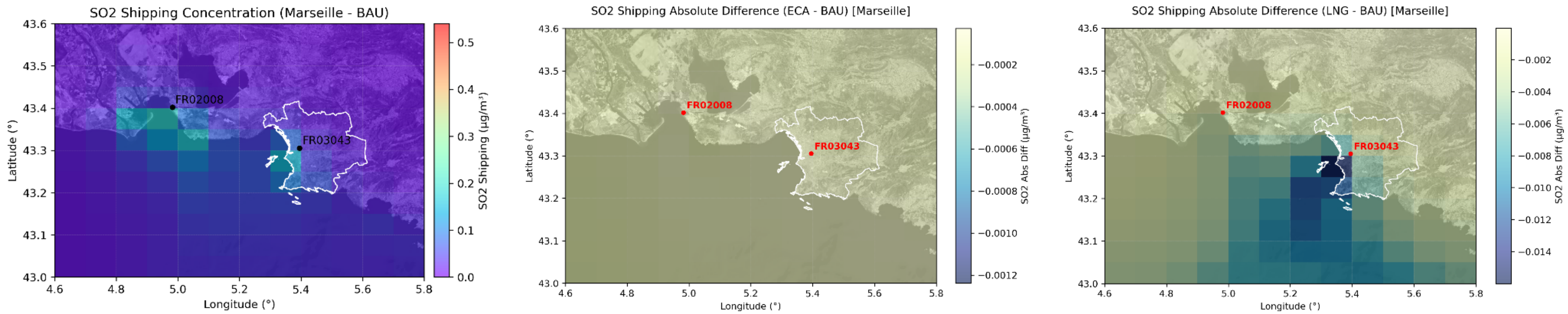
The city core area is highlighted in white. Observation stations marked as points.

Figure 67 *Annual averaged shipping $PM_{2.5}$ surface concentrations in µg/m^3 (left) within the Marseille city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

Figure 68 *Annual averaged shipping SO_2 surface concentrations in µg/m^3 (left) within the Marseille city core area, and predicted absolute concentration difference attributed to shipping between the 2030 all-EU ECA and the 2030 BAU scenarios (middle), and between the 2030 LNG and 2030 BAU scenarios (right)*



The city core area is highlighted in white. Observation stations marked as points.

Sectoral contribution to air pollutant concentrations within each city core area

Antwerp

Figure 69 *Annual relative contribution of aggregated sectors on NO_2 (left) and SO_2 (right) concentrations in Antwerp [Antwerpen] for the 2023 base case and the 2030 future scenarios*

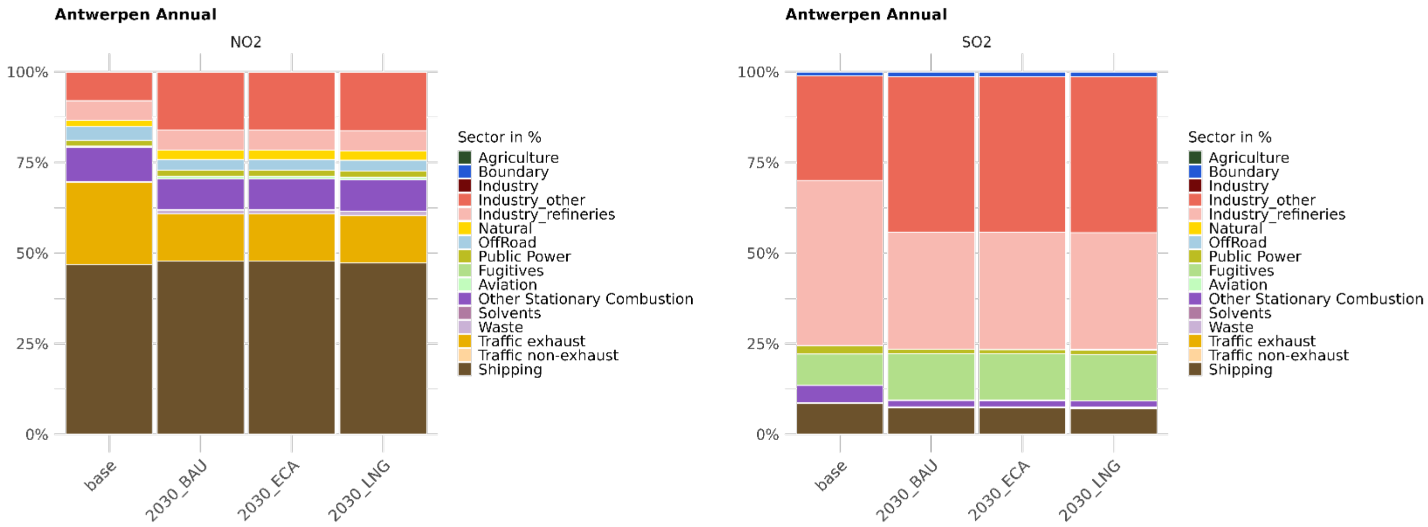
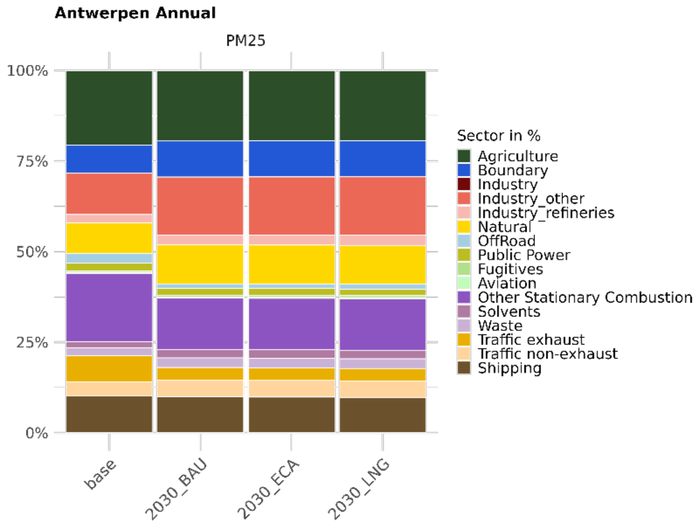
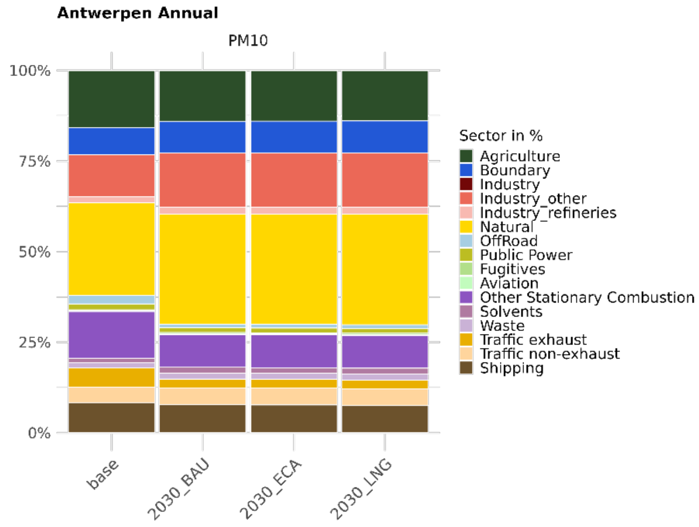


Figure 70 *Annual relative contribution of aggregated sectors on $PM_{2.5}$ (left) and PM_{10} (right) concentrations in Antwerp [Antwerpen] for the 2023 base case and the 2030 future scenarios*





Rotterdam

Figure 71 *Annual relative contribution of aggregated sectors on NO_2 (left) and SO_2 (right) concentrations in Rotterdam for the 2023 base case and the 2030 future scenarios*

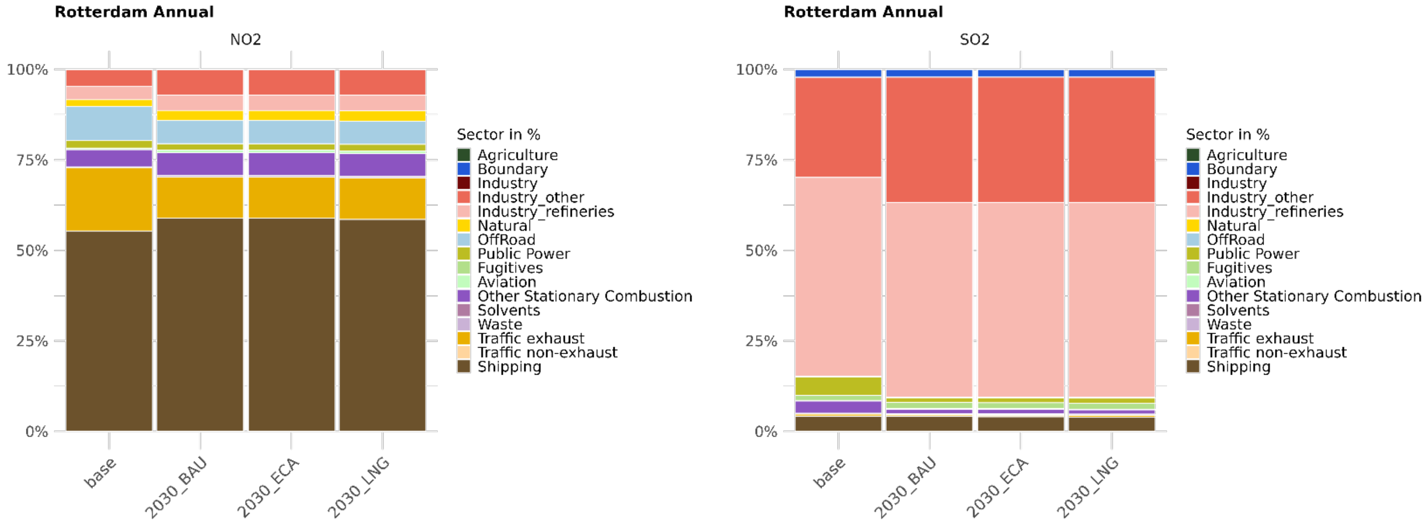
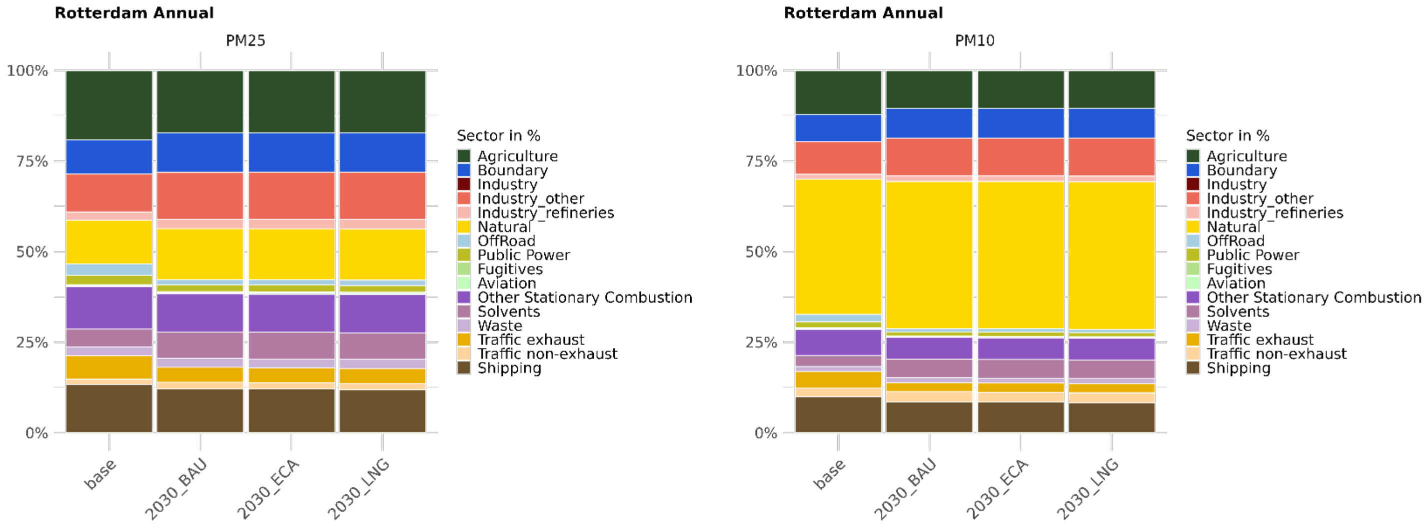
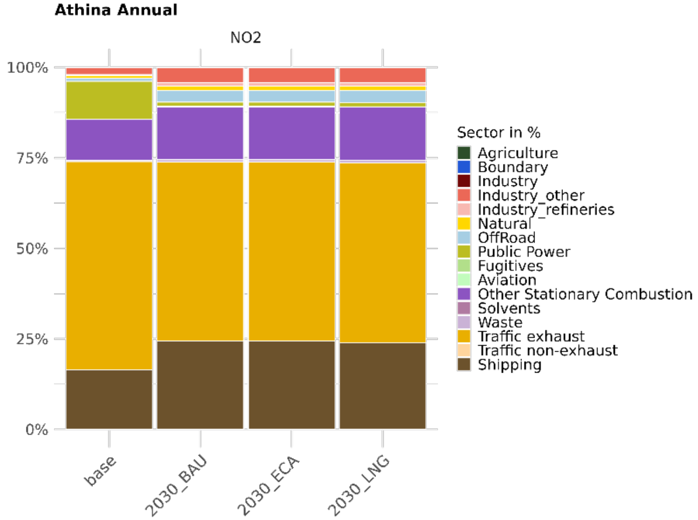


Figure 72 *Annual relative contribution of aggregated sectors on $PM_{2.5}$ (left) and PM_{10} (right) concentrations in Rotterdam for the 2023 base case and the 2030 future scenarios*



Athens

Figure 73 *Annual relative contribution of aggregated sectors on NO_2 (left) and SO_2 (right) concentrations in Athens [Athina] for the 2023 base case and the 2030 future scenarios*



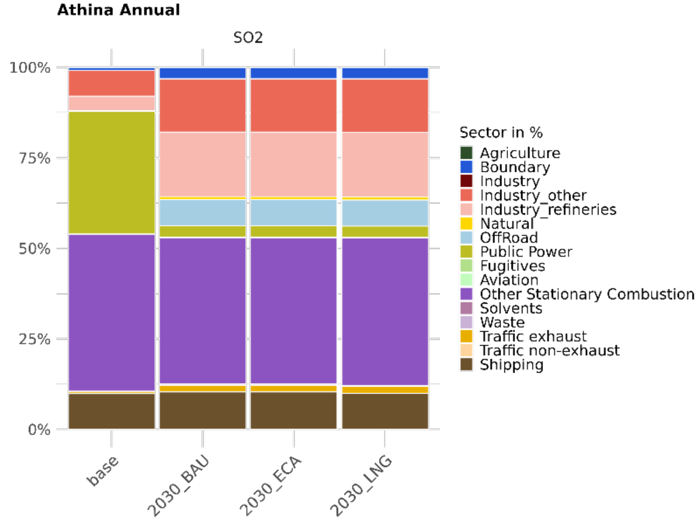
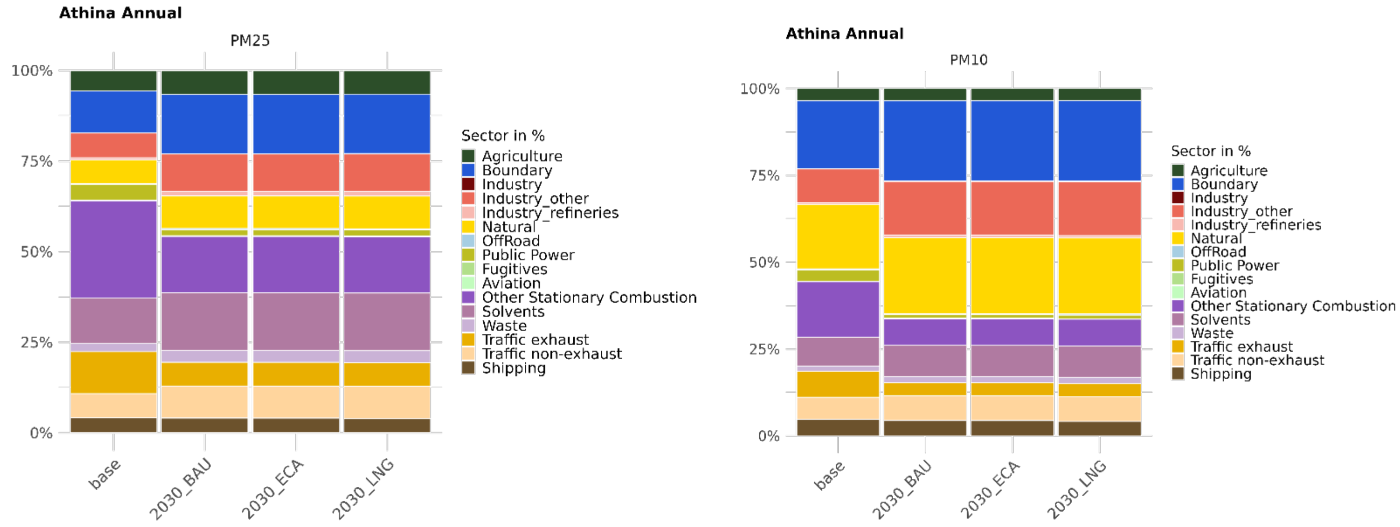


Figure 74 *Annual relative contribution of aggregated sectors on $PM_{2.5}$ (left) and PM_{10} (right) concentrations in Athens [Athina] for the 2023 base case and the 2030 future scenarios*



Marseille

Figure 75 *Annual relative contribution of aggregated sectors on NO_2 (left) and SO_2 (right) concentrations in Marseille for the 2023 base case and the 2030 future scenarios*

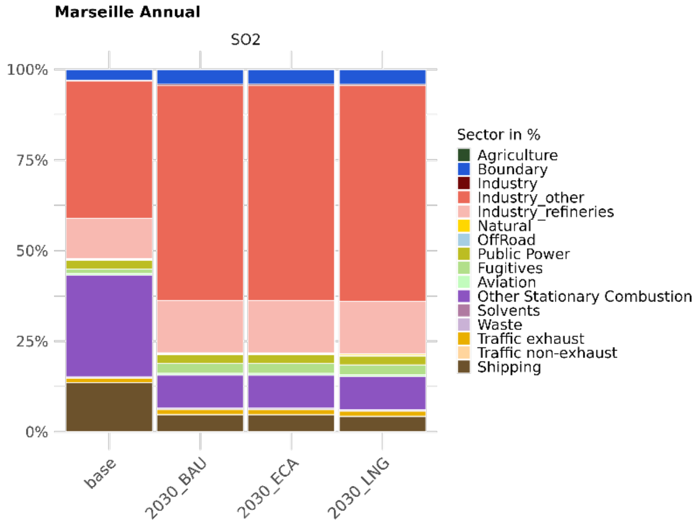
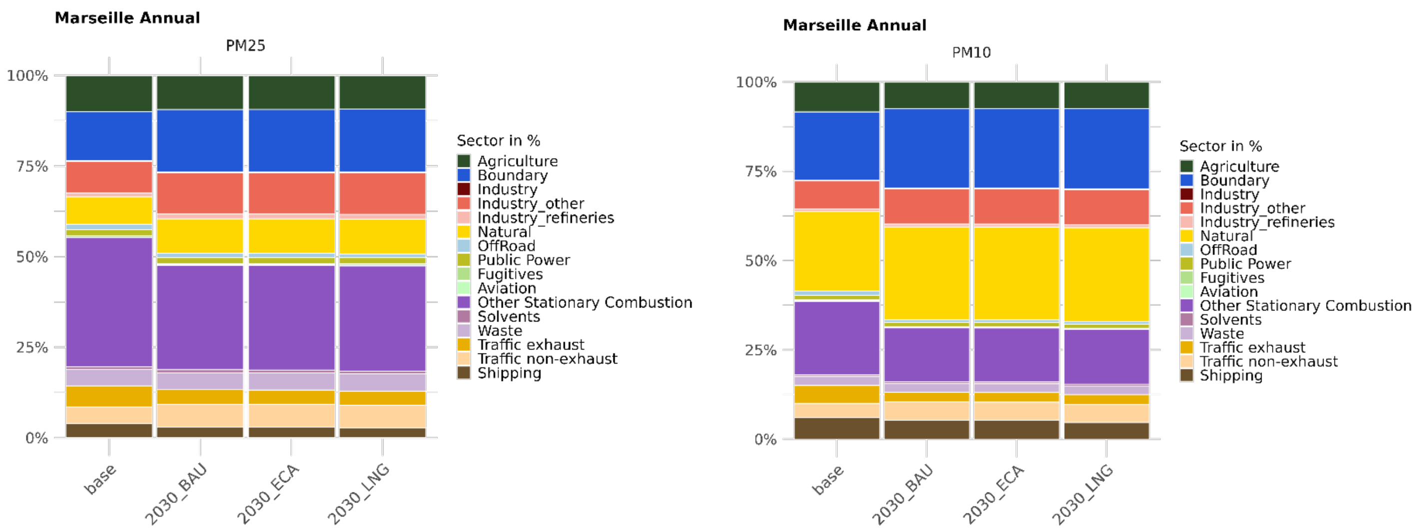


Figure 76 *Annual relative contribution of aggregated sectors on $PM_{2.5}$ (left) and PM_{10} (right) concentrations in Marseille for the 2023 base case and the 2030 future scenarios*



B3 TABLES FOR ALL PORT AREAS

Antwerp

Table 17 *Predicted annual average NO_2 concentrations per sector (in $\mu g/m^3$) in Antwerp*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	0.09	0.11	0.11	0.11
Boundary	0.01	0.01	0.01	0.01
Fugitives	0.02	0.01	0.01	0.01
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	2.01	2.73	2.73	2.73
Industry refineries	1.38	0.95	0.95	0.95
Natural	0.42	0.43	0.43	0.43
Off road	0.98	0.50	0.50	0.50
Other stationary combustion	2.38	1.46	1.46	1.46
Public power	0.41	0.29	0.29	0.29
Road transport exhaust diesel	5.59	2.05	2.06	2.05
Road transport exhaust gasoline	0.20	0.16	0.16	0.16
Road transport exhaust LPG gas	0.01	0.02	0.02	0.02
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	11.93	8.16	8.01	8.15
Solvents	0.01	0.01	0.01	0.01
aste	0.04	0.19	0.19	0.19
Total (sum)	**25.47**	**17.09**	**16.95**	**17.09**
Shipping contribution	**46.83%**	**47.72%**	**47.24%**	**47.71%**

Table 18 *Predicted annual average $PM_{2.5}$ concentrations per sector (in $\mu g/m^3$) in Antwerp*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	0.96	0.72	0.71	0.72
Agricultural other	1.02	0.76	0.75	0.76
Aviation	0.03	0.03	0.03	0.03
Boundary	0.75	0.75	0.75	0.75
Fugitives	0.03	0.04	0.04	0.04
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	1.09	1.22	1.22	1.22
Industry refineries	0.22	0.21	0.21	0.21
Natural	0.82	0.81	0.81	0.81
Off road	0.25	0.10	0.10	0.10
Other stationary combustion	1.82	1.08	1.08	1.08
Public power	0.22	0.14	0.14	0.14
Road transport exhaust diesel	0.61	0.20	0.20	0.20
Road transport exhaust gasoline	0.08	0.06	0.06	0.06
Road transport exhaust LPG gas	< 0.01	0.01	0.01	0.01
Road transport non-exhaust	0.38	0.35	0.35	0.35
Shipping	0.97	0.76	0.73	0.75
Solvents	0.17	0.17	0.17	0.17
Waste	0.21	0.20	0.20	0.20
Total (sum)	**9.62**	**7.61**	**7.56**	**7.58**
Shipping contribution	**10.09%**	**9.96%**	**9.66%**	**9.85%**

Table 19 *Predicted annual average SO_2 concentrations per sector (in µg/m^3) in Antwerp*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	< 0.01	0.01	0.01	0.01
Boundary	0.06	0.05	0.05	0.05
Fugitives	0.47	0.56	0.56	0.56
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	1.56	1.87	1.87	1.87
Industry refineries	2.47	1.40	1.40	1.40
Natural	< 0.01	< 0.01	< 0.01	< 0.01
Off road	< 0.01	< 0.01	< 0.01	< 0.01
Other stationary combustion	0.25	0.07	0.07	0.07
Public power	0.12	0.05	0.05	0.05
Road transport exhaust diesel	0.01	0.01	0.01	0.01
Road transport exhaust gasoline	< 0.01	< 0.01	< 0.01	< 0.01
Road transport exhaust LPG gas	< 0.01	< 0.01	< 0.01	< 0.01
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	0.46	0.32	0.31	0.32
Solvents	< 0.01	< 0.01	< 0.01	< 0.01
Waste	< 0.01	< 0.01	< 0.01	< 0.01
Total (sum)	**5.41**	**4.35**	**4.34**	**4.35**
Shipping contribution	**8.45%**	**7.28%**	**7.12%**	**7.25%**

Table 20 *Predicted annual average PM_{10} concentrations per sector (in $\mu g/m^3$) in Antwerp*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	1.21	0.89	0.88	0.89
Agricultural other	1.08	0.82	0.81	0.82
Aviation	0.03	0.03	0.03	0.03
Boundary	1.08	1.08	1.08	1.08
Fugitives	0.04	0.04	0.04	0.04
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	1.68	1.82	1.83	1.82
Industry refineries	0.24	0.23	0.23	0.23
Natural	3.72	3.72	3.72	3.72
Off road	0.33	0.13	0.13	0.13
Other stationary combustion	1.86	1.10	1.10	1.10
Public power	0.24	0.16	0.16	0.16
Road transport exhaust diesel	0.69	0.23	0.23	0.23
Road transport exhaust gasoline	0.09	0.06	0.06	0.06
Road transport exhaust LPG gas	< 0.01	0.01	0.01	0.01
Road transport non-exhaust	0.62	0.57	0.57	0.57
Shipping	1.21	0.95	0.91	0.94
Solvents	0.17	0.19	0.19	0.19
Waste	0.21	0.20	0.20	0.20
Total (sum)	**14.50**	**12.24**	**12.18**	**12.21**
Shipping contribution	**8.34%**	**7.78%**	**7.49%**	**7.68%**

Rotterdam

Table 21 *Predicted annual average NO_2 concentrations per sector (in µg/m^3) in Rotterdam*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	0.10	0.12	0.12	0.12
Boundary	0.01	0.01	0.01	0.01
Fugitives	< 0.01	< 0.01	< 0.01	< 0.01
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	1.09	1.15	1.15	1.15
Industry refineries	0.85	0.70	0.70	0.70
Natural	0.43	0.46	0.46	0.46
Off road	2.17	1.05	1.05	1.05
Other stationary combustion	1.12	1.01	1.01	1.01
Public power	0.50	0.30	0.30	0.30
Road transport exhaust diesel	3.65	1.48	1.48	1.48
Road transport exhaust gasoline	0.39	0.30	0.30	0.30
Road transport exhaust LPG gas	0.02	0.09	0.09	0.09
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	12.90	9.65	9.49	9.65
Solvents	0.02	0.02	0.02	0.02
Waste	0.02	0.05	0.05	0.05
Total (sum)	**23.29**	**16.38**	**16.22**	**16.38**
Shipping contribution	**55.38%**	**58.94%**	**58.54%**	**58.93%**

Table 22 *Predicted annual average $PM_{2.5}$ concentrations per sector (in µg/m^3) in Rotterdam*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	0.68	0.54	0.54	0.54
Agricultural other	0.86	0.65	0.64	0.65
Aviation	0.03	0.03	0.03	0.03
Boundary	0.75	0.75	0.75	0.75
Fugitives	0.02	0.02	0.02	0.02
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	0.84	0.89	0.89	0.89
Industry refineries	0.18	0.18	0.18	0.18
Natural	0.97	0.97	0.97	0.97
Off road	0.26	0.10	0.10	0.10
Other stationary combustion	0.94	0.72	0.72	0.72
Public power	0.20	0.13	0.13	0.13
Road transport exhaust diesel	0.42	0.18	0.18	0.18
Road transport exhaust gasoline	0.10	0.09	0.09	0.09
Road transport exhaust LPG gas	< 0.01	0.01	0.01	0.01
Road transport non-exhaust	0.12	0.12	0.12	0.12
Shipping	1.07	0.84	0.81	0.83
Solvents	0.40	0.51	0.51	0.51
Waste	0.19	0.17	0.17	0.17
Total (sum)	**8.03**	**6.90**	**6.86**	**6.88**
Shipping contribution	**13.32%**	**12.16%**	**11.85%**	**12.05%**

Table 23 *Predicted annual average SO_2 concentrations per sector (in µg/m^3) in Rotterdam*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	0.01	0.01	0.01	0.01
Boundary	0.06	0.06	0.06	0.06
Fugitives	0.04	0.04	0.04	0.04
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	0.74	0.91	0.91	0.91
Industry refineries	1.47	1.41	1.41	1.41
Natural	< 0.01	< 0.01	< 0.01	< 0.01
Off road	< 0.01	< 0.01	< 0.01	< 0.01
Other stationary combustion	0.09	0.03	0.03	0.03
Public power	0.13	0.03	0.03	0.03
Road transport exhaust diesel	0.01	0.01	0.01	0.01
Road transport exhaust gasoline	< 0.01	< 0.01	< 0.01	< 0.01
Road transport exhaust LPG gas	< 0.01	< 0.01	< 0.01	< 0.01
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	0.11	0.11	0.10	0.11
Solvents	< 0.01	0.01	0.01	0.01
Waste	< 0.01	< 0.01	< 0.01	< 0.01
Total (sum)	**2.67**	**2.62**	**2.61**	**2.62**
Shipping contribution	**4.23%**	**4.08%**	**3.91%**	**4.04%**

Table 24 *Predicted annual average PM_{10} concentrations per sector (in $\mu g/m^3$) in Rotterdam*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	0.76	0.63	0.62	0.62
Agricultural other	0.91	0.69	0.68	0.69
Aviation	0.03	0.03	0.03	0.03
Boundary	1.02	1.02	1.02	1.02
Fugitives	0.02	0.02	0.02	0.02
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	1.24	1.32	1.32	1.32
Industry refineries	0.19	0.19	0.19	0.19
Natural	5.11	5.11	5.10	5.10
Off road	0.29	0.12	0.12	0.12
Other stationary combustion	0.98	0.75	0.75	0.75
Public power	0.23	0.15	0.15	0.15
Road transport exhaust diesel	0.50	0.21	0.21	0.21
Road transport exhaust gasoline	0.11	0.09	0.09	0.09
Road transport exhaust LPG gas	< 0.01	0.01	0.01	0.01
Road transport non-exhaust	0.35	0.34	0.34	0.34
Shipping	1.35	1.07	1.03	1.06
Solvents	0.43	0.64	0.64	0.64
Waste	0.19	0.17	0.17	0.17
Total (sum)	**13.73**	**12.58**	**12.52**	**12.55**
Shipping contribution	**9.87%**	**8.54%**	**8.26%**	**8.45%**

Athens

Table 25 *Predicted annual average NO_2 concentrations per sector (in µg/m^3) in Athens*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	0.04	0.03	0.03	0.03
Boundary	0.01	0.01	0.01	0.01
Fugitives	< 0.01	< 0.01	< 0.01	< 0.01
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	0.71	0.98	0.98	0.98
Industry refineries	0.12	0.22	0.22	0.22
Natural	0.26	0.27	0.27	0.27
Off road	0.33	0.76	0.76	0.76
Other stationary combustion	4.13	3.37	3.38	3.37
Public power	3.87	0.27	0.27	0.27
Road transport exhaust diesel	17.01	9.31	9.32	9.31
Road transport exhaust gasoline	3.93	1.86	1.86	1.86
Road transport exhaust LPG gas	0.35	0.36	0.36	0.36
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	6.07	5.68	5.53	5.68
Solvents	0.02	0.03	0.03	0.03
Waste	0.13	0.15	0.15	0.15
Total (sum)	**36.98**	**23.31**	**23.17**	**23.31**
Shipping contribution	**16.43%**	**24.38%**	**23.85%**	**24.38%**

Table 26 *Predicted annual average $PM_{2.5}$ concentrations per sector (in $\mu g/m^3$) in Athens*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	0.24	0.21	0.21	0.21
Agricultural other	0.42	0.33	0.33	0.33
Aviation	< 0.01	< 0.01	< 0.01	< 0.01
Boundary	1.37	1.36	1.36	1.36
Fugitives	0.02	0.02	0.02	0.02
Industry	0.01	0.01	0.01	0.01
Industry other	0.80	0.86	0.86	0.86
Industry refineries	0.08	0.10	0.10	0.10
Natural	0.75	0.75	0.75	0.75
Off road	0.04	0.03	0.03	0.03
Other stationary combustion	3.18	1.30	1.30	1.30
Public power	0.50	0.13	0.13	0.13
Road transport exhaust diesel	1.05	0.37	0.37	0.37
Road transport exhaust gasoline	0.30	0.16	0.16	0.16
Road transport exhaust LPG gas	0.02	0.01	0.01	0.01
Road transport non-exhaust	0.79	0.74	0.74	0.74
Shipping	0.49	0.34	0.32	0.34
Solvents	1.46	1.32	1.32	1.32
Waste	0.28	0.28	0.28	0.28
Total (sum)	**11.79**	**8.34**	**8.32**	**8.34**
Shipping contribution	**4.12%**	**4.05%**	**3.87%**	**4.04%**

Table 27 *Predicted annual average SO_2 concentrations per sector (in $\mu g/m^3$) in Athens*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	< 0.01	< 0.01	< 0.01	< 0.01
Boundary	0.06	0.06	0.06	0.06
Fugitives	< 0.01	< 0.01	< 0.01	< 0.01
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	0.53	0.29	0.29	0.29
Industry refineries	0.30	0.36	0.36	0.36
Natural	0.02	0.02	0.02	0.02
Off road	< 0.01	0.14	0.14	0.14
Other stationary combustion	3.27	0.81	0.81	0.81
Public power	2.55	0.06	0.06	0.06
Road transport exhaust diesel	0.02	0.02	0.02	0.02
Road transport exhaust gasoline	0.02	0.01	0.01	0.01
Road transport exhaust LPG gas	< 0.01	< 0.01	< 0.01	< 0.01
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	0.74	0.21	0.20	0.21
Solvents	< 0.01	< 0.01	< 0.01	< 0.01
Waste	0.01	0.01	0.01	0.01
Total (sum)	**7.53**	**2.00**	**1.99**	**2.00**
Shipping contribution	**9.87%**	**10.34%**	**10.00%**	**10.34%**

Table 28 *Predicted annual average PM_{10} concentrations per sector (in $\mu g/m^3$) in Athens*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	0.26	0.23	0.23	0.23
Agricultural other	0.46	0.38	0.37	0.38
Aviation	0.01	0.01	0.01	0.01
Boundary	3.98	3.98	3.98	3.98
Fugitives	0.02	0.02	0.02	0.02
Industry	0.02	0.02	0.02	0.02
Industry other	1.99	2.67	2.67	2.67
Industry refineries	0.10	0.12	0.12	0.12
Natural	3.77	3.76	3.76	3.76
Off road	0.07	0.05	0.05	0.05
Other stationary combustion	3.26	1.33	1.33	1.33
Public power	0.66	0.18	0.18	0.18
Road transport exhaust diesel	1.20	0.45	0.45	0.45
Road transport exhaust gasoline	0.32	0.17	0.17	0.17
Road transport exhaust LPG gas	0.02	0.02	0.02	0.02
Road transport non-exhaust	1.32	1.24	1.24	1.24
Shipping	0.95	0.76	0.71	0.76
Solvents	1.69	1.55	1.55	1.55
Waste	0.30	0.29	0.29	0.29
Total (sum)	**20.39**	**17.25**	**17.20**	**17.25**
Shipping contribution	**4.65%**	**4.39%**	**4.12%**	**4.38%**

Marseille

Table 29 *Predicted annual average NO_2 concentrations per sector (in µg/m^3) in Marseille*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	0.10	0.09	0.09	0.09
Boundary	0.01	0.01	0.01	0.01
Fugitives	< 0.01	< 0.01	< 0.01	< 0.01
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	0.87	0.79	0.79	0.79
Industry refineries	0.09	0.08	0.08	0.08
Natural	0.21	0.22	0.22	0.22
Off road	0.37	0.24	0.24	0.24
Other stationary combustion	2.34	1.18	1.18	1.18
Public power	0.07	0.08	0.08	0.08
Road transport exhaust diesel	6.54	2.30	2.29	2.30
Road transport exhaust gasoline	0.18	0.15	0.15	0.15
Road transport exhaust LPG gas	0.02	0.08	0.08	0.08
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	1.73	1.33	1.21	1.33
Solvents	0.03	0.03	0.03	0.03
Waste	0.04	0.02	0.02	0.02
Total (sum)	**12.60**	**6.58**	**6.46**	**6.58**
Shipping contribution	**13.74%**	**20.16%**	**18.75%**	**20.16%**

Table 30 *Predicted annual average $PM_{2.5}$ concentrations per sector (in $\mu g/m^3$) in Marseille*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	0.28	0.22	0.21	0.22
Agricultural other	0.34	0.24	0.23	0.24
Aviation	0.01	0.01	0.01	0.01
Boundary	0.84	0.83	0.83	0.83
Fugitives	0.02	0.02	0.02	0.02
Industry	0.02	0.02	0.02	0.02
Industry other	0.54	0.55	0.55	0.55
Industry refineries	0.06	0.06	0.06	0.06
Natural	0.47	0.46	0.46	0.46
Off road	0.09	0.05	0.05	0.05
Other stationary combustion	2.21	1.40	1.40	1.40
Public power	0.11	0.08	0.08	0.08
Road transport exhaust diesel	0.32	0.14	0.14	0.14
Road transport exhaust gasoline	0.05	0.04	0.04	0.04
Road transport exhaust LPG gas	< 0.01	0.01	0.01	0.01
Road transport non-exhaust	0.28	0.30	0.30	0.30
Shipping	0.25	0.15	0.13	0.14
Solvents	0.04	0.04	0.04	0.04
Waste	0.28	0.23	0.23	0.23
Total (sum)	**6.20**	**4.85**	**4.81**	**4.84**
Shipping contribution	**3.96%**	**3.00%**	**2.64%**	**2.94%**

Table 31 *Predicted annual average SO_2 concentrations per sector (in $\mu g/m^3$) in Marseille*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	< 0.01	< 0.01	< 0.01	< 0.01
Agricultural other	< 0.01	< 0.01	< 0.01	< 0.01
Aviation	< 0.01	< 0.01	< 0.01	< 0.01
Boundary	0.04	0.03	0.03	0.03
Fugitives	0.02	0.02	0.02	0.02
Industry	< 0.01	< 0.01	< 0.01	< 0.01
Industry other	0.47	0.49	0.49	0.49
Industry refineries	0.14	0.12	0.12	0.12
Natural	< 0.01	< 0.01	< 0.01	< 0.01
Off road	< 0.01	< 0.01	< 0.01	< 0.01
Other stationary combustion	0.35	0.08	0.08	0.08
Public power	0.03	0.02	0.02	0.02
Road transport exhaust diesel	0.01	0.01	0.01	0.01
Road transport exhaust gasoline	< 0.01	< 0.01	< 0.01	< 0.01
Road transport exhaust LPG gas	< 0.01	< 0.01	< 0.01	< 0.01
Road transport non-exhaust	< 0.01	< 0.01	< 0.01	< 0.01
Shipping	0.17	0.04	0.04	0.04
Solvents	< 0.01	< 0.01	< 0.01	< 0.01
Waste	< 0.01	< 0.01	< 0.01	< 0.01
Total (sum)	**1.24**	**0.83**	**0.82**	**0.83**
Shipping contribution	**13.58%**	**4.74%**	**4.27%**	**4.73%**

Table 32 *Predicted annual average PM_{10} concentrations per sector (in $\mu g/m^3$) in Marseille*

Sector	2023 base case	2030 BAU scenario	2030 LNG scenario	2030 all-EU ECA scenario
Agricultural livestock	0.29	0.23	0.23	0.23
Agricultural other	0.63	0.48	0.47	0.48
Aviation	0.02	0.02	0.02	0.02
Boundary	2.11	2.10	2.10	2.10
Fugitives	0.02	0.02	0.02	0.02
Industry	0.02	0.02	0.02	0.02
Industry other	0.87	0.93	0.93	0.93
Industry refineries	0.07	0.07	0.07	0.07
Natural	2.46	2.45	2.45	2.45
Off road	0.14	0.08	0.08	0.08
Other stationary combustion	2.27	1.43	1.43	1.43
Public power	0.14	0.10	0.10	0.10
Road transport exhaust diesel	0.49	0.20	0.20	0.20
Road transport exhaust gasoline	0.06	0.05	0.05	0.05
Road transport exhaust LPG gas	< 0.01	0.01	0.01	0.01
Road transport non-exhaust	0.43	0.48	0.48	0.48
Shipping	0.67	0.50	0.44	0.50
Solvents	0.04	0.05	0.05	0.05
Waste	0.29	0.23	0.23	0.23
Total (sum)	**11.04**	**9.45**	**9.37**	**9.44**
Shipping contribution	**6.10%**	**5.32%**	**4.69%**	**5.27%**

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ISBN 978-2-87567-217-9