CRUISE AND PASSENGER SHIP AIR QUALITY IMPACT MITIGATION ACTIONS (CAIMANS)

RESULTS OF THE FIRST STEP OF THE CAIMANs PROJECT

AIR QUALITY IMPACT AND GREEN HOUSE GASES ASSESSMENT FOR CRUISE AND PASSENGER SHIPS

June, 2015

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THE CAIMANs APPROACH

CAIMANs addresses the air quality impact and population health risk associated with cruise and passenger maritime traffic, focusing on port areas where human pressure is high and which are among the most inhabited areas in Europe. These can be even more important in the Mediterranean coasts where port terminals are often at the very heart of the cities, which have historically expanded around them.

CAIMANs project is based on high resolution dispersion modeling of passenger ships plumes and on the assessment of the population exposed to these plumes. The analysis is performed for present and mid-term future scenarios with and without mitigation actions that are under consideration in the five pilot city harbors: Barcelona, Marseille, Genoa, Venice and Thessaloniki. The comparison among the pollutant surface concentrations and the population exposures with or without the specific mitigation actions are assumed as the metrics to assess the effectiveness of the mitigation actions themselves.

The CAIMANs modeling approach can be described as “source oriented” because it starts from the sources (the ships emissions) and estimates the concentrations in the territory, by applying dispersion algorithms mainly driven by meteorological parameters. An analytical bottom-up approach is utilized for emission estimation, starting from harbor passenger ship traffic, recorded hour by hour all year long for the current situation, and including the estimation of the air pollutant ship emissions for the various time spent by the ships in hoteling, maneuvering and cruise phases. For such a detailed calculation of the emissions, a specific informatics tool has been set up and applied for all the five pilot areas; an adaptive tool which has very good potential for transferability to other port cases.

Within CAIMANs both transnational and local mitigation actions are investigated. As a transnational mitigation action, the replacement of the passenger fleet with ships fuelled by Liquefied Natural Gas (LNG) is applied on both transnational and local level and its effects are studied over the pilot harbor areas and the whole Mediterranean basin (see Appendix). As local action, the “On Shore Power Supply” of cruise and passenger ships during the hoteling phase is also applied. This action, even if local, would be magnified by a transnational approach meant to guarantee an equal competitiveness among harbors.

For the worldwide famous case of Venice and the large cruise ships arriving at the very heart of the historical city, additional local hypothesis are considered, as the displacement of terminals or maneuvering routes to minimize the impact on population exposure or the change in fuel during maneuvering phase (as the Blue Flag Agreement signed by the cruise companies in Venice in the past years).

Two of the main advantages of the CAIMANs approach are that the outcomes refer not only to specific sites (as measurements do) but they are produced in the form of maps covering the whole investigated areas; moreover the modeling tools allow scenario analysis to forecast pollutant concentrations and population exposures for different situations and hypothesis of interest to serve the purpose of the project.

The report has the following structure: Chapter 1 presents the methodology applied for the estimation of cruise and passenger ship pollutant emissions, followed by the emission outcomes for the present time. In Chapter 2, the modeling approach for each harbor is described and the present time pollutant surface concentrations due to ship plumes are presented and discussed. Chapters 3 and 4 show respectively how the pollutant emissions and air quality are expected to change in the mid-term future when compared with the present time situation. The local actions to mitigate the cruise and passenger ship emissions are presented in detail in Chapter 5 and their effectiveness is studied in terms of impact on the future air quality of each pilot area. Chapter 6 focuses on the population exposed to ship plumes in each study area in the cases of the present, future trend and future mitigation emission scenarios. In all chapters, comparison of the results is performed and the similarities and differences among harbors are revealed. Finally, the main results of the project are summarized and concluding remarks are provided. The report is complemented by an Annex where the future air quality impact and effectiveness of a common transnational emission mitigation action over the whole Mediterranean area is investigated.

1. PRESENT TIME POLLUTANT EMISSIONS FROM PASSENGER SHIPS

1.1. METHODOLOGY APPLIED FOR THE BOTTOM UP ESTIMATION OF SHIP AIR POLLUTANT EMISSIONS

Passenger ship air pollutant emissions have been estimated using a software tool, developed by ARPAV in Fortran 90 language, implementing the European reference methodology for ship traffic emissions (EMEP/EEA Emission Inventory Guidebook, 2013) and using as input the ships movements recorded in the five ports. The program translates the Tier 3 ship movement methodology of the EMEP/EEA Guidebook, the most detailed approach that is recommended when detailed ship movement data as well technical information on the ships are available.

Once defined the extent of the domain of the study, that is the length of the route sailed in the cruise and the maneuvering mode, the program estimates the air pollutant emissions of vessels in a harbor, during a reference year or a part of it. The input needed by this “Bottom-Up Harbor” program (hereafter referred to as BUH) is the database of the ship calls recorded in a single year in the harbor, completed with data concerning the category and the Gross Tonnage (GT) of each ship, the hour of arrival/departure as well as the time spent in the maneuvering phase, the quay or terminal of docking and the origin/destination information. The BUH program calculates the emissions associated to each ship movement (from the arrival to the departure), splitting in fuel and navigation phases (hoteling, maneuvering, cruising). Moreover the program calculates the hourly emissions associated to all the ships berthing in a terminal, subdividing each ship movement emission during the time spent in each navigation phase and summing up the emissions that occur at the same time. This latter output is used as input for the next step of the air pollution dispersion modeling. The program estimates also the contribution from the tug assistance during the maneuvering phase, starting from the average gross tonnage of the tug fleet.

The main assumptions of the estimation are those of the EMEP/EEA methodology itself, which are:

- exhaust emissions computed as contribution by main engines, mostly used for the propulsion, and auxiliary engines, for power and services within the vessels;
- emission estimation based on installed engine power, this latter calculated as a function of the GT of the ship, engine load factor, and time spent in the different navigation phases (hoteling, maneuvering and cruising);
- nine ship categories (liquid bulk ships, dry bulk carriers, container, general cargo, ro-ro cargo, passenger, fishing, other, tugs);
- five engine typologies (slow-, medium- and high-speed diesel, gas turbine and steam turbine);
- two fuel types (Bunker Fuel Oil BFO and Marine Diesel/Marine Gas Oil MDO/MGO, these latter two undistinguished);
- pollutant emission factors and specific fuel consumptions depending on the different engine types/fuel combinations and vessel trip phases (cruising, hoteling, maneuvering);
- sulfur dioxide (SO_2) emissions proportional to the fuel consumption and the sulfur content in the fuel;
- classification of the ships into combination of engine types and fuels using international statistics, as the 2010 world fleet.

The air pollutant covered by the code are both macropollutants, such as oxides of nitrogen (NOx), carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulfur dioxide (SO_2), particulate matter (PM) and micropollutants, such as metals (Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn) and organic species: Polychlorinated biphenyl (PCB), Hexachlorobenzene, (HCB) and Dioxins and Furans (PCDD/F). As for particulate matter, the Tier 3 emission factors used were not distinguished between TSP (Total Suspended Particles) and PM_{10} and PM2.5.

Beside the pollutants covered by the EMEP/EEA methodology, the BUH code implements two different estimation for the Benzo(a)pyrene (BaP), a polycyclic aromatic hydrocarbon for which there’s a growing interest both for its health effect (IARC, 2015) and for its widespread environmental contamination due to its formation during incomplete combustion or pyrolysis of carbon-containing materials.

The two estimations are based on the Cooper and Gustafsson (2004) and Agrawal (2010) works that give a substantial different assessment for BaP emitted by shipping mainly for a higher emission factor in Agrawal for slow speed diesel engines running on Bunker Fuel Oil. The BUH program has been applied in all the five CAIMANs pilot harbors both for the present and the future passenger traffic scenario, allowing to base the air quality impact assessment on a common "metrology" and making robust the comparison analysis among the cities.

1.2. POLLUTANT EMISSIONS OF THE PORT CITIES

1.2.1. Barcelona

Cruise and passenger ships emissions have been estimated for the year 2013 in a 30 x 30 km^2 domain with a horizontal resolution of 100m. This domain covered the greater area of Barcelona. Barcelona is located in the Western Mediterranean, precisely in the northeastern part of Spain, in the central Mediterranean of Catalonia. The port area of Barcelona includes six different piers (Fig. 1.2.1.1). The cruises terminal includes two piers (Adossat Wharf and Barcelona Wharf); meanwhile the ferries terminal comprises four different piers in total, facilitating passenger and cruise ship traffic (Fig 1.2.1.2).

Shipping emissions have been calculated according to the activity data provided by the Barcelona Port Authority SA using the methodology of EEA (2013) described in Section 1.1. A 0.1% of sulfur content has been estimated for vessels using Marine Diesel Oil/Marine Gas Oil (MDO/MGO), while a 2.7% is used as basis for the estimation of sulfur emissions when Bunker Fuel Oil (BFO) is used. Moreover, according to the Barcelona Port Authority, tugs are used during the maneuvering phase of cruise ships. The number of tugs used depends on cruise ships; 3 tugs are used for is used Costa Mediterranean cruise (85 619 GT), while two and one tugs are used for several other cruises.

Fig. 1.2.1.2. The port of Barcelona.

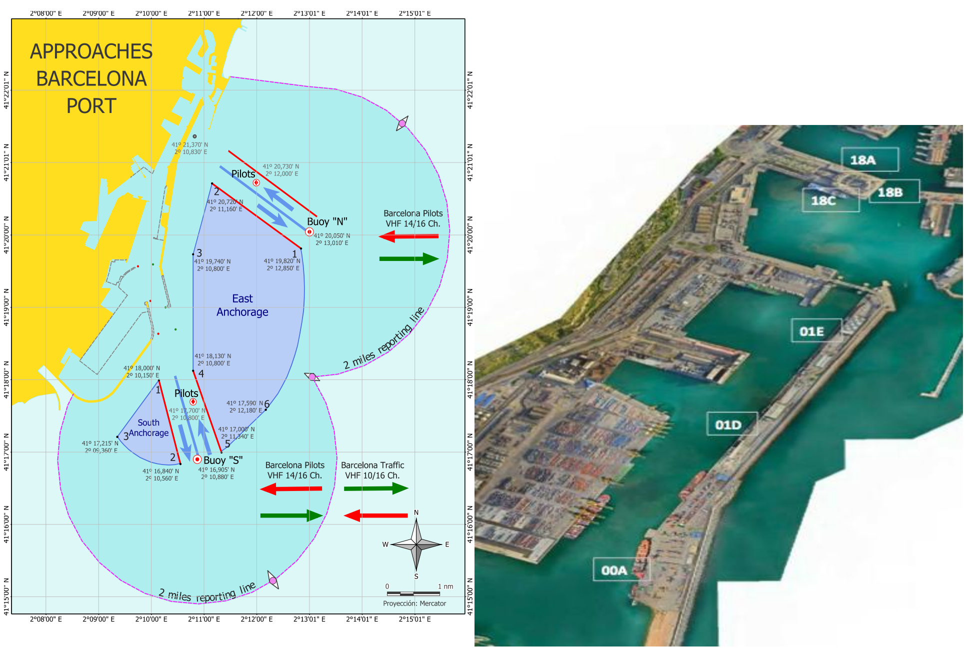


Fig. 1.2.1.2. Cruises terminal in the port of Barcelona.

For the year 2013, ferries were also a large contributor to total shipping emissions for all pollutants. Moreover, shipping emissions during the cruising mode represented the highest share of total emissions in the domain included from all operation modes (cruising, manoeuvring and hoteling) due to the highest emission of air pollutants during that mode. Finally, focusing in the port area of Barcelona, emissions during the hoteling mode were higher than those in maneuvering because of the more time spent by ships in the harbor area (Fig. 1.2.1.3).

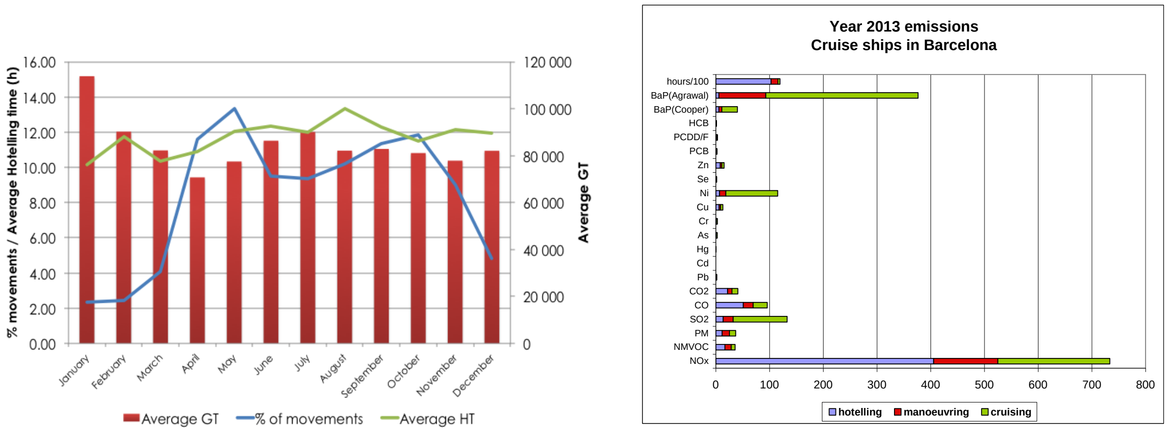


Fig. 1.2.1.3. (Left) Annual distribution of cruise movements, averaging hoteling time and average gross tonnage of cruises. (Right) Emissions in the port of Barcelona domain in the different phases (blue: hoteling; red: maneuvering; green: cruise). Results are shown in Mg/year for NOx, NMVOC, PM, SO_2, CO; kt/year for CO_2; kg for metals; g for HCB and PCB and mg-ITEQ for PCDD/F.

1.2.2. Genoa

The Genoa urban area extends for about 32 kilometres along East-West direction on the coast of Liguria Sea and the maritime station is located in the middle of the coast side of the city, between the industrial port (West side) and the Old Harbor (East side). Five docks are reserved to passenger ships (Ro-pax and Cruises) berthing, which takes place on 15 different points, depending on vessel type and ship company. Ship traffic data for the year 2013 were extracted by data available online at Genoa Port Authority website (www.porto.genova.it/).

Fig.1.2.2.1. The Genoa Maritime Station located between the industrial harbor and the old harbor. The stars indicates the five passenger ships docks.

The passenger ship traffic database obtained by the above data was converted to be an input for the BUH Program, developed by ARPAV, which implements the EEA methodology (see section 1.1) allowing for the calculation of ship emissions.

The most relevant contribution to passenger ship emissions in Genoa area is due to Ro-pax vessels. Indeed, even if a single Ro-pax vessel is usually characterized by lower emissions with respect to a cruise one, represent the 63% of the total passenger ships traffic. Maneuvering times are quite short, thus the hoteling phase is prevalent in the total emission values. Emissions from ships approaching the Genoa's harbor entrance in the cruise phase were not calculated because the sources were outside the simulation domain. Thus the emissions of vessels were calculated only in hoteling and maneuvering phases. It is worth noting that no tugs are used in the maneuvering phase for passenger ship vessels in Genoa harbor.

For the sake of clarity it must be remarked that the analysis of Genoa area was performed considering the temporal distribution of passenger maritime traffic, which is mainly limited to the summer period: 75% of Ro-pax vessel traffic and 55% of cruise traffic, correspond to 68% of the total passenger ship traffic. Thus we focused our attention on the period between May and September, and we got results for the whole year 2013 with projections and further considerations. In particular:

- emission data were projected according to the monthly traffic data (available for both Ro-pax and cruise vessels), introducing a very slight approximation;
- concentration data must be considered as a safe approach of estimation for annual mean values, while no difference is expected to be revealed on hourly data series, whose maximum values over the year 2013 are expected to correspond to the maximum values over the May-September period at least for the highest rank positions to be considered for legal limits.

1.2.3. Marseille

Marseilles port consists of an east and west basin (Fig. 1.2.3.1). The eastern part, located inside Marseilles city, mainly handles passengers, general cargo, roll-on/roll-off activities and ship repairs. The western part is mainly used for oil chemicals and refined activities, crude oil and container-related activities. Also, a branch of the container activities is located at the eastern part. In this report, a focus is done on the eastern part of the port as all passenger activities are located in this area.

Input data required to calculate emissions from maritime transport are obtained from Marseille-Fos port authority (GPMM) by means of a traffic database given ship types, gross tonnage, stop duration, quay location, origin and destination ports for every ship calling at Marseille-Fos port during 2013. Thanks to this database, an extraction of ship calls related to passenger activities is computed, composed of cruise ships and ferries. Cruise ships are mainly located in the northern part of the port, whereas ferries mainly stopped in the southern part (Fig. 1.2.3.2). Emissions are computed using a common methodology shared by each partner and described in Section 1.1.

Fig.1.2.3.1. Marseilles port situation (source: Google Earth).

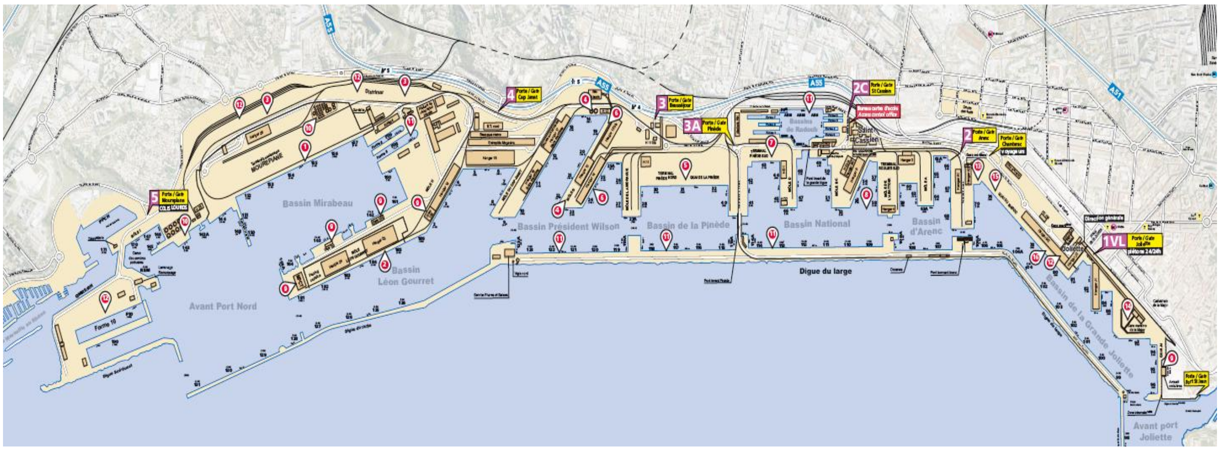


Fig.1.2.3.2. Eastern harbor plan.

During the year 2013, ferry activity is more developed than cruise activity in Marseilles with around five times more calls and a total annual time spent at berth height times more important. Consequently, pollutant emissions are dominated by ferries emissions for each operation mode (hoteling, maneuvering and cruising). Inside the port area, including both hoteling and maneuvering phases, shipping emissions are not dominated by one of these phases, depending on pollutants taken into consideration. Actually, time spent during hoteling phase is significantly higher than during maneuvering phase but fuel consumption is more important for this second phase. So, NO_x emissions as well CO, CO_2, BaP (estimated with emission factor of Cooper et al. Gustafsson, 2004) and some trace metals are mainly released during the hoteling phase whereas the other major pollutants are mainly issue from the maneuvering phase.

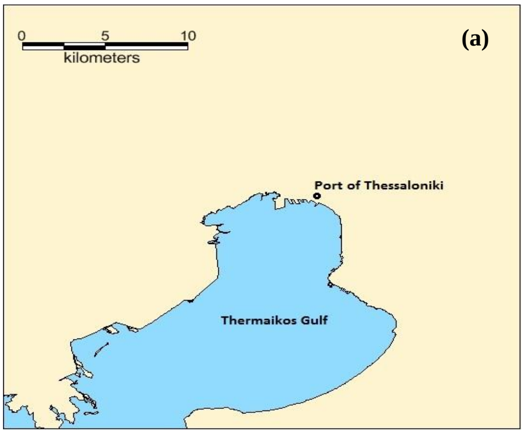
It is important to pointing out that Ro-pax vessels have been considered as Ro-cargo vessels as in the GPMM classification. Since in the worldwide fleet used in the BUH program the percentage of slow speed diesel running on BFO is much greater than that of the passenger category, the divergence among BaP estimation by Cooper et al. Gustafsson (2004) and Agrawal (2010) is magnified, with this latter estimation being greater. The same classification in Ro-cargo category has meant an estimation for all the other pollutants (especially SO_2 and PM) that can be considered certainly an upper estimation.

Emissions from ships approaching the Marseille harbor in the cruise phase are outside the simulation domain of 12x12 km^2 (see paragraph 2.2.3), thus analysis of emissions is limited to hoteling and maneuvering mode.

1.2.4. Thessaloniki

Cruise and passenger ships emissions have been estimated for the year 2013 in a 100m horizontal resolution domain with an extent of 30 km x 30 km^2 covering the greater area of Thessaloniki (Fig. 1.2.4.1a). Thessaloniki is situated in the northern part of Greece. The port area of Thessaloniki is located in the inner part of the Thermaikos Gulf and includes six piers. The passenger terminal is located between Piers 1 and 2

(Fig. 1.2.4.1b) and includes 5 docks in total facilitating passenger and cruise ship traffic. The Port of the Thessaloniki is located west to the center of the city at very close distance of about 2km.



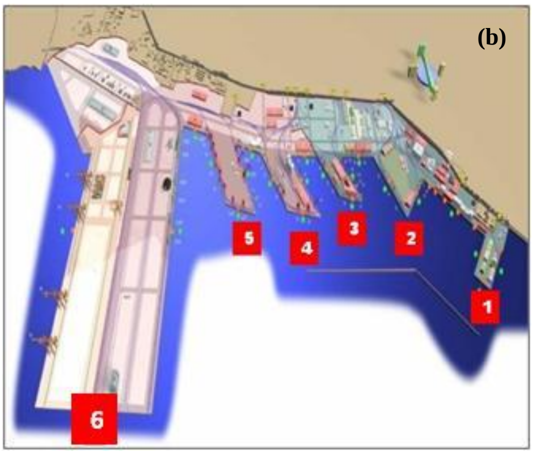


Fig. 1.2.4.1. (a) Study area of Thessaloniki and (b) Port of Thessaloniki.

Shipping emissions have been calculated according to the activity data provided by the Thessaloniki Port Authority SA (TH.P.A. SA) using the methodology of EEA (2013) described in Section 1.1. It should be noted that according to an amendment of the directive 2005/33/EC (FEK 173B – 30/08/2007), all ships in the area of Greece have to change their marine fuel used before entering into the port (during maneuvering and hoteling modes) with a sulfur content not exceeding 0,1 % by mass. Moreover, according to TH.P.A S.A, tugs are used during the maneuvering phase of cruise ships. The number of tugs used depends on the length of the cruise ships; one tug is used for ships with length less than 150m and two tugs for larger ships.

For the year 2013, other passenger ships were the major contributor to total shipping emissions for all pollutants. Moreover, shipping emissions during the cruising mode represented the highest share of total emissions from all operation modes (cruising, maneuvering and hoteling) due to the higher load factor of main engines for this mode and, in the case of NOx, also to higher emission factors. Finally, focusing in the port area of Thessaloniki, emissions during the hoteling mode were higher than those in maneuvering because of the more time spent by ships in the harbor area.

1.2.5. Venice

Ships emissions have been estimated for the year 2013, considering all the typology of ships. However, for the comparison with the other CAIMANs pilot harbors, in the present report only passenger and cruise ships are focused.

Venice is situated on the Adriatic Sea in the North-East part of Italy. The port of Venice is located inside the Venetian Lagoon and includes three main port areas: the terminals in the ancient city, the terminals in Porto Marghera in the inner shoreline of the Lagoon, and the terminal of San Leonardo, mainly for oil tanks, at the Southern and inner part of the Lagoon.

In the year 2013 mostly of the passenger and cruise ships had been docking at the terminals in the ancient cities (Santa Marta and San Basilio areas), whereas starting from 2014 most of the Ro-pax ships were transferred in the Porto Marghera area, in a temporary quays waiting for the new Ro-pax Terminal, in Fusina area, under construction.

The main terminal for cruise ships is the Marittima, on the South East part of the ancient city, where all the largest cruises docks; smaller cruise ships hotels also in other part of the ancient city (Santa Marta/San Basilio, Punta della Salute, Riva Sette Martiri) and all arrive and departure by “bocca di Lido”, the northern entrance of the Venetian Lagoon (Fig. 1.2.4.1).

Since 2014 Ro-pax ships reach the Porto Marghera harbor area by the Malamocco entrance, sailing along the Malamocco channel and the Oil Channel.

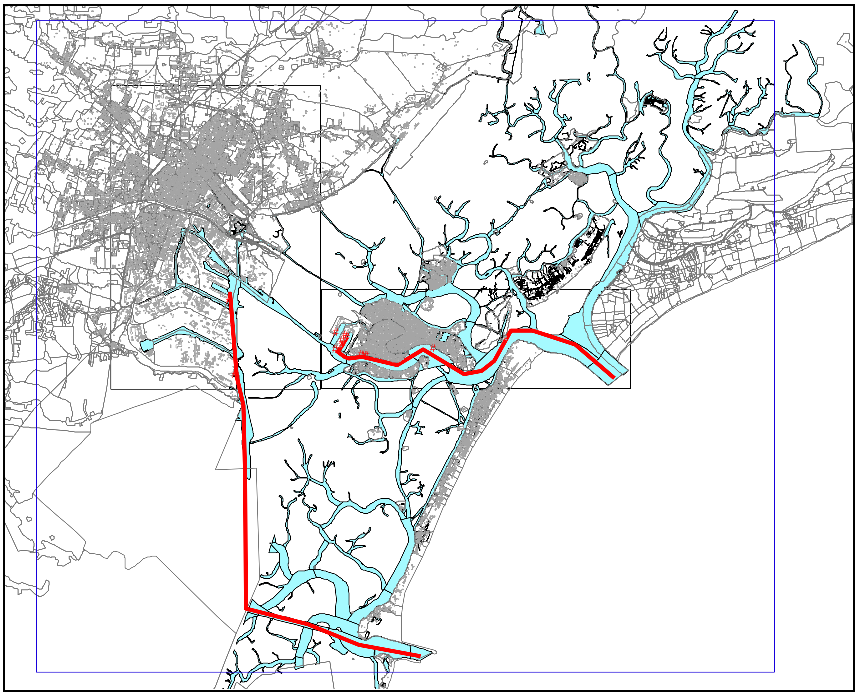


Fig.1.2.4.1. Study area of Venice.

Shipping emissions have been calculated according to the ship movements provided by the Venice Harbor Master with details about hour of arrival/departure, time spent in manoeuvring phase, gross tonnage, typology, quay, destination and origin of every ship and using the BUH code based on the EEA methodology (2013) described in Section 1.1.

It should be noted that, according to a voluntary agreement signed by almost all the cruise companies under the direction of the Venice Municipality, during the 2013 season, cruise ships inside the lagoon had to use marine fuel with a sulphur content not exceeding 0,1 % by mass. So the emissions estimated both for maneuvering and hoteling phase of all the cruise ships considered a no consumption of Bunker Fuel Oil (BFO), whose formulation can't accomplish so low sulphur limit. For the Ro-pax vessels, instead, the estimation considered the sulphur limit of 1,5% by mass, set by the Directive EC 33/2012 for passenger ships, and a consumption of BFO and distillate fuels accordingly to statistics of the passenger ship worldwide fleet reported in EEA (2013).

Cruise phase emissions have been calculated for about 10 km or route outside the Venetian Lagoon. Tug emissions have been estimated considering one tug in assistance to the maneuvering of ships with length less than 125 m and two for longer ships.

Since the GT of the cruise ships are much larger than those of the other passenger vessels, even if the total amount of time spent in a year by all the passenger ships in Venice is greater than that of the cruise ships, this latter group of vessels is responsible of the major emissions for year 2013 for all the pollutants, as can be seen on the graphs in Figure 1.2.4.2.

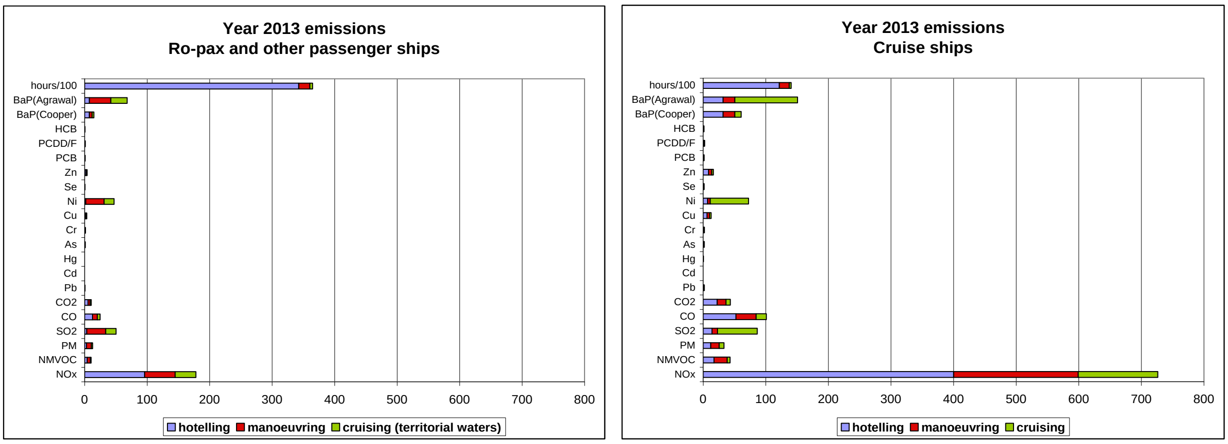


Fig. 1.2.4.2. Annual emissions for Ro-pax and other passenger vessels (left) and cruise ships (right) in the different phases (blue: hoteling; red: maneuvering; green: cruise). Results are shown in Mg/year for NOx, NMVOC, PM, SO_2, CO; kt/year for CO_2; kg for metals, ; g for PCB and HCB; mg I-TEQ for PCDD/F. Total time spent in the various navigation modes by all the ships is shown in the histograms in hours/100.

1.3. COMPARISON OF THE PORT CITIES IN TERMS OF PRESENT TIME POLLUTANT EMISSIONS

1.3.1. Cruise ships

The graph in Figure 1.3.1.1 compares the total time spent in hoteling and maneuvering phase in the year 2013 by all the cruise ships of the five CAIMANs cities, whereas their average and total gross tonnage are compared in the graph in Figure 1.3.1.2. Both the graphs are important to understand the outcomes, since emissions increase both with the total amount of hours spent in the various navigation phases and with the ship gross tonnage.

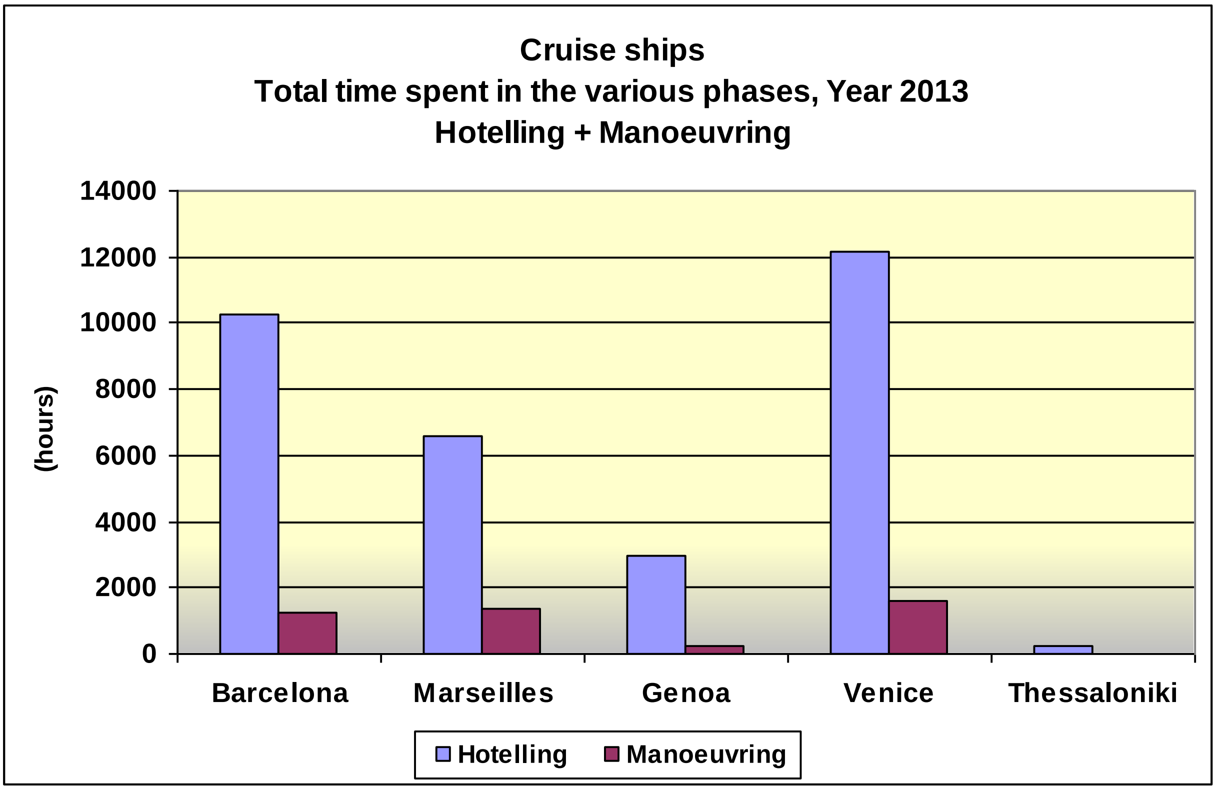


Fig. 1.3.1.1. Total time spent by all cruise ships in 2013.

Letting aside the case of Thessaloniki, currently with very low cruise traffic, the other CAIMANs ports records around 500 calls in a year, including in this amount also the ships that start and end their trip in the port.

Venice records the highest values of hours both for hoteling and maneuvering phase. The hoteling time is very high in Venice since most of the cruises starts and ends their trip around the Mediterranean Sea in the home port of Venice; the hoteling average time per ship is around 18 hours, whereas in other cities cruise ships usually remain at dock for less hours. Also the maneuvering phase is quite long in Venice, since it starts and ends at the lagoon entrance and it lasts about 3 hours summing up the arrival and the departure time.

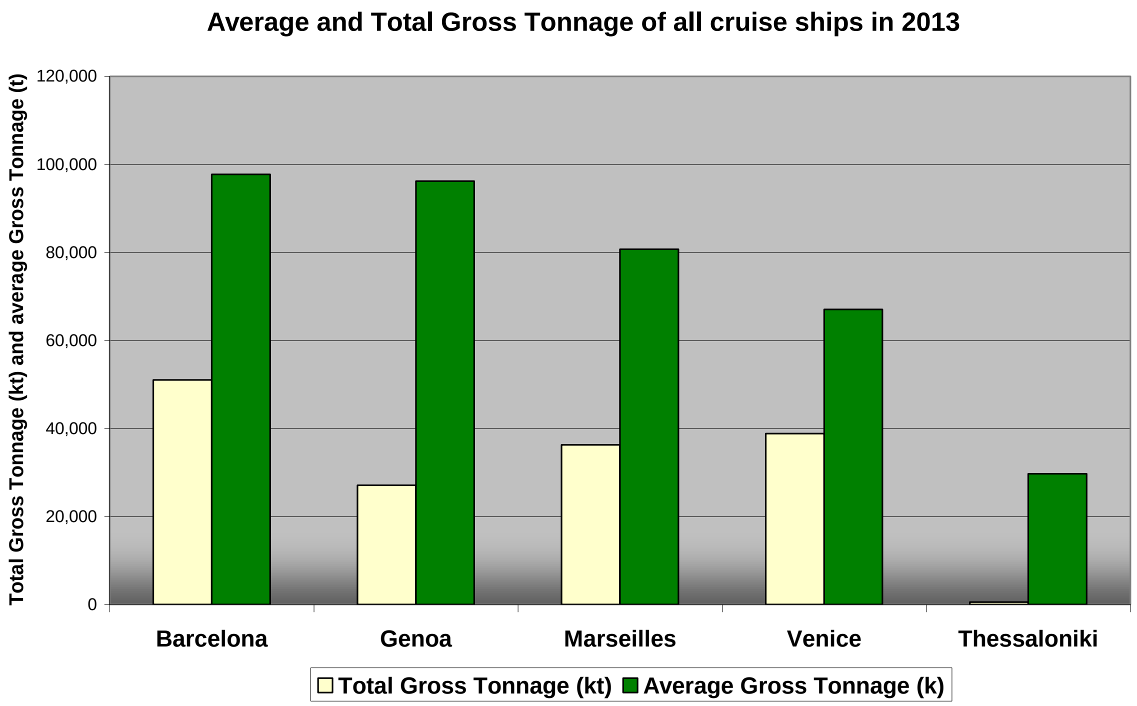


Fig. 1.3.1.2. Average and total gross tonnage of all cruise ships in 2013.

As for the gross tonnage of the cruise ships (see Figure 1.3.1.2), Barcelona records the highest values both for the total amount and the average value. Note that the Total Gross Tonnage (that is the sum of all the GT of all the cruise ships calling the harbor in a year) is expressed in thousands of tons, whereas the average value of the cruise fleet is in tons.

Comparison of the various air pollutant emissions for the year 2013 among the harbors in hoteling and maneuvering phase is presented here below by histograms. Unless otherwise specified, emissions are expressed in Megagrams (Mg = 10^6 g) that corresponds to tons.

The hoteling phase emissions have been estimated in every city considering that the 0,1% sulfur content limit for fuels to be used while ships are docking, set by the 2005/33/EC Directive, resulting in a total turn down of Bunker Fuel Oil (BFO) consumption during this phase.

A similar ban for the BFO has been considered in the maneuvering phase in Venice, due to the application of the Blue Flag 2 Agreement signed by the cruise companies in the 2013 season.

Emissions of Nitrogen Oxides (NO_x), Particulate Matter (PM_{10}/$PM_{2.5}$) and Sulfur dioxide (SO_2) in the five cities are presented for the hoteling phase in Figure 1.3.1.3 and for the maneuvering phase in Figure 1.3.1.4. Please note that PM and SO_2 are plotted on the left-Y axis whereas NO_x on the right one, and that the two Y-axes have a different maximum value: 140 against 450 Mg.

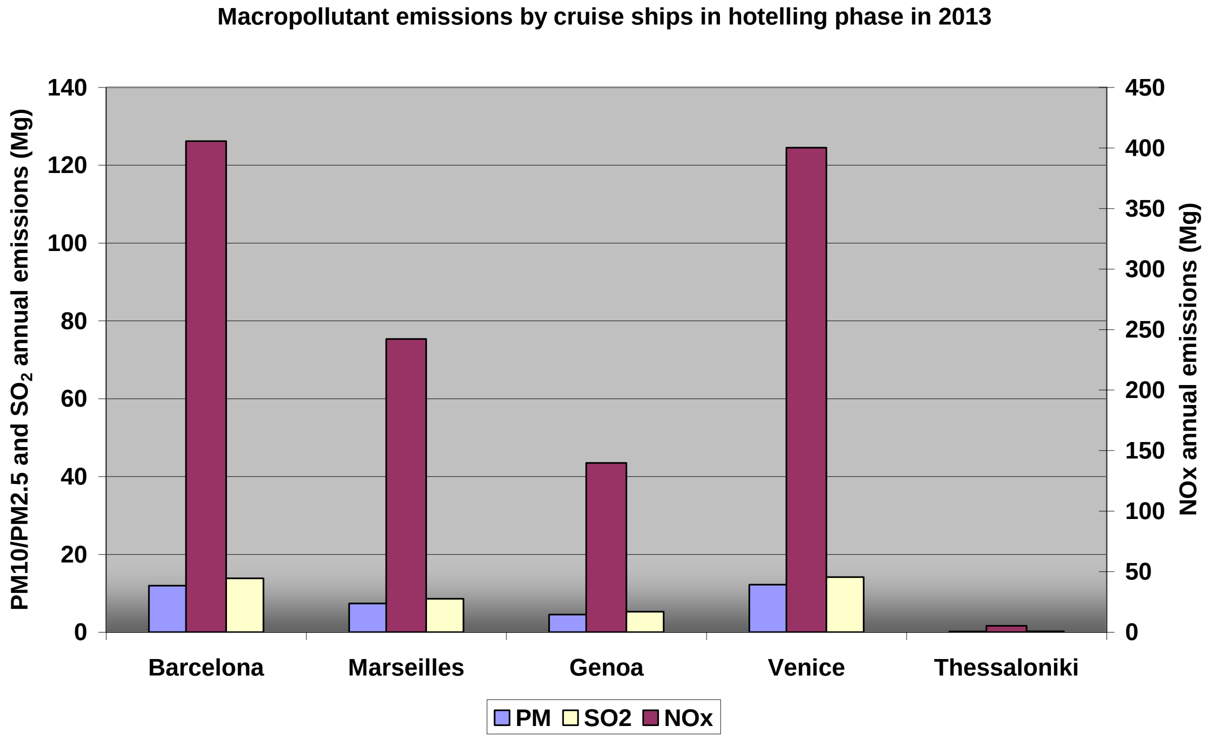


Fig. 1.3.1.3. Macropollutant emissions by cruise ships in hoteling phase in 2013.

Macropollutant emissions by cruise ships in manoeuvring phase in 2013

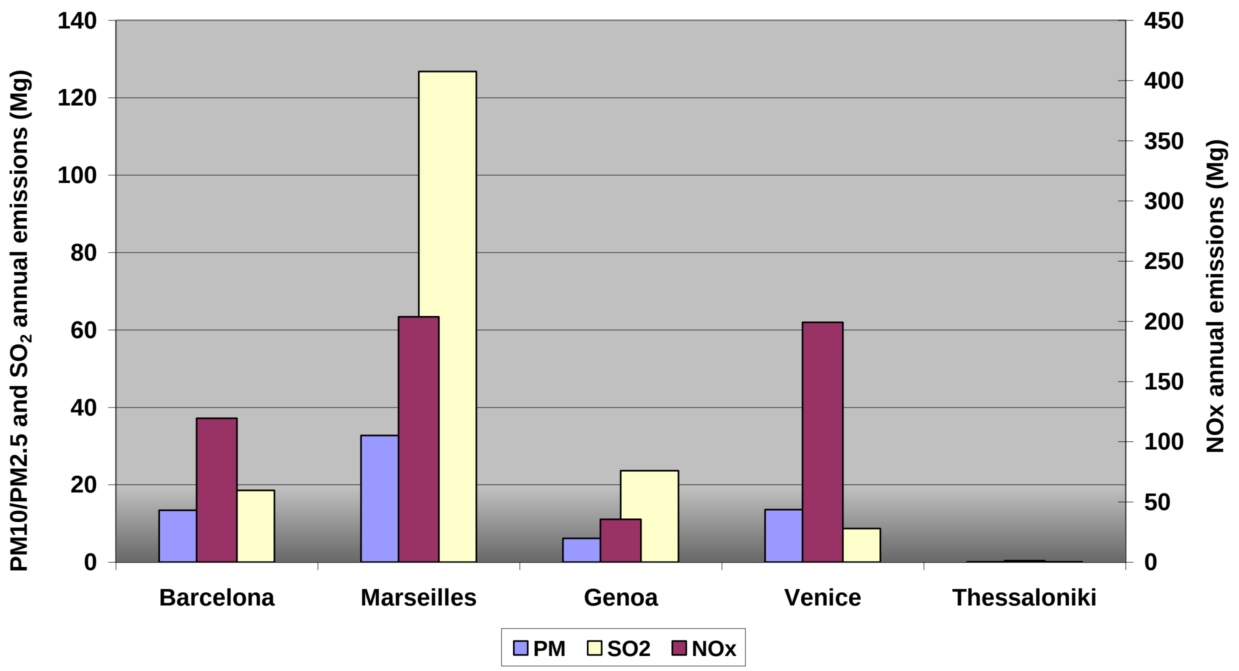


Fig. 1.3.1.4. Macropollutant emissions by cruise ships in maneuvering phase in 2013.

NO_x are the most emitted air pollutants in both hoteling and maneuvering phase. Even if emission factors and the load factors of the engines are smaller in hoteling mode, the annual emissions of all the cruise ships due to hoteling phase are much greater (2 to 4 times more) than those of the maneuvering phase in all the harbors. This pattern is due to the much greater number of hours spent in a year in hoteling time than in maneuvering (see Figure 3.1.1.1).

The ranking among the cities for NO_x emissions follows the correspondent total amount of hours spent in the various phases, with Barcelona and Marseilles in the highest positions, because the ships arriving in these cities have generally a larger gross tonnage (see Figure 1.3.1.2).

In Barcelona, Genoa and Marseilles SO_2 is emitted the most in maneuvering phase, both because BFO, used in this phase, has greater emission factors and because the load factor of the engines are higher than in maneuvering phase. On the other hand, in Venice and Thessaloniki, where BFO is banned also in maneuvering phase, due to prolongation of the 0,1% sulfur limit also in maneuvering and even in cruising phase, as the case of Thessaloniki, SO_2 emissions are mostly due to hoteling contribution.

The metal emissions are compared in the graph in Figure 1.3.5 for the hoteling phase and in Figure 1.3.6 in the maneuvering emissions. The metals there shown are those covered by the EMEP/EEA methodology followed in the estimation.

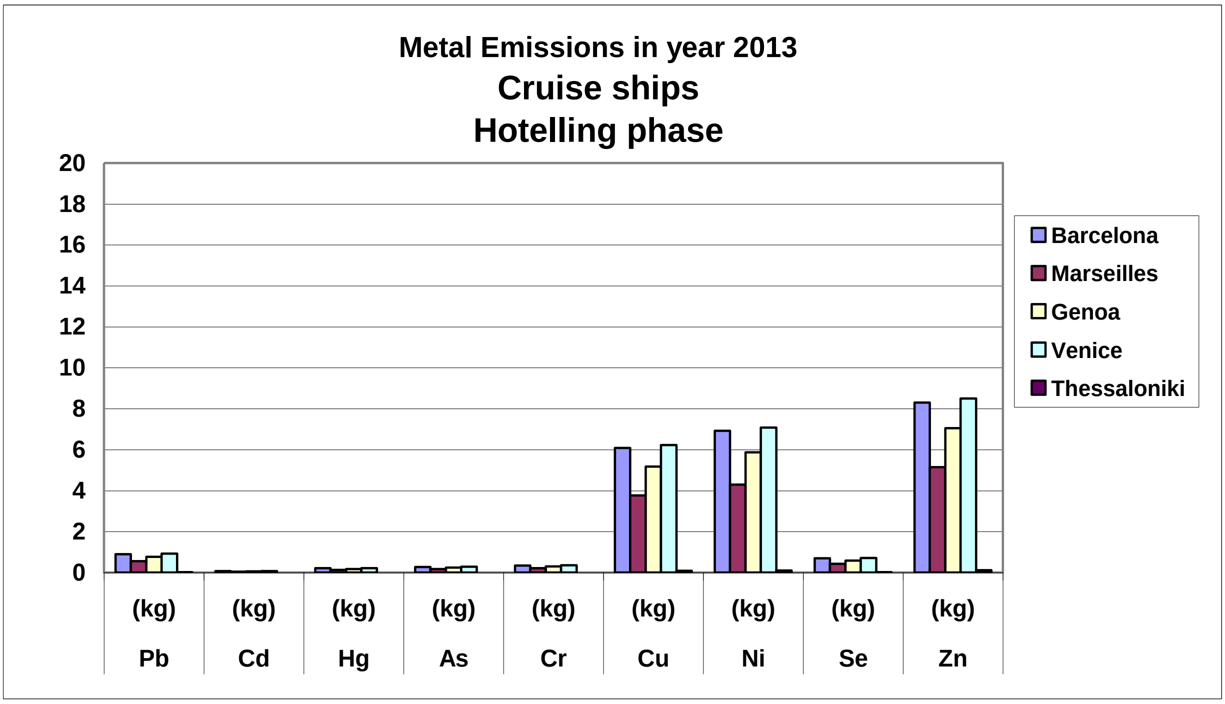


Fig. 1.3.1.5. Metal emissions by cruise ships in hoteling phase in 2013.

All the metal emissions in Figure 1.3.1.5 follow the ranking due to the different total time spent in hoteling in the various cities, with Venice having the highest values. As for the comparison among metals, Zinc (Zn), Nickel (Ni) and Copper (Cu) are the most emitted, followed by Lead (Pb), Chromium (Cr), Arsenic (As), Mercury (Hg) and Cadmium (Cd). This proportion among metal emissions reflects the assumption of a total turn down of Bunker Fuel Oil in the hoteling phase, as already specified.

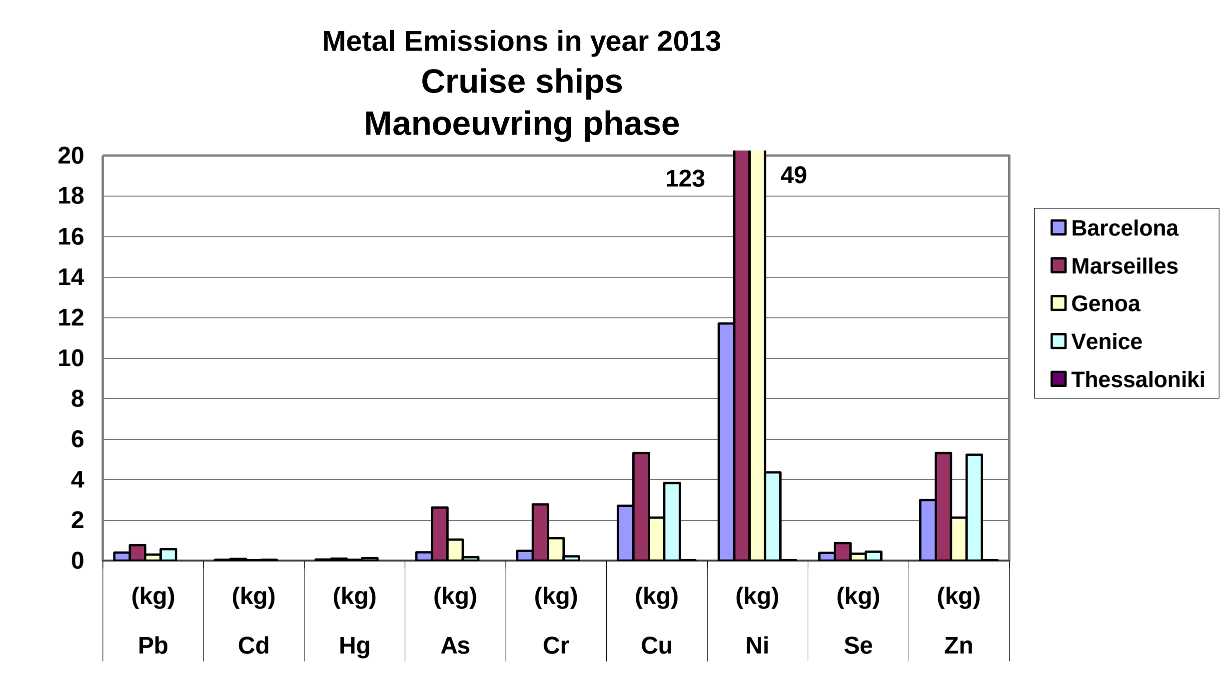


Fig. 1.3.1.6. Metal emissions by cruise ships in maneuvering phase in 2013.

A different pattern is noticeable in the case of the maneuvering phase for metal emissions (Figure 1.3.1.6), with Marseilles at the highest rank for all the metals, especially Nickel. Please note in the graph in Figure 1.3.1.6 that the values for Marseilles and Genoa are out of scale (specific values are reported in the graph). Nickel is a metal associated to Bunker Fuel Oil and in fact it has very low value in the case of the maneuvering emissions in Venice, estimated considering a total removal of the Fuel Oil due to the Blue Flag 2 Agreement, as already explained.

The organic micropollutant emissions of hoteling phase are compared in the graph in Figure 1.3.1.7 and those of the maneuvering phase in Figure 1.3.1.8. The organic micropollutant there shown are those covered by the EMEP/EEA methodology, that are Polychlorinated biphenyl (PCB), Hexachlorobenzene, (HCB) and Dioxins and Furans (PCDD/F); moreover in the graphs the two estimations for Benzo(a)pyrene (BaP) using the different estimation by Cooper and Gustafsson (2004) and Agrawal (2010) are shown as well. Please note the different unit of measure of the emissions (grams for all but PCDD/F in mg I-TEQ).

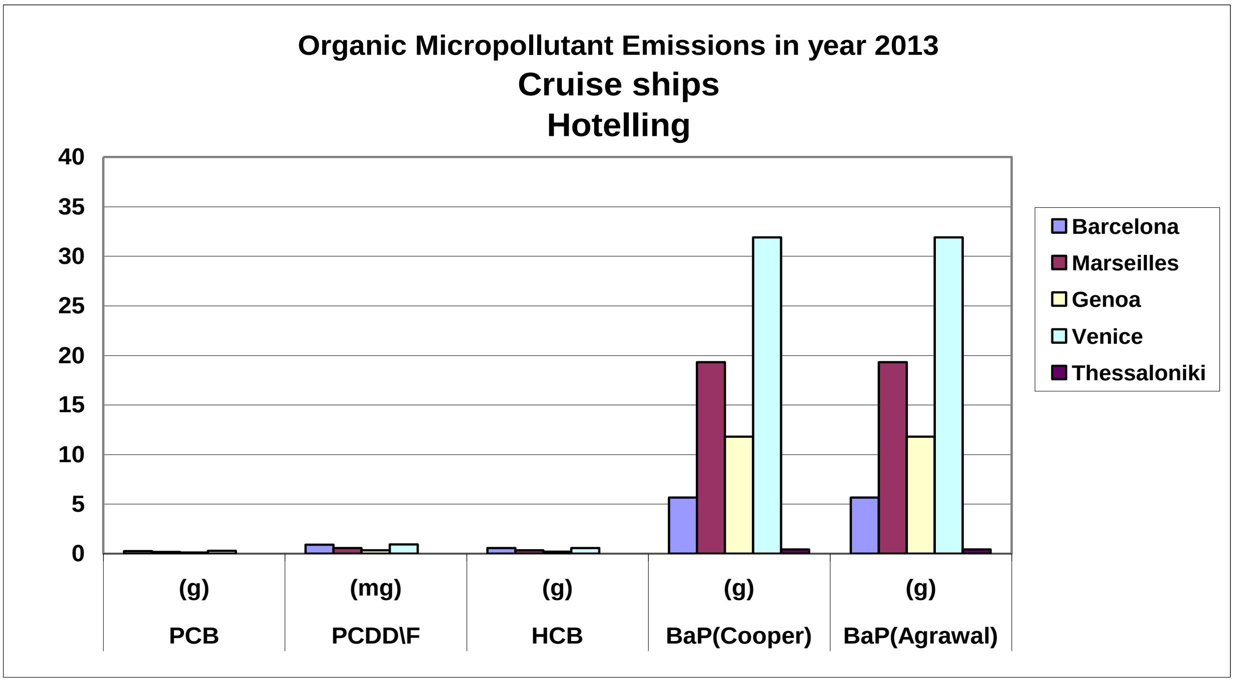


Fig. 1.3.1.7. Organic micropollutant emissions by cruise ships in hoteling phase in 2013.

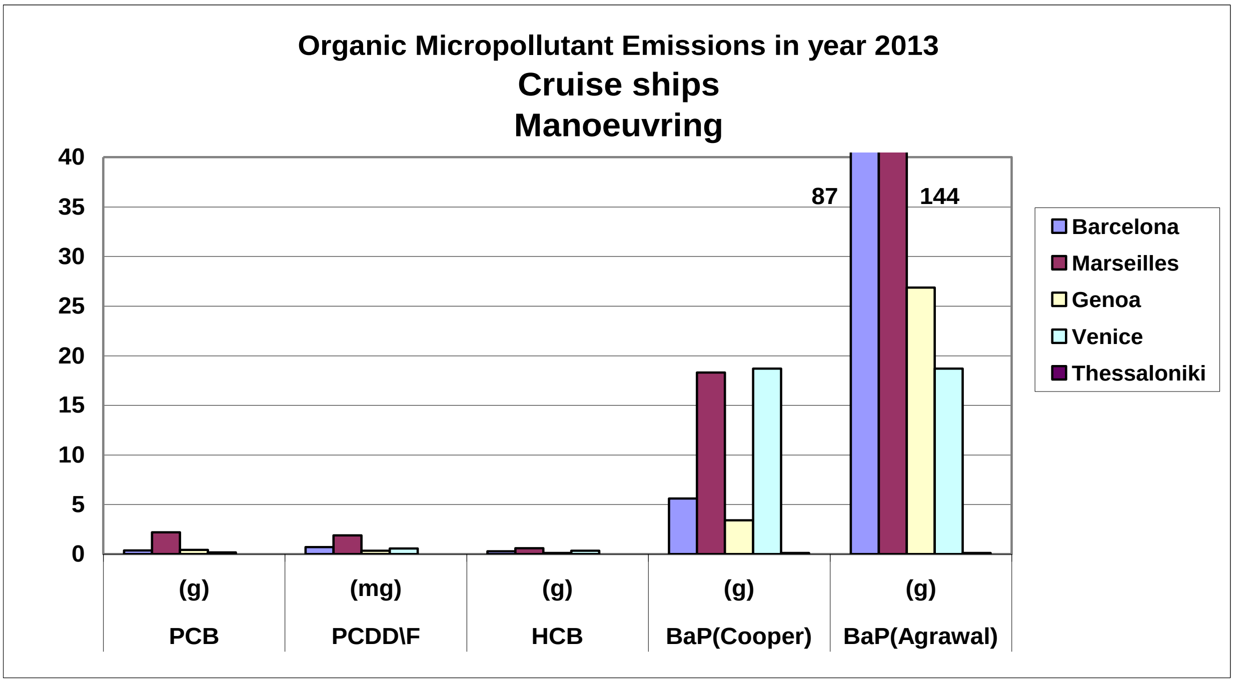


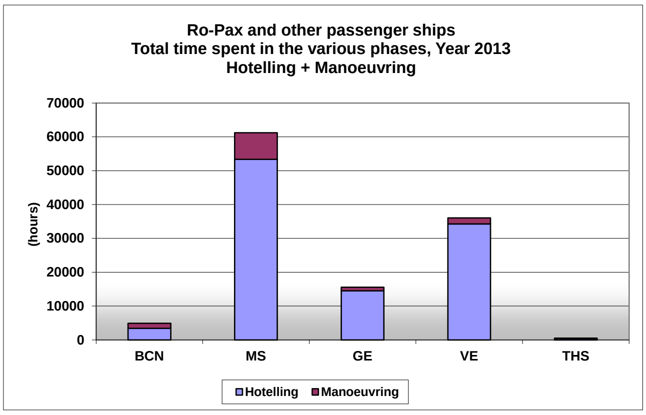
Fig. 1.3.1.8. Organic micropollutant emissions by cruise ships in maneuvering phase in 2013.

Focusing on the BaP estimation, as already explained, the two different methodologies applied differ mainly for the greater emission factors reported by Agrawal (2010) for slow speed diesel running on BFO. This fact is evident comparing the emissions in Figure

1.3.1.7 and Figure 1.3.1.8. For the hoteling phases, for which BFO is not used, there's no difference between the two estimations, whereas the differences are evident in the case of maneuvering emissions for all the cities except Venice and Thessaloniki, where the BFO is banned also in maneuvering phase, thanks to the Venice Blue Flag 2 Agreement in Venice and the amendment to the 2005/33/EC Directive (FEK 173B – 30/08/2007) in Thessaloniki.

1.3.2. Other passenger ships

In Figure 1.3.2.1 the total time spent in 2013 in hoteling and maneuvering mode by all the Ro-pax vessels and other passenger ships in the five pilot harbors is placed alongside the correspondent time spent by the cruise ships.



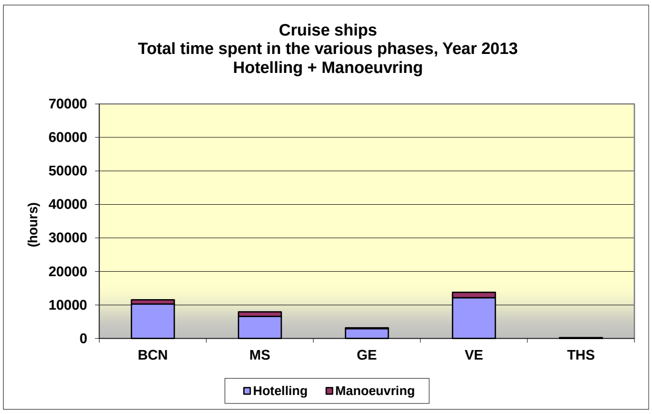
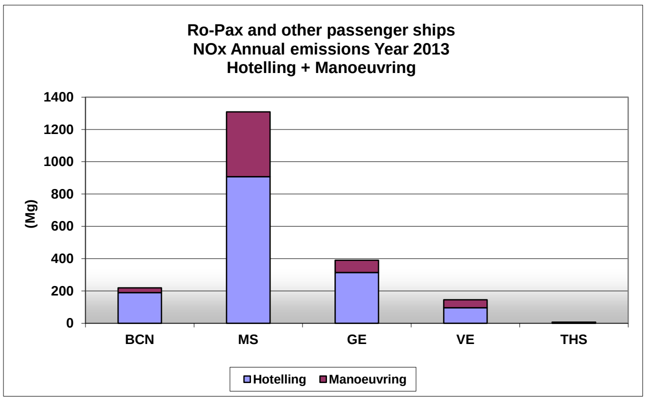


Fig 1.3.2.1. Total time spent by Ro-pax and other passenger ships (left) and cruise ships (right) in 2013.

As already commented for the cruise ships analysis, the time spent is one of the main driver of the total annual emission estimation. In Figure 1.3.2.1 the high values for Ro-pax vessels is very evident and in fact in Marseilles the Ro-pax emissions are predominant in respect to the cruise ones.

Summing up the total hours spent in hoteling and in maneuvering phases, the greatest ratio (in percentage value) between other passenger vessels and cruise ships is recorded for Marseilles, with about a 800%, followed by Genoa with about a 500%; in Thessaloniki the two values are approximately equal (186%), whereas in Barcelona the cruise ships values are predominant (43%). In Venice, summing up all the other passenger ships than cruise vessels, the ratio is around 260%.

To understand the outcomes of the Ro-pax and cruise emission ratio is also important to remind that the emissions depend on the gross tonnage of the ships, so the ratio between the total time is not always confirmed in the emissions, given the typical greater tonnage of the cruise ships in respect to the all the other passenger fleet. This pattern is evident in the following figures the makes a comparison for the various pollutants.



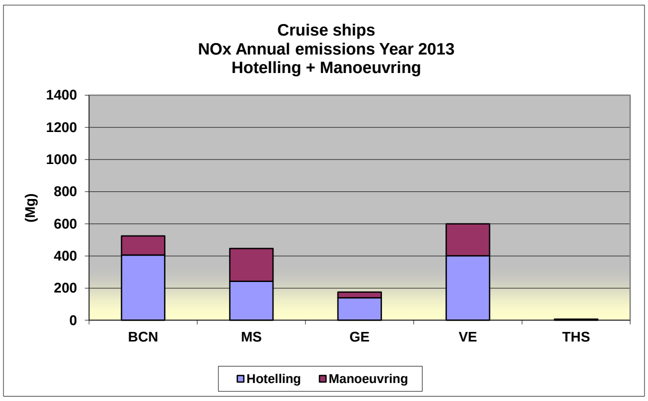


Fig. 1.3.2.2. Annual NO_x emissions by Ro-pax and other passenger ships (left) and cruise ships (right) in 2013.

Ro-pax NO_x emissions are higher than cruise vessels ones in Marseilles and Genoa and lesser in Barcelona and Venice; Thessaloniki's ones are almost the same (Figure 1.3.2.2). The ratio (in percentage value) between Ro-pax and other passenger ship NO_x emissions and cruise NO_x emissions are the following: Marseilles around 300%, Genoa around 220%, Thessaloniki 100%, Barcelona 40%, Venice 25%.

Focusing on Ro-pax emissions, the hoteling component is prevailing also for this typology of ship, as already commented for the cruise ships. The ranking among the cities is: Marseilles, Genoa, Barcelona, Venice and Thessaloniki.

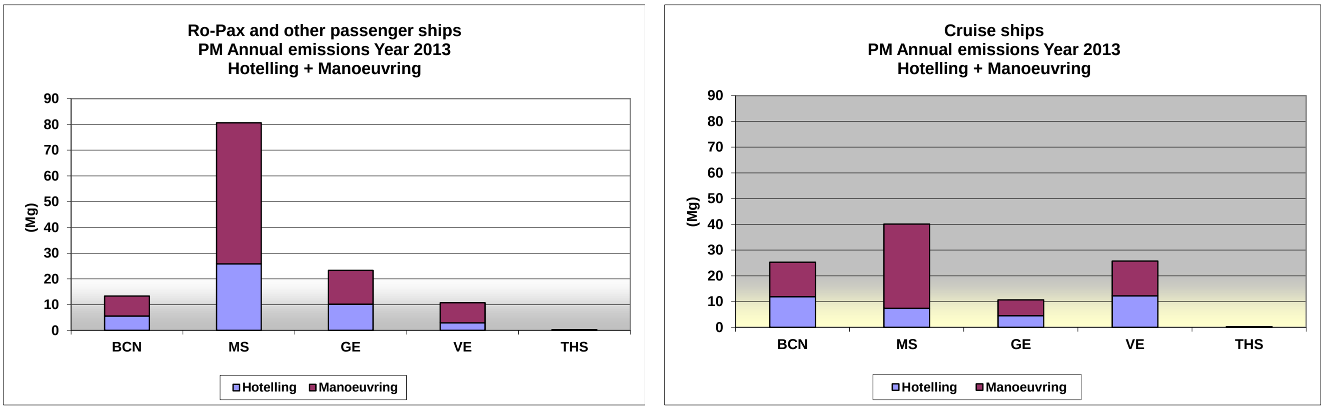


Fig. 1.3.2.3. Annual PM emissions by Ro-pax and other passenger ships (left) and cruise ships (right) in 2013.

The same ranking is recorded among the cities for the PM emissions (Figure 1.3.2.3). For this pollutant the prevailing emissions are from the maneuvering phase in all the cities. Summing up the two phase emissions, the ratio (in percentage value) between Ro-pax and other passenger ship PM emissions and cruise PM emissions are the following: Genoa around 220%, Marseilles 200%, Thessaloniki 110%, Barcelona 53%, Venice 40%.

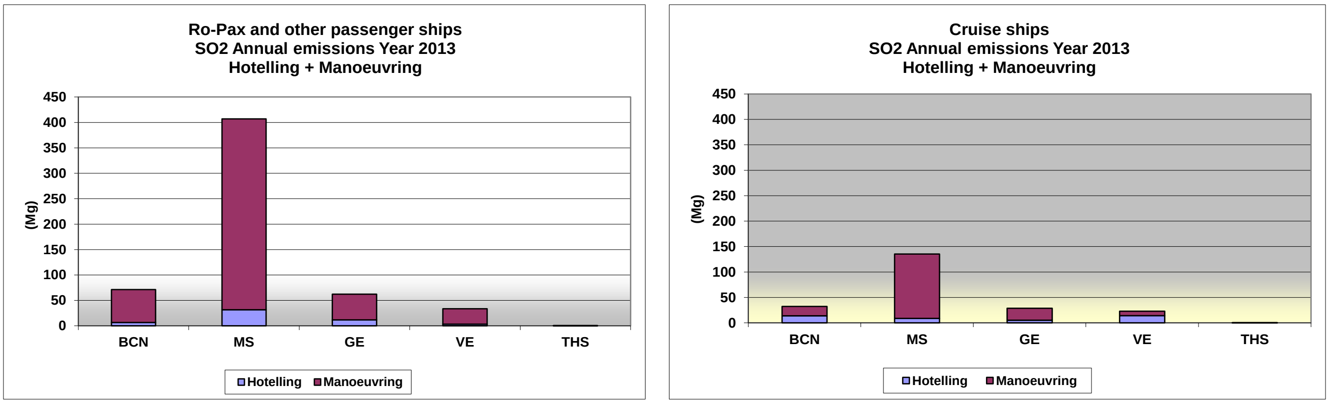


Fig. 1.3.2.4. Annual SO_2 emissions by Ro-pax and other passenger ships (left) and cruise ships (right) in 2013.

The overriding of the maneuvering phase emissions for SO_2 is even more evident than the PM (see Figure 1.3.2.4). For Ro-pax and other passenger vessels SO_2 emissions have been estimated considering the 1.5% sulfur limit for all the passenger ships inside European territorial waters beside the 0.1% sulfur limit in force for all the typologies of ships during hoteling phase (2012/33/EU Directive).

The ratio (in percentage value) between Ro-pax and other passenger ship SO_2 emissions and cruise SO_2 emissions are the following: Marseilles around 300%, Genoa and Barcelona around 220%, Venice 150% and Thessaloniki 100%.

In Figure 1.3.2.5 annual metal emissions in 2013 by Ro-pax and other passenger ships (left) are compared to cruise ship ones (right), for hoteling phase (top) and maneuvering phase (bottom). Please note that the maximum value of the histograms for the maneuvering emissions are much greater than those of hoteling, mainly because the nickel emissions in maneuvering phase are of one order of magnitude higher, linked to the use of BFO.

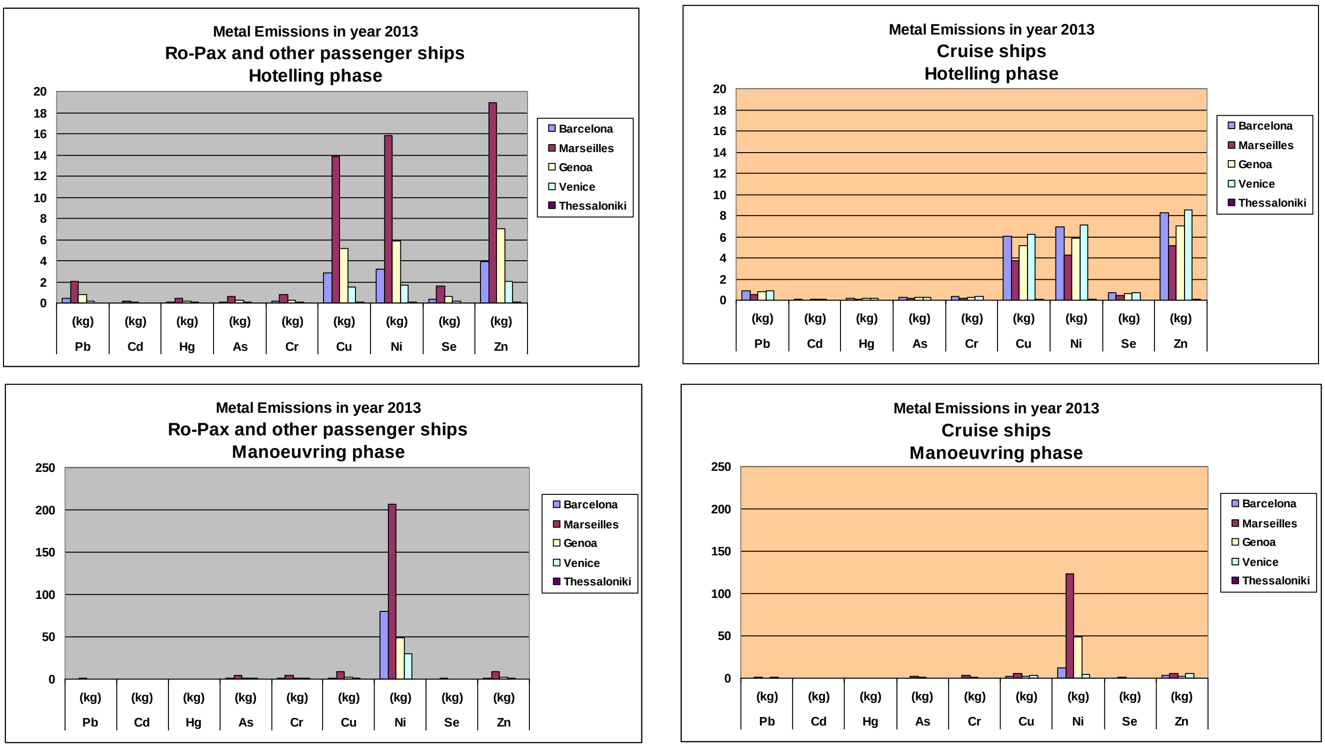


Fig. 1.3.2.5. Annual metal emissions in 2013 by Ro-pax and other passenger ships (left) and cruise ships (right); hoteling emissions (top) and maneuvering emissions (bottom).

The last comparison is for the organic micropolluntant emissions in Figure 1.3.6.

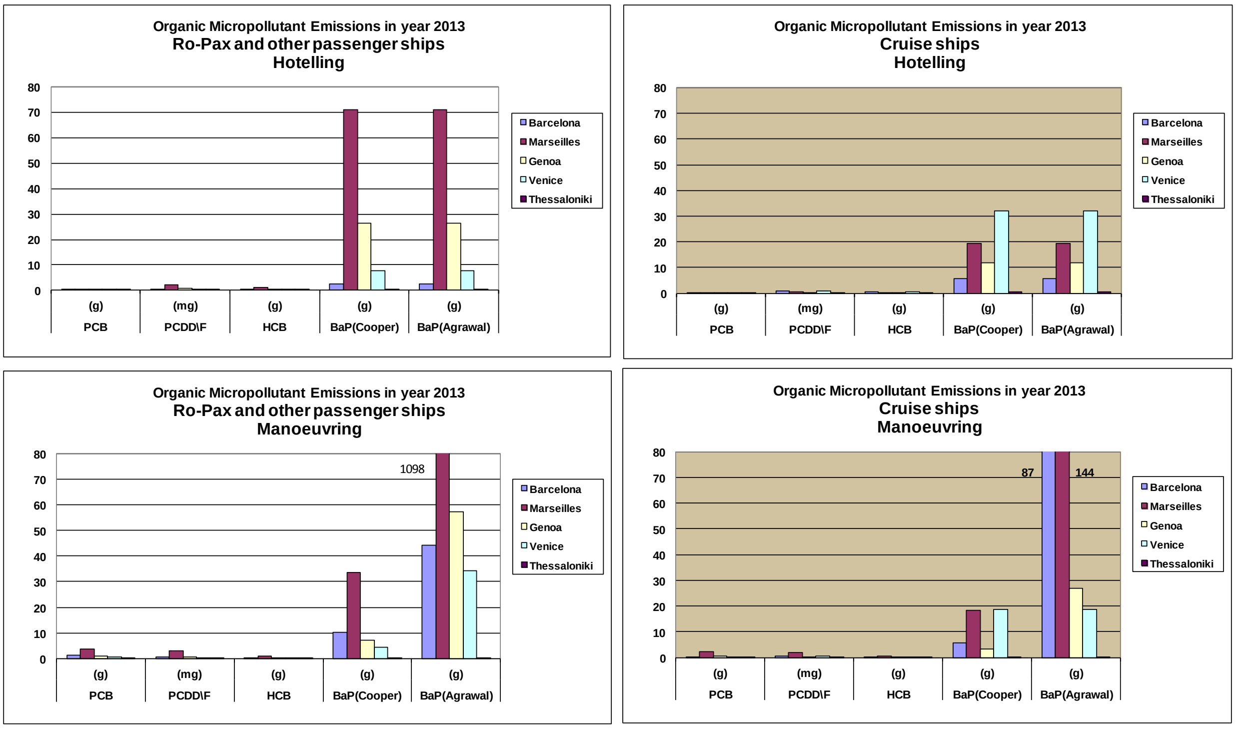


Fig. 1.3.2.6. Annual organic micropollutant emissions in 2013 by ro-pax and other passenger ships (left) and cruise ships (right); hoteling emissions (top) and maneuvering emissions (bottom).

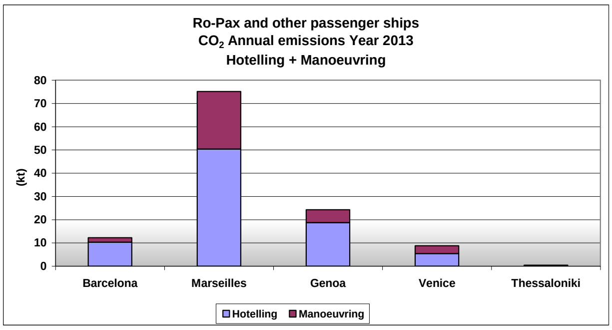
As already commented for cruise ships, the different emission factors for the BaP estimation is evident on the outcomes for the maneuvering phase, with a divergence, in the case of the ro-pax vessels in Marseilles, even more magnified between the Cooper and Gustafsson (2004) estimation and the Agrawal (2010) one because, as already explained, Ro-pax vessels have been classified as Ro-cargo vessels and for this category of ships, in the worldwide fleet assumed as reference statistic of the methodology, the percentage of slow speed diesel running on BFO is about seven times that of the passenger category.

1.4. METHODOLOGY APPLIED FOR THE CO2 EMISSION ESTIMATION

Carbon dioxide (CO_2) emissions from cruise and passenger ships have been estimated on the basis of fuel consumptions according to the methodology of EEA (2013) (already described in Section 1.1). Since the EEA guidebook does not include any emission factor for CO_2, the CO_2 emission factors were taken from the report of the International Maritime Organization (IMO, 2009). More specifically, according to the IMO (2009) report, two CO_2 emission factors for all operational phases and engine types for the two different fuels were used; 3130 kg/ton for BFO and 3190 kg/ton for MDO/MGO.

1.5. COMPARISON OF THE PORT CITIES IN TERMS OF CO2 EMISSIONS

In Figure 1.5.1 annual CO_2 emissions in 2013 by Ro-pax and other passenger ships (left) and by cruise ship (right) are compared among the harbors. CO_2 emissions are split into the two components of hoteling phase (blue bars) and maneuvering phase (red bars).



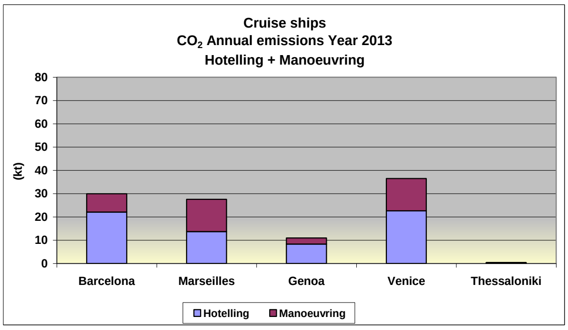


Fig. 1.5.1. Annual CO_2 emissions by ro-pax and other passenger ships (left) and cruise ships (right) in 2013.

CO2 emission ratios between the two phases and between Ro-pax and cruise vessels have similar patterns of the NOx emission (see Fig 1.3.2.2).

Hoteling component is the prevailing one in all the five harbours both for Ro-pax and cruise ships, since the greater total time spent by all the ships in this phase. In Marseilles and Genoa, Ro-pax emissions are greater than cruise ones, whereas in Barcelona and Venice the proportion is the opposite; for Thessaloniki the two components are almost the same.

2. AIR DISPERSION MODEL APPLICATION FOR THE PRESENT TIME

2.1. AIR QUALITY IMPACT APPROACH

Chapter 2 focuses on the presentation of the passenger ship plume dispersion for the present scenario in the different study areas. The reference year for present simulations was 2013. The modeling exercises consider the emissions described in Chapter 1 implemented in different dispersion models, which will be described in Section 2.2 for each study area, together with a modeled meteorology covering the entire year 2013.

The simulations were performed for macro-pollutants (i.e. NO_2, SO_2, PM_{10} and $PM_{2.5}$) and micro-pollutants (Ni, Pb, As, Cd and BaP). For all these pollutants, the European Union, with the EU DIRECTIVE 2008/50/EC, has established health-based air quality limits (AQL) which are summarized in the website http://ec.europa.eu/environment/air/quality/standards.htm. These AQL apply over differing periods of time because the observed health impacts associated with the various pollutants occur over different exposure times. In this sense, AQL limits exist for the long-term pollutant concentrations: the annual NO_2, PM_{10} and $PM_{2.5}$ values should not exceed 40 μg/m^3, 40 μg/m^3 and 25 μg/m^3 respectively; while the AQL for the annual concentrations of Pb, As, Ni, Cd and BaP has been set to 0.5 μg/m^3, 6 ng/m^3, 20 ng/m^3, 5 ng/m^3 and 1 ng/m^3. AQL limits exist also for the short-term pollutant concentrations. According to the EU legislation, the SO_2 daily concentrations should not exceed 125 μg/m^3 more than 3 times in a year, so the 99.2 percentile of the SO_2 daily concentration timeseries should not exceed 125 μg/m^3; similarly, since the SO_2 hourly concentrations should not exceed 350 μg/m^3 more than 24 times in a year, the 99.7 percentile of the SO_2 hourly concentration timeseries should not exceed 350 μg/m^3. For PM_{10}, the 90.4 percentile of the daily concentration timeseries should not exceed 50 μg/m^3, because the EU legislation allows no more than 35 PM_{10} daily concentrations in a year exceeding 50 μg/m^3. Finally, for NO_2, the 99.8 percentile of hourly concentration timeseries should not be higher than the value of 200 μg/m^3, of which 18 exceedences in a year are allowed for the NO_2 hourly concentrations. Considering also the protection of the vegetation, an AQL exists for the annual (and winter) SO_2 concentration which should not exceed 20 μg/m^3.

Within the project, taking into account also the fact that only ship emissions were dispersed in the modeling domains of the study areas, a criterion was selected so as to identify the pollutants emitted from passenger ships which could be considered as more critical in the future time air quality of the city-ports. According to the criterion, a pollutant is highlighted when its domain-wide maximum long-term and/or short-term simulated concentration statistic, as described in the previous paragraph, is exceeding the 5% of the AQL. The 5% percentage has been agreed so as to be in accordance with previous relevant air quality studies and the air quality model results of the project APICE (funded within the same MED Programme), according to which the contribution of maritime activities in the $PM_{2.5}$ levels in the studied Mediterranean port-cities (the same with these of the CAIMANs project) is in most cases higher than 5%.

2.2. PRESENT TIME PASSENGER SHIPS PLUMES DISPERSION IN EACH PORT CITY

2.2.1. Barcelona

The assessment of air pollution impact at the port of Barcelona, due to passenger and cruise ships, is implemented with CALPUFF v6.4 air dispersion model (Scire et al., 2000a), coupled to CALMET (Scire et al., 2000b). A domain of 30 x 30 km^2 extend with a horizontal resolution of 100 x 100 m is considered, in order to cover the largest part of the territorial cruising.

Elevation, land use and meteorological data fields are necessary to be inserted in the model. The land use and terrain effects have been taken from CORINE and ASTER's global Digital Elevation Model and were provided by AUTH. Further detail can be found below for Thessaloniki (Section 2.2.4). Meteorological fields near the surface were generated with the WRF-ARW model (Skamarock et al., 2008). A horizontal resolution of to 2 km has been set with 32 layers on the vertical for a domain covering the entire north-eastern Spanish Mediterranean coast. Output meteorological fields for the year 2013 are provided every hour.

In the frame of the project, all the species with air quality standards defined by EU Directives, namely nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO), arsenic (As), lead (Pb), cadmium (Cd) and nickel (Ni) are modeled with CALPUFF. The updated RIVAD/ISORROPIA scheme (Karamchandani et al., 2008; Fountoukis and Nenes 2007; Nenes et al., 1998) is used, since it uses explicit thermodynamic partitioning for gas-liquid equilibrium. Also with this mechanism, addition capabilities are included, such as aqueous phase transformation and an updated wet deposition, where the latter takes into account the in/below-cloud chemistry.

All the emissions have been introduced into the CALPUFF modeling system as time and space-variant discrete point sources. Further details regarding source parameterization in CALPUFF can be found in Table 2.2.1.1.

Table 2.2.1.1. Source parameterization used in CALPUFF for Barcelona ship emissions.

Temperature of the effluent at stack outlet (exit gas temperature)	160° C
Exit velocity of the effluent at stack outlet (exit velocity	10 m/s
Diameter of the stack	1.5 m
Height of the stack, depending on the gross tonnage (GT) of the ships	
in hoteling mode:	
for GT < 40 ktons	10 m
for 40 ktons< GT < 90 ktons	30 m
for 90 ktons< GT < 115 ktons	55 m
for GT > 115 ktons	60 m
in maneuvering and cruise mode:	
for GT < 40 ktons	10 m
for GT > 40 ktons	30 m

The vessels emissions have been estimated by splitting them into the three phases of navigation (cruising, manoeuvring and hoteling). Then, considering representative velocities along the track mode of the vessels, points for every 15 minutes are determined and the respective emissions (for every simulated pollutant) are redistributed among them. Finally, an emission rate is assigned to every point, for a duration of 1 second in cruising/maneuvering mode and 1 minute during hoteling. Thus, when a ship reaches one point, a puff is released on the same timeframe. In this manner, it is possible to track the movement of the vessel, resulting in more realistic simulations.

For the base case scenario regarding the present situation (BC2013) at the port of Barcelona, the analysis of the results shown that the most important pollutants to be considered (in terms of Air Quality impact) are NO_2, SO_2, PM_{10} and Ni. These are the only that exceed at least the 5% of the air quality standards/limits (AQL) for at least one of annual average, 1-hour and daily percentile.

With respect to the NO_2 maximum 1-hour average considering the whole domain, the concentrations exceed the AQL (129.9%), with the respective annual value over the 23.1% of the reference framework. On the other hand, SO_2 is also above the 5% of the air quality standard for the 1-hr values (7.6% of AQL) and the annual mean (8.5% of AQL), being the daily concentrations close to the 5% of AQL (4.7%). For PM_{10}, the daily concentrations do not meet the value of the 5% of the air quality threshold considered (8.1%), with annual average much lower (only 2.0%). Last, the annual mean concentrations for Ni can represent a 6.5% of the corresponding AQL.

The 1-hour average NO_2 surface concentrations can reach up to 260 μg/m^3 just over the coastline, exceeding considerably the AQL (200 μg/m^3, 99.8% percentile of the 8760 hourly concentrations). The central part of the port of Barcelona is affected the most, with concentrations ranging from 75 to 100 μg/m^3, as seen in Figure 2.2.1.1 (left).

Regarding the SO_2 max. 1-hr concentration (Figure 2.2.1.1, right), which shows the temporal variations with ships movement, we can identify that the region with the highest concentrations is found around the Buoy “N” (together with the last part of cruising, where the ships still consume BFO as a fuel). This area comprises the route of maneuvering for the north pier, and has the highest concentrations over the domain, with 26.7 μg/m^3 (about 7.6% of AQL: 350 μg/m^3, 99.7% percentile of the 8760 hourly concentrations).

When considering the daily values, we observe that the most affected areas by PM_{10} in the port are those related to the arrival and hoteling of ferries (Figure 2.2.1.2), with concentrations reaching 4 μg/m^3 (8.1% of AQL: 50 μg/m^3, 90.4% percentile of the 365 daily concentrations).

Last, the annual values are strongly influenced by the maneuvering phase, as can seen in Figure 2.2.1.3. Maximum annual values are found near the Buoy “S”, where the approach to the Addosat Wharf begins. The pollutants that play an important role from an annual perspective are NO_2 (9.2 μg/m^3; 23.1% of AQL: 40 μg/m^3), SO_2 (1.7 μg/m^3; 8.5% of AQL: 20 μg/m^3), and Ni (1.29 ng/m^3; 6.5% of the AQL: 20 ng/m^3).

Due to the temporal character, both 1-hour and daily averages depend strongly on the ships type specifications (ferry or cruise, gross tonnage, etc.). Thus, differences of orders of magnitudes can appear between them and the annual averages, where the latter depends also on vessels traffic.

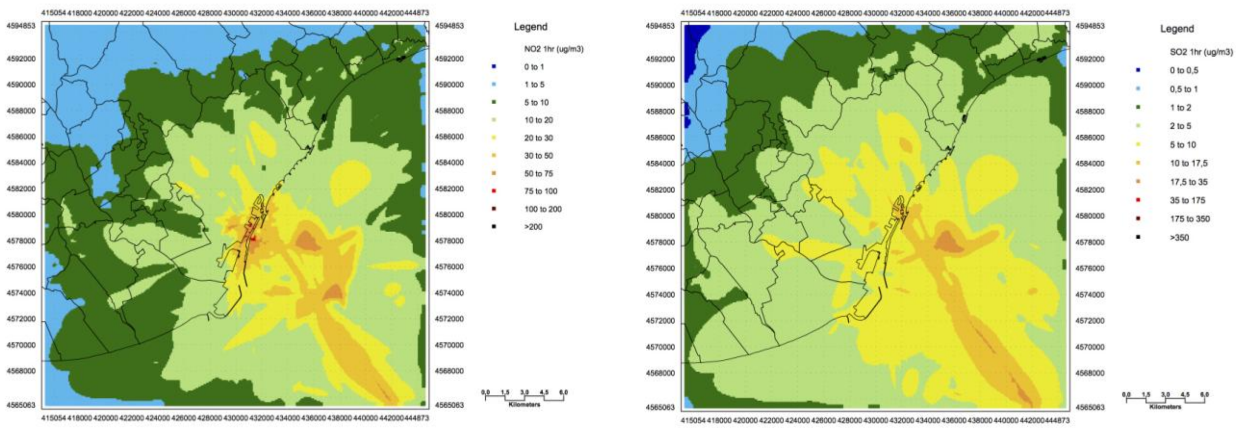


Fig. 2.2.1.1. (left) 99.8% percentile of the 8760 1-hr NO_2 concentrations.
(right) 99.7% percentile of the 8760 1-hr SO_2 concentrations. Reference year 2013.

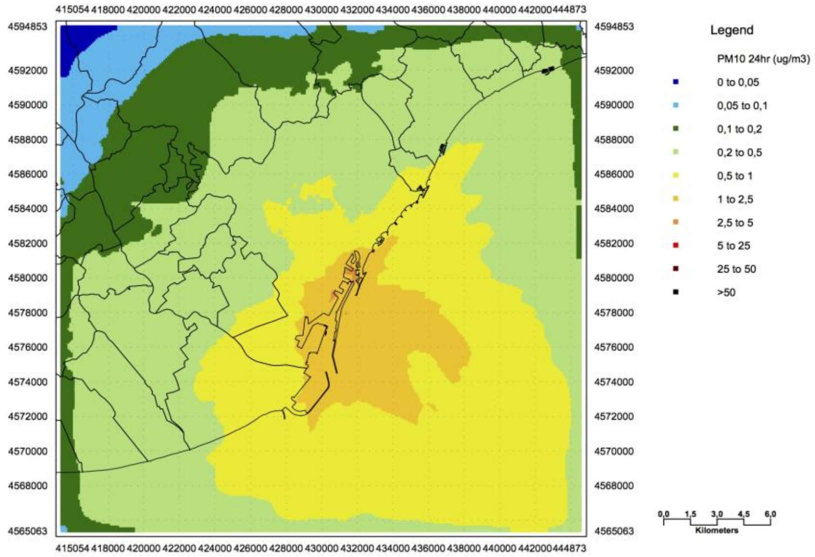


Fig. 2.2.1.2. 90.4% percentile of the 365 daily PM_{10} concentrations. Reference year 2013.

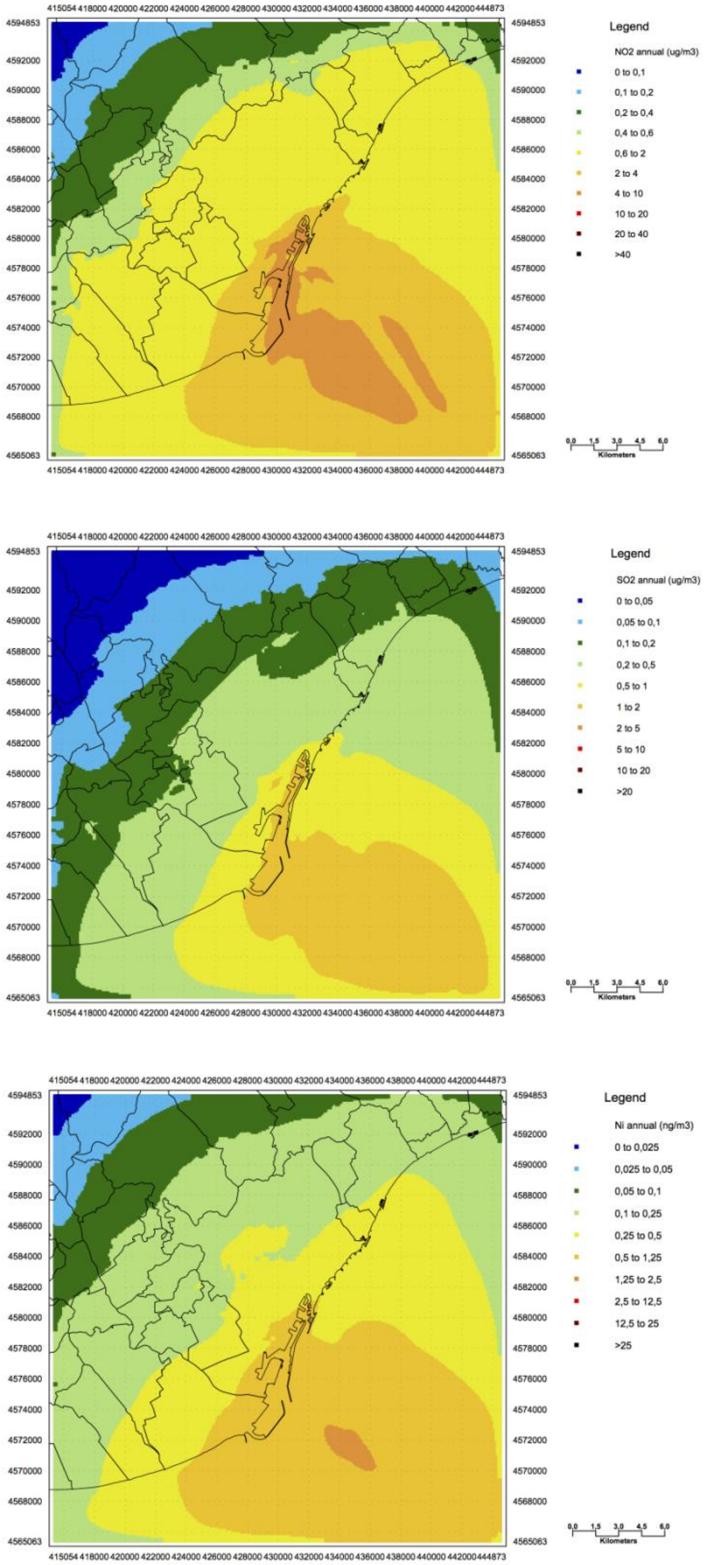


Fig. 2.2.1.3. Annual NO_2 (top), SO_2 (center) and Ni (bottom) concentrations in the domain of Barcelona for the reference year 2013.

2.2.2. Genoa

Simulations for the Genoa area were performed with ADMS 4.2 code developed by CERC. ADMS is a steady-state gaussian plume dispersion model, able to simulate buoyant and passive releases from different kind of sources (point, jet, line, area and volume sources). It has been extensively validated and it is commonly used for environmental impact assessment with scientific and regulatory purposes.

Meteorological input data are extracted by non-hydrostatic mesoscale model WRF-ARW (Skamarock et al., 2008), operative at Physics Department of Genoa University. Simulations were performed over a large 10km x 10km spatial resolution domain including the whole Europe then downscaled to an intermediate 3 x 3 km^2 domain over the Northern Italy then finally providing hourly simulations over the whole Liguria Region (including Genoa domain), with spatial resolution of 1 x 1 km^2.

The description of boundary layer is obtained by FLOWSTAR code (integrated with ADMS), which describes the air flow over complex terrain, including stratification effects. Complex terrain is described by orography and roughness data, provided with spatial resolution of 90m x 90m (orography data were obtained by national IGM database while roughness values were calculated on the basis of CORINE Land Cover CLC2000 data).

Pollutant emissions are calculated using the BUH program developed by ARPAV (see section 2.1.2 for further details). Ships in hoteling phase are described as buoyant line source of 5 m width and 30 m length, with height of 60m and 30m, respectively for cruises ships and other passenger ships. Ships in maneuvering phase are described as buoyant line source of 10 m width, with height of 60m and 30m, respectively for cruises ships and other passenger ships, and the total maneuver is assumed to be 3200 m long. In Figure 2.2.2.1 we report a picture of Genoa Maritime Station where we show the sources geometry defined for the simulation.

Fig. 2.2.2.1 – Passenger ships emission sources in Genoa area simulations. On the left ships in hoteling phase, on the right ships in maneuvering phase.

The simulation domain covers a 10 x 10 km^2 area centered on Genoa touristic harbor and including the urban inhabited area most affected by the emissions due to passenger ships (see Figure 2.2.2.2). Receptors for pollutant concentration calculation are placed on a regular square grid with spatial resolution approximately 100m. Simulations are performed on hourly basis. Wet and dry deposition are considered, while a simple chemistry scheme is adopted, describing NO-NO_2 balance.

Fig. 2.2.2.2 – Simulation domain for the Genoa area. The cyan box includes the touristic harbor and the violet box show the simulation domain.

In the following figures we report the concentration maps obtained by simulation analysis for the pollutant with the most relevant impact with respect to air quality limits set by the EU regulation.

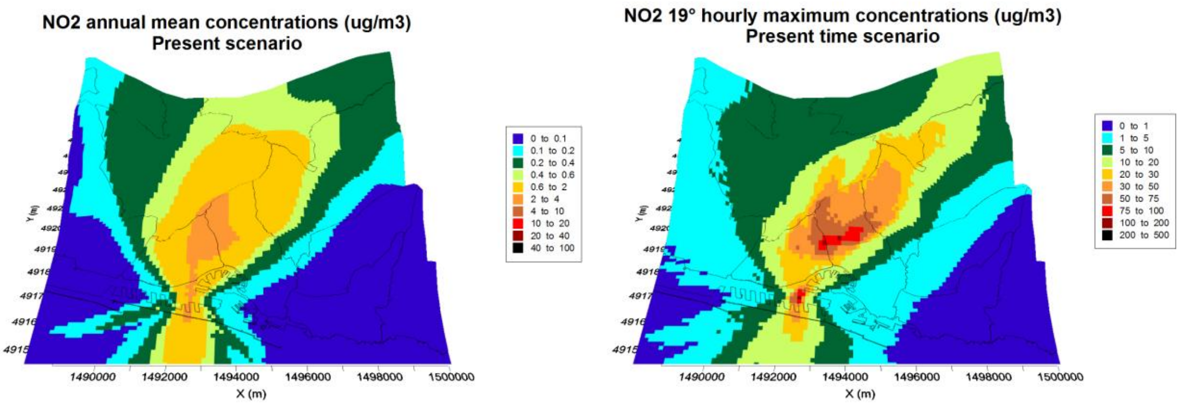


Fig. 2.2.2.3 – NO_2 concentration maps obtained with ADMS simulations. On the left side average values over the simulation period. On the right side 19^{th} maximum values of hourly concentrations.

The highest impact was observed for NO_2 and SO_2, with pollutant concentrations in a relevant area extending from the maritime station docks to the partially inhabited hills above the harbor (NE side) exceeding the 5% of air quality limits. In particular the most critical situation was obtained for NO_2, with the following maximum values observed over the simulation domain:

- 270 µg/m^3 for the 99.8 percentile of hourly NO_2 concentration, corresponding to 135% of air quality limit (AQL).
- 2,98 µg/m^3 for the annual mean of hourly NO_2 concentration, corresponding to 7.5% of AQL.

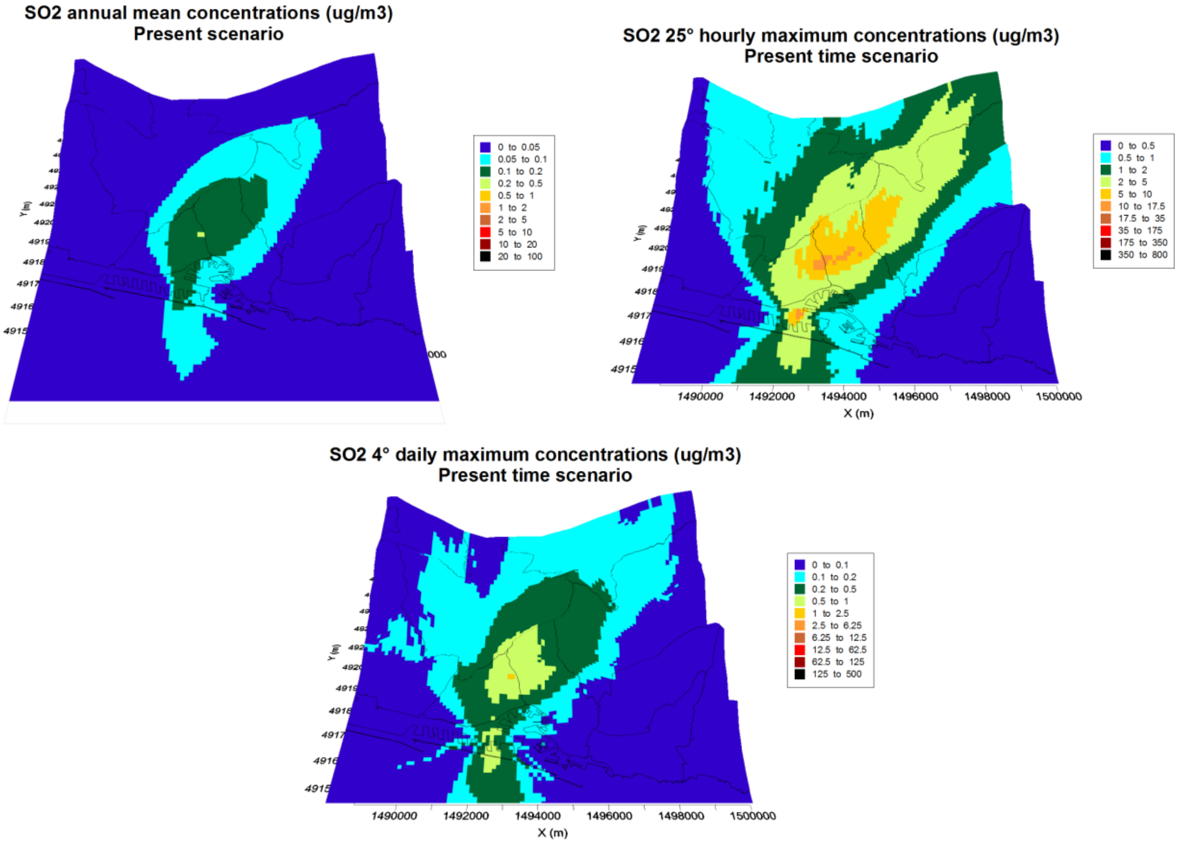


Fig. 2.2.2.4. SO_2 concentration maps obtained with ADMS simulations. On top left side average values over the simulation period. On the top right side the 25th maximum values of hourly concentrations. The bottom figure reports 4th daily maximum concentration values.

SO_2 concentrations were less alarming, showing the effectiveness of the legally introduced reduction of sulphur content in fuel for ships in hoteling phase. The only remarkable value was obtained for the hourly concentrations, with maximum percentile values close to 5% of AQL:

- 15.7 μg/m^3 (99.7 percentile, corresponding to 4,5% of SO_2 air quality limit (AQL).

2.2.3. Marseille

Over the Marseille area, ADMS Urban (v3.1) is used to compute plume dispersion outcomes from ships emissions. This model is a Gaussian model designed to run at the scale of an urban area with finer resolutions. It provides a dispersion of pollutants released by multiple sources without particles chemistry.

The ADMS Urban model is used over a domain including the Eastern port of Marseille with an adaptive spatial resolution: finer close to the main pollutant sources and over the areas including a potential mitigation action (Figure 2.2.3.1). Receptor points are computed with a height of 1.5m. Meteorological data are taken from a meteorological station located in Marseille. Sources associated to maritime activity are modeled as explicit sources. They are included as volumetric sources between 20 and 50m above the sea level to consider the different stack heights of ships and also the spatial dispersion of trajectories.

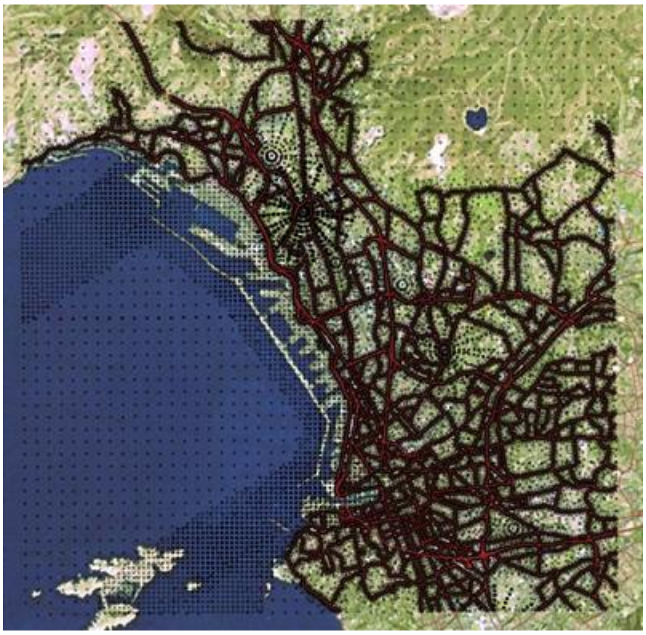


Fig. 2.2.3.1 ADMS Urban simulation area and receptor points (grey dots).

According to the criterion defined in this project, i.e. to consider any pollutant exceeding the 5% of the short-term (hourly, daily) and/or long-term (annual) air quality limits (AQL) set by EU, the most important results to be considered in this project in the Marseille area are NO_2, SO_2 and Ni.

Figure 2.2.3.2 presents map results for NO_2 pollutant. Figures 2.2.3.3 shows the dispersion results for SO_2 pollutant while Figure 2.2.3.4 illustrates the results obtained for Nickel.

In Figure 2.2.3.2a, showing the 99.8 percentile of the hourly NO_2 concentrations, the domain wide maximum value for this NO_2 statistic is estimated to be localized over the port with the maximum value of 80 µg/m^3 representing 40% of the hourly AQL for NO_2 (i.e. 200 µg/m^3). The 5% of the hourly AQL for NO_2 is exceeded all over the urban area, i.e. in the whole simulation domain. In the Figure 2.2.3.2b, showing the annual concentrations of NO_2, the domain wide maximum NO_2 annual value is simulated over the port and reaches the value of 15 µg/m^3 representing 38% of the NO_2 annual AQL.

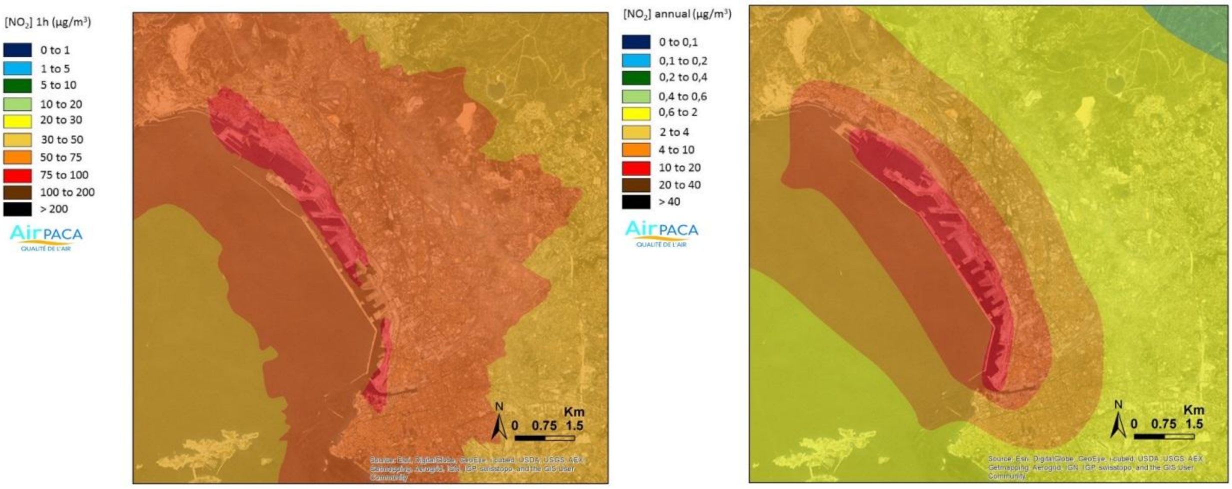


Fig. 2.2.3.2. Dispersion results for NO_2 pollutant, at present time (a) 99.8 percentile of the hourly concentrations (b) annual mean.

Figure 2.2.3.3 shows the statistics obtained for the SO_2 pollutant at present time. Daily, hourly and annual SO_2 levels are exceeding 5% of the corresponding AQL value mainly on the port area, but also on a big part of the urban area for the 99.7 percentile of the hourly SO_2 concentrations time series. In Figure 2.2.3.3 (c), the domain wide maximum value for the SO_2 statistic is estimated close to the port, and more specifically on the cruise terminal (Northern part of the port). It reaches the value of 68 µg/m^3 representing 19% of the hourly AQL for SO_2 (i.e. 350 µg/m^3).

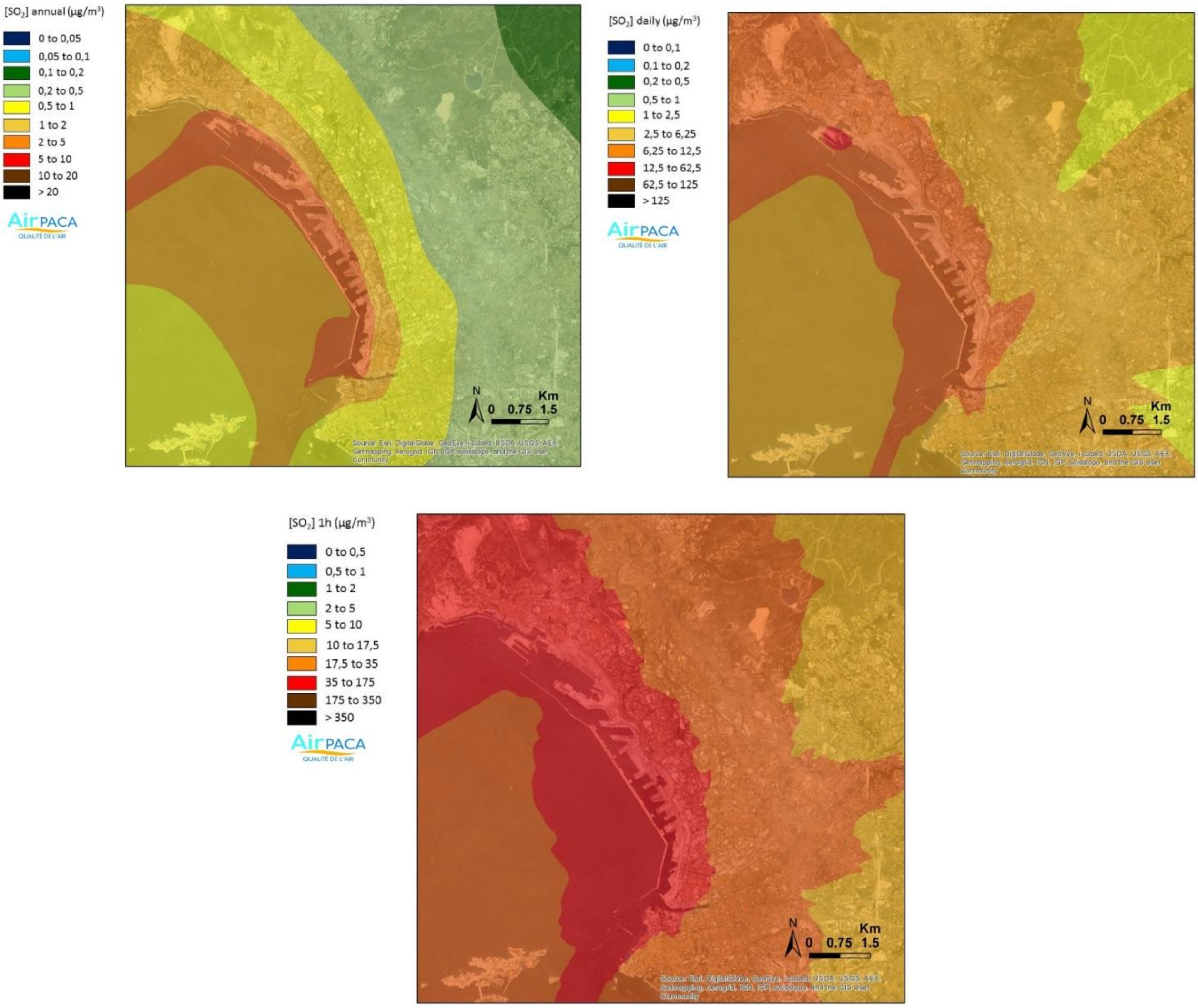


Fig. 2.2.3.3. Dispersion results for SO_2 pollutant, at present time
(a) annual mean (b) 99.2 percentile of the daily concentrations and (c) 99.7 percentile of the hourly concentrations.

Figure 2.2.3.4 presents the annual mean obtained for the Ni pollutant at present time. This pollutant is a specific tracer for maritime emissions with Bunker Fuel Oil. The 5% of AQL is exceeded all over the port area. Maximum Ni concentrations are forecasted over the cruise terminal (Northern part of the port), with a maximum value of 2 ng/m^3, representing 10% of the corresponding AQL (20 ng/m^3). Concentrations over the urban area are however remaining lower than the 5% of the AQL.

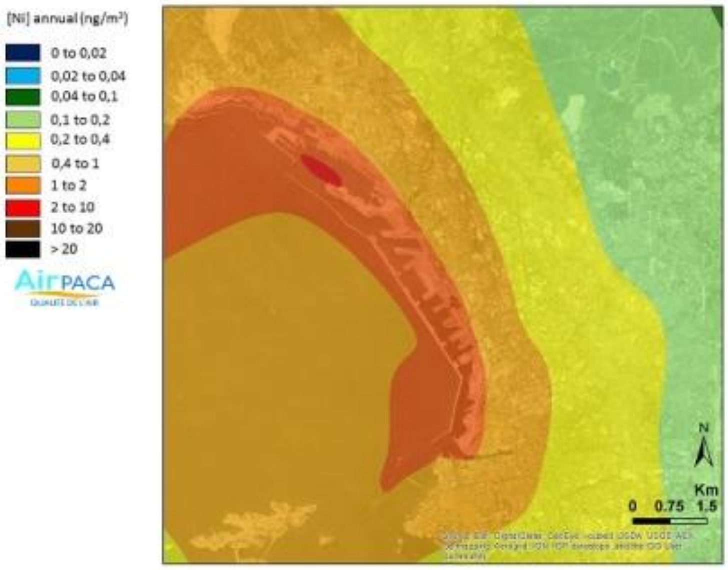


Fig. 2.2.3.4. Dispersion results (annual mean) for Ni pollutant, at present time

2.2.4. Thessaloniki

The assessment of the impact of passenger and cruise ships on the air quality of Thessaloniki was performed with the CALPUFF v6.4 air dispersion model (Scire et al., 2000a).

The model was applied over a domain of 30km x 30 km extent of 100 m grid resolution covering the largest part of the ship routes within the Thermaikos Gulf (Fig.1.2.4.1).The preprocessor used for the preparation of the meteorological fields ready for the implementation of CALPUFF is CALMET (Scire et al., 2000b). Elevation, land use and meteorological data are necessary as input data for the application of this preprocessor.

The CORINE 2000 database was used to provide land use information for 44 land use types in 100m horizontal spatial resolution. To properly resolve the terrain effects within CALMET, the 30m spatial resolution ASTER's global Digital Elevation Model (provided by the U.S. Geological Survey web site, http://earthexplorer.usgs.gov/) was chosen. CALMET was implemented driven by the simulations of the Weather Research and Forecast - Advanced Research Weather (WRF-ARW, version 3.5.1) meteorological model (Skamarock et al., 2008). The WRF model was applied over a coarse domain in 10 km spatial resolution covering the Eastern Mediterranean region and a nested domain in 2 km spatial resolution covering the greater Thessaloniki area. The WRF-

ARW grid consisted of 27 vertical layers up to 100hPa. The model developed initial and boundary conditions based on the re-analysis forecast of ECMWF in 0.25^o spatial resolution. WRF-ARW and CALMET output meteorological fields were calculated every hour spanning the year 2013.

The updated RIVAD/ISORROPIA scheme (Karamchandani et al., 2008; Fountoukis and Nenes 2007; Nenes et al., 1998) was utilized among the chemical mechanisms available within CALPUFF, since it uses explicit thermodynamic partitioning for gas-liquid equilibrium. Also this mechanism includes aqueous phase transformations and is associated with an updated wet deposition taking into account the in/below-cloud chemistry. Monthly values of O_3, NH_3, H_2O_2 concentrations representative of the study domain were used as CALPUFF input data. These values were estimated on the basis of the near surface results of the Comprehensive Air Quality Model with extensions model (CAMx version 5.30) applied over the greater Thessaloniki area in 2km spatial resolution for the year 2013 in the framework of the EU FP7 project “Monitoring Atmospheric Composition and Climate Interim Implementation” (MACC II) (Grant agreement no: 283576).

Great care has been taken to accurately describe the ship pollutant emissions along the vessel’s trajectory while using a number of discrete point sources. Ship emissions calculated separately for the cruising and maneuvering operation modes, as described in chapter 1, were released in the atmosphere in instantaneous emission puffs every 1 minute. In order to track the vessels’ movement, the point sources were moving with the velocity of the ship along the ship route. Ship emissions in the hoteling phase were simulated as continuous releases from a stationary point source.

Considering as a significant impact of cruise and passenger ships on air quality the pollutant concentrations exceeding the 5% of the short-term (i.e. hourly, daily) and/or long-term (i.e. annual) air quality limits (AQL) set by EU then, according to the CALPUFF results for the reference year 2013, it is revealed that the most important pollutants to be considered for the air quality of Thessaloniki are NO_2 and SO_2. Figures 2.2.4.1 and 2.2.4.2 present maps of specific percentiles of the timeseries of the hourly and daily NO_2 and SO_2 concentrations. The percentiles shown are linked to the number of exceedances of the EU AQL. Figure 2.2.4.3 show the spatial distribution of the NO_2 and SO_2 annual values.

In Figure 2.2.4.1a, the domain wide maximum value for the NO_2 statistic is estimated close to the passenger terminal and it takes the value of 270 μg/m^3 representing 135% of the hourly AQL for NO_2 (i.e. 200 μg/m^3). The 5% of the hourly AQL for NO_2 is exceeded over the city center of Thessaloniki, the east coast and the greater part of the maritime areas of the modeling domain. Over the urban center of Thessaloniki the 99.8 percentile of the hourly NO_2 concentrations timeseries takes values that range between 20 and 100 μg/m^3. In Figure 2.2.4.3a, the domain wide maximum NO_2 annual value is simulated over the port and takes the value of 2.6 μg/m^3 representing 6.4% of the NO_2 annual AQL.

As for SO_2, it is only the 99.7 percentile of the hourly SO_2 concentrations timeseries that is exceeding the 5% for the corresponding AQL. Daily and annual SO_2 levels are generally low. In Figure 2.2.4.1b, the domain wide maximum value for the SO_2 statistic is estimated close to the passenger terminal of the port and it takes the value of 24 μg/m^3 representing 6.9% of the hourly AQL for SO_2 (i.e. 350 μg/m^3).

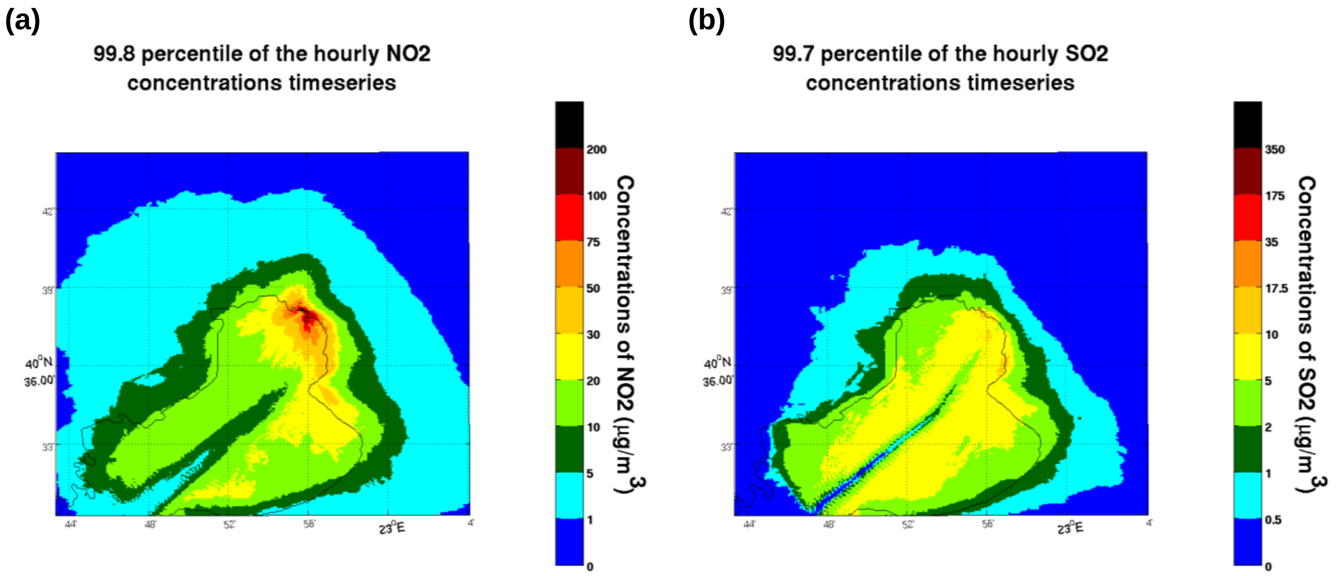


Fig. 2.2.4.1. Percentiles of the timeseries of hourly pollutant concentrations for the year 2013: (a) NO_2 and (b) SO_2.

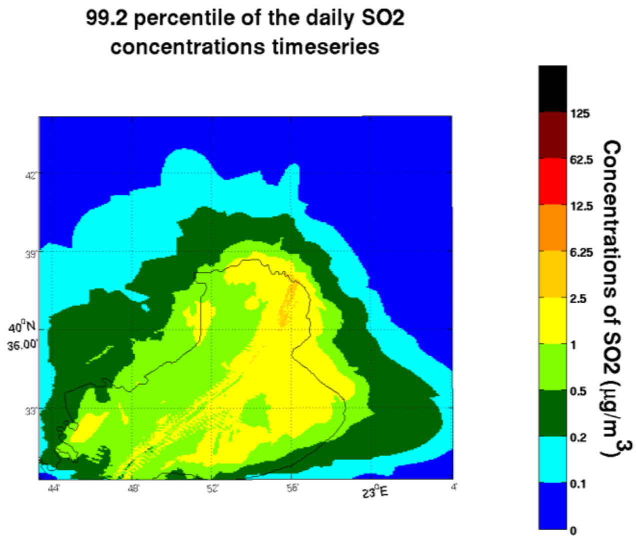


Fig. 2.2.4.2. 99.2 percentile of the timeseries of daily SO_2 concentrations for the year 2013.

(a) **(b)**

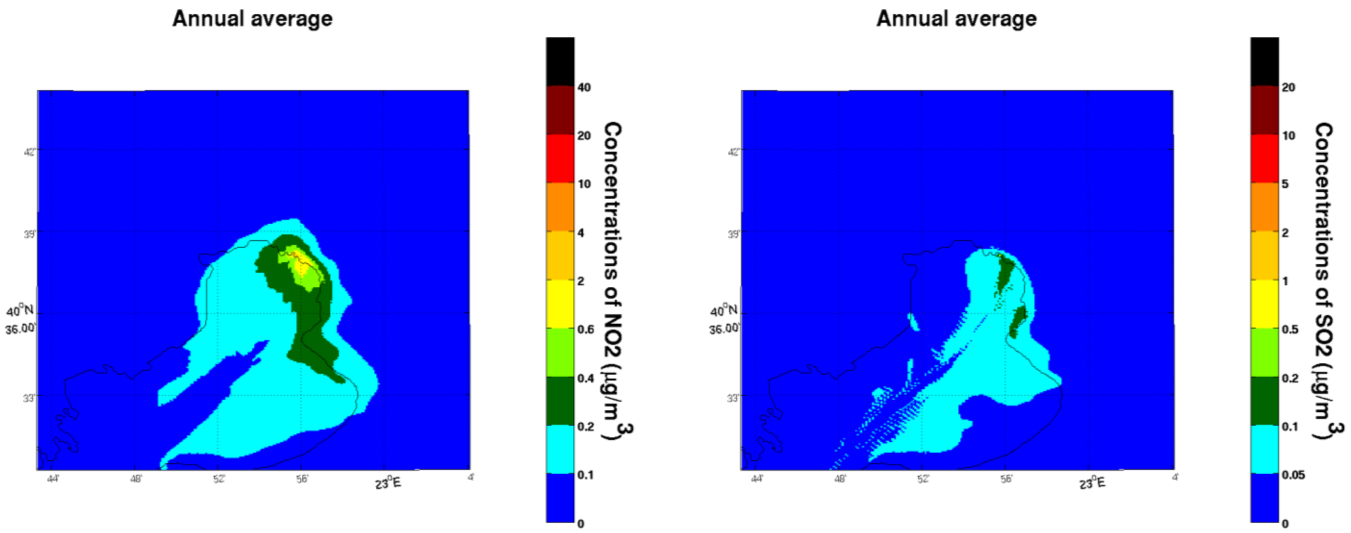


Fig. 2.2.4.3. 2013 annual concentrations of (a) NO_2 and (b) SO_2.

2.2.5. Venice

The assessment of air pollution impact for all ships arriving and departing to and from the Port of Venice is implemented with CALPUFF air dispersion model (Scire et al., 2001, v. 5.8, EPA approved). A domain of 23.5-by-23 km^2 extend with 500 m grid resolution is utilized, in order to cover all the historical city, the urban area of Mestre, that is the mainland of Venice, the maneuvering routes inside the Venetian lagoon and about 10 km of cruise route outside the Lido entrance of the Lagoon. Over both the historical city of Venice and the mainland area of Mestre a resolution of 100 m is reached by additional receptor points (see Fig. 2.2.5.1).

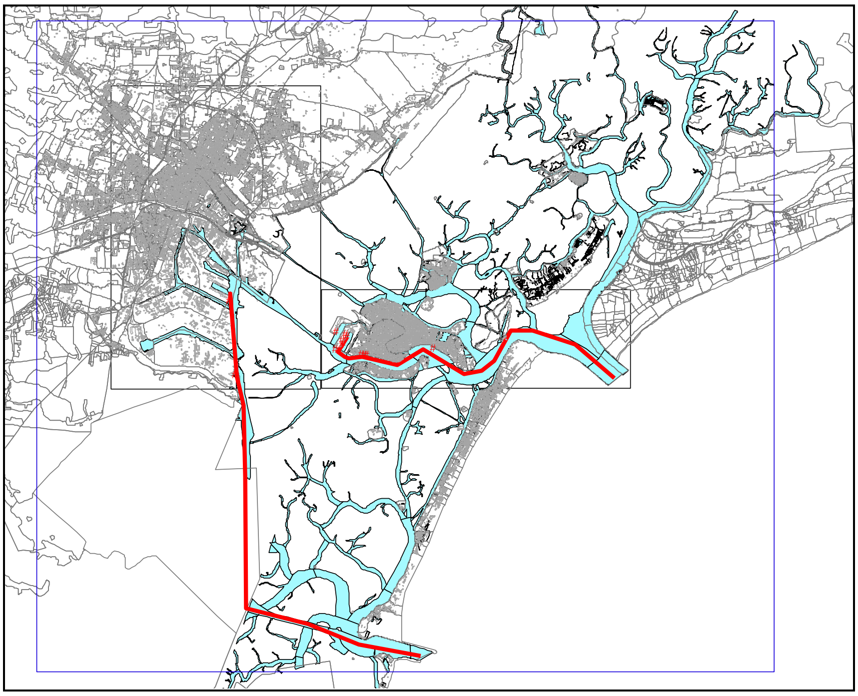


Fig. 2.2.5.1. Study area of Venice (blue area with 500x500m^2 horizontal resolution and inner areas over Mestre and Venice with 500x500m^2 horizontal resolution).

The meteorological input to CALPUFF is obtained by the diagnostic 3-dimensional meteorological model CALMET (Scire et al., 2000, v. 5.8). The meteorological fields over the domain of 23.5-by-23 km^2 with 500 m grid resolution are calculated as downscaling of a wider domain all over the Veneto Region area, with an extension of around 200-by-168 km^2 and 4 km resolution. The CALMET model is implemented from observed data recorded in 40 meteorological stations, of which 9 synoptic stations by the Italian Air Force Met Service, 30 by the ARPAV meteorological network, and 1 station by the private network of Association of Industries in Porto Marghera (EZI, http://www.entezona.it/). On the sea, data from the meteorological station, operated by the Venice Municipality and sited on the National Researches Centre (CNR) platform, are used, whereas upper air data are taken from the 3 nearest RAOB Sounding Stations (Milano-Linate, Udine-Campoformio and Bologna-San Pietro Capofiume). The vertical grid definition considers 10 layers till 3000 m of height. Output meteorological fields are provided every hour, spanning all the year 2013.

In the frame of the project, all the species with air quality standards, defined by EU Directives (Directive 2008/50/EC), are simulated (NO_2, SO_2, PM, CO, As, Pb, Cd, Ni). CALPUFF run is set up with the RIVAD/ARM3 chemical mechanism, that treats the NO to NO_2 conversion process in addition to the NO_2 to total NO_3 and SO_2 to SO_4 conversions, with equilibrium between gaseous HNO_3 and ammonium nitrate aerosol. The necessary ozone concentrations are taken as hourly values from ARPAV air quality stations, whereas the ammonia concentration is settled to 10 ppb, as default.

Ship emissions in all the three modes (hoteling, maneuvering and cruising) are entered in CALPUFF as stationary stack emissions, inputting hour by hour the flow rates estimated by the BUH program (see Chapter 1) aggregated for ship typology (cruise ships, other passenger ships and commercial ships) and quays groups. More precisely, thanks to the information about the quay registered for the hoteling of every ship in the db of the 2013 ship calls, emissions have been aggregated into around 40 groups of quays whose position is used for the hoteling parameterization.

Maneuvering emissions are further aggregated summing up all the quays of the main terminals (Marittima, Santa Marta/San Basilio, Riva 7 Martiri/San Biagio, Salute, Porto Marghera) and emissions are released every 250 m of the maneuvering route that, for the mean velocity of the ship in maneuvering mode, corresponds to about a position every 10 minutes.

Cruise emissions are similarly managed as multiple stack releases every 500 m of cruise route outside the Lido lagoon entrance, summing up all the ships arriving or departing at the same hour of the year. Further details about the point source parameterization set up in CALPUFF are listed in table 2.2.5.1.

For the present case scenario of the port of Venice, analysis of the air dispersion outcomes shows that the most important pollutants in terms of Air Quality impact are

NO_2 and SO_2. These are the only pollutants that exceed the 5% of the air quality limits (AQL): NO_2 for both the long term limit (annual average) and short term limit (1-hour percentile) whereas SO_2 only for the 1-hour percentile. Specifically, the maximum value on the territory for the annual NO_2 concentrations (Figure 2.2.5.1) is less than 4 µg/m^3 (around 9% of the AQL set at 40 µg/m^3) and its forecast by the model on the water in front of and behind the Marittima Terminal in the historical city. The area exceeding the 5% of the AQL reaches also a very limited area of the city (mainly the passenger terminal itself).

Table 2.2.5.1. Source parameterization used in CALPUFF for Venice ship emissions.

Temperature of the effluent at stack outlet (exit gas temperature)	160° C
Exit velocity of the effluent at stack outlet (exit velocity	10 m/s
Diameter of the stack	1.5 m
Height of the stack, depending on the gross tonnage (GT) of the ships	
in hoteling mode:	
for GT < 40 ktons	10 m
for 40 ktons < GT < 90 ktons	30 m
for 90 ktons < GT < 115 ktons	55 m
for GT > 115 ktons	60 m
in maneuvering and cruise mode:	
for GT < 40 ktons	10 m
for GT > 40 ktons	30 m

As for the short term limit of NO_2 (Figure 2.2.5.2), the maximum value of 99.8 percentile of the hourly NO_2 concentrations in a year (that corresponds to the 19th rank of the hourly concentrations in a year) is estimated close to the cruise terminal (174 µg/m^3, around 87% of the hourly AQL set at 200 µg/m^3); over the Venice historical center, the 99.8 percentile of the hourly NO_2 concentrations ranges between 50 and 120 µg/m^3 (from 25% to 60% of the AQL).

For the hourly limit of SO_2 concentrations, the maximum value of 99.7 percentile of the hourly SO_2 concentrations in a year (that corresponds to the 25th rank of the hourly concentrations in a year) calculated in the lagoon area is 22 µg/m^3 (6% of the hourly AQL). A greater concentration of 32 µg/m^3 is estimated outside the lagoon, where the cruise ships are considered to use also BFO that is, on the other end, banned by the

Blue Flag 2 Agreements signed by the Cruise Company in 2013 for the maneuvering phase inside the Venetian lagoon.

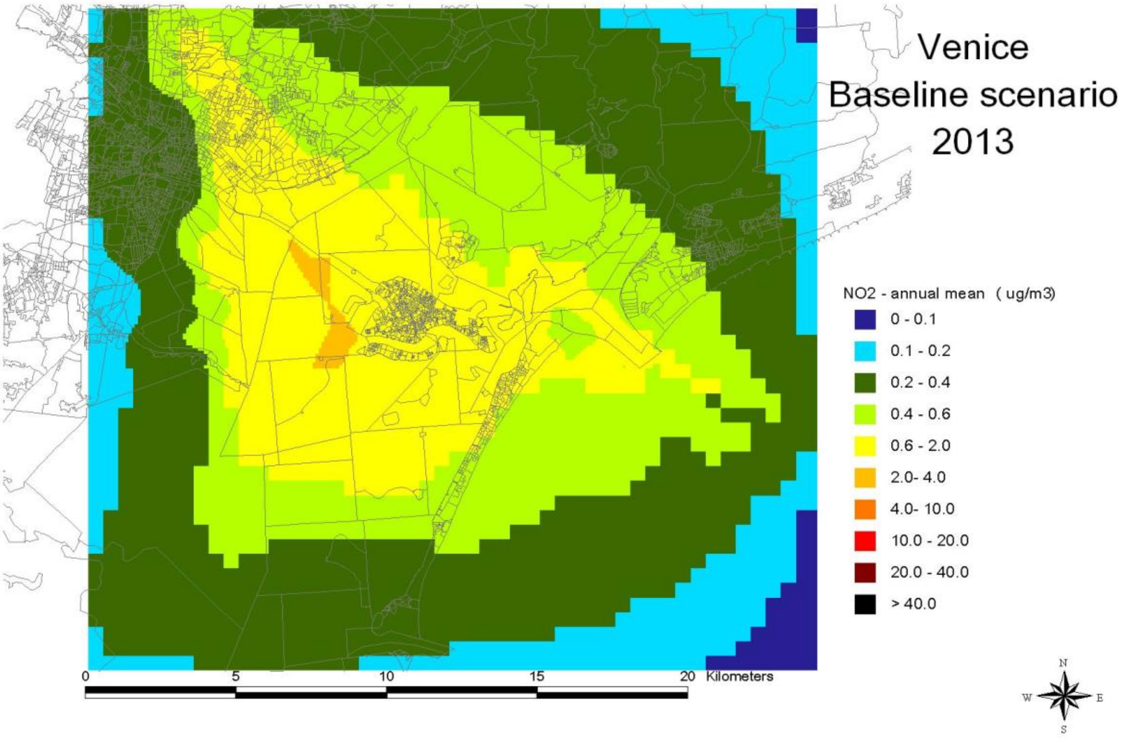


Figure 2.2.5.1. Annual NO_2 concentrations for the reference year 2013.

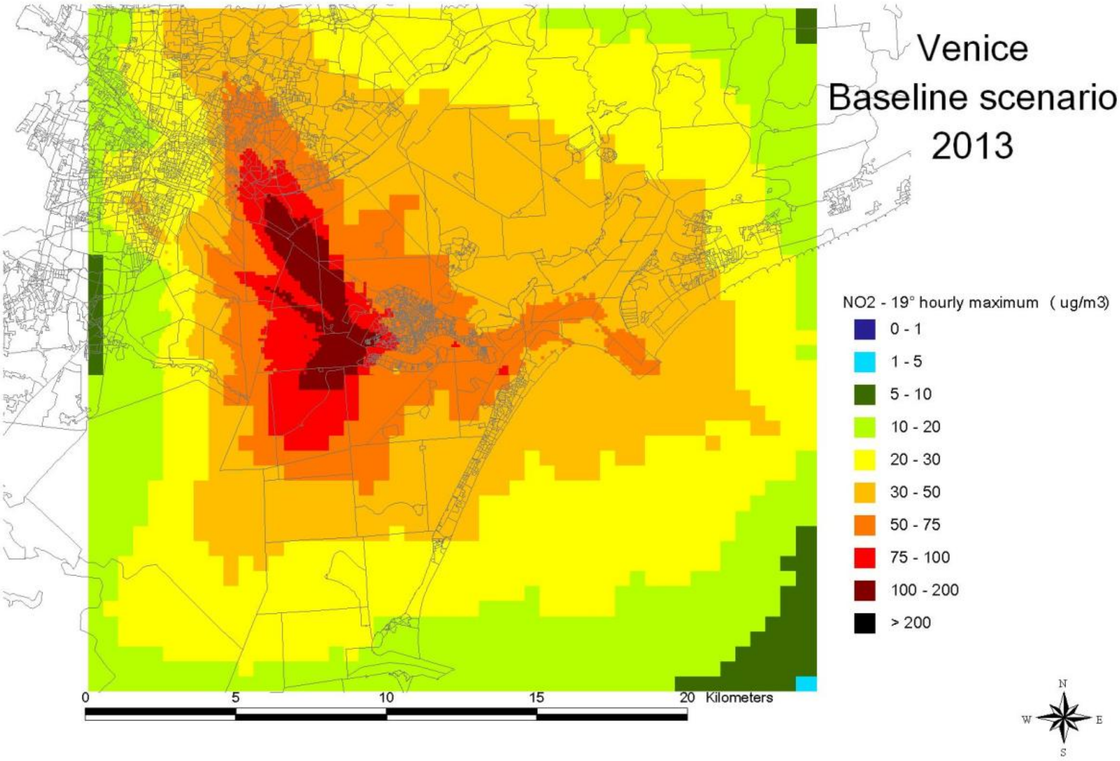


Figure 2.2.5.2. Hourly NO_2 concentrations for the reference year 2013.

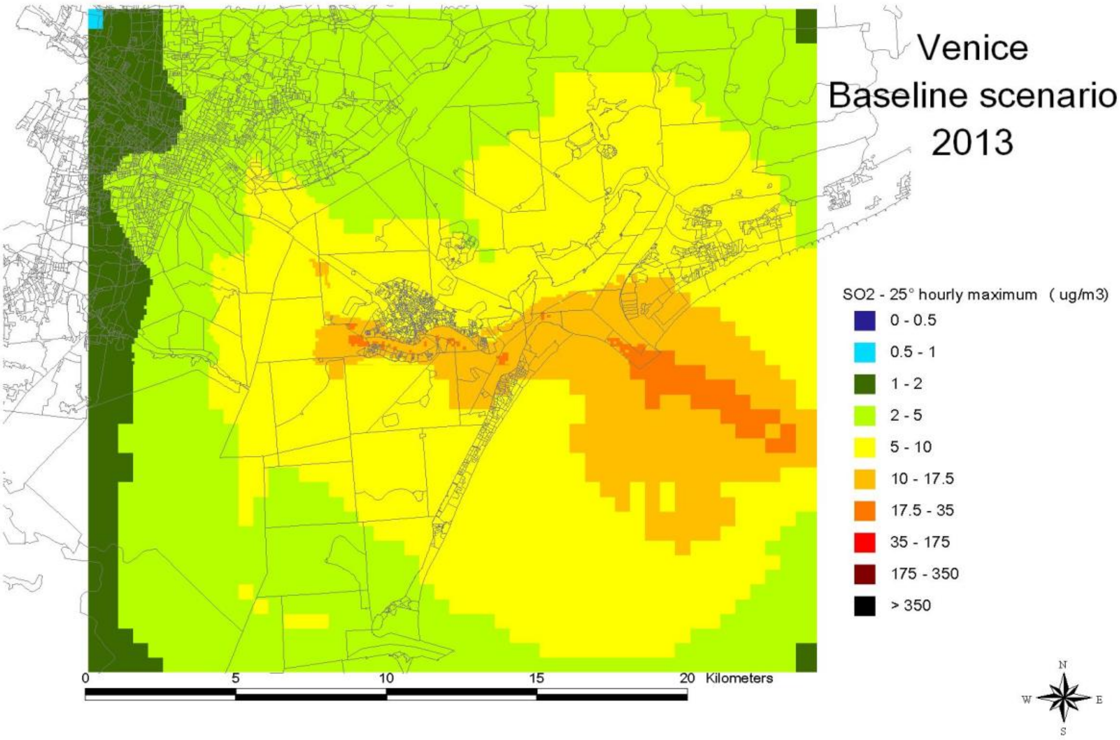


Figure 2.2.5.3. Hourly SO_2 concentrations for the reference year 2013.

The contribution of passenger ships to PM_{10} concentration (Fig. 2.2.5.4) is not particularly relevant (less than 1% of the annual AQL). Also the contribution to micropollutants concentration is generally not significant and less than 0.1% of the correspondent annual AQL for lead (Pb), cadmium (Cd), arsenic (As) and benzo(a)pyrene (BaP). The micropollutant with highest concentrations is nickel, for which the maximum value in the domain represents around 1.5% of its annual AQL (Fig. 2.2.5.5).

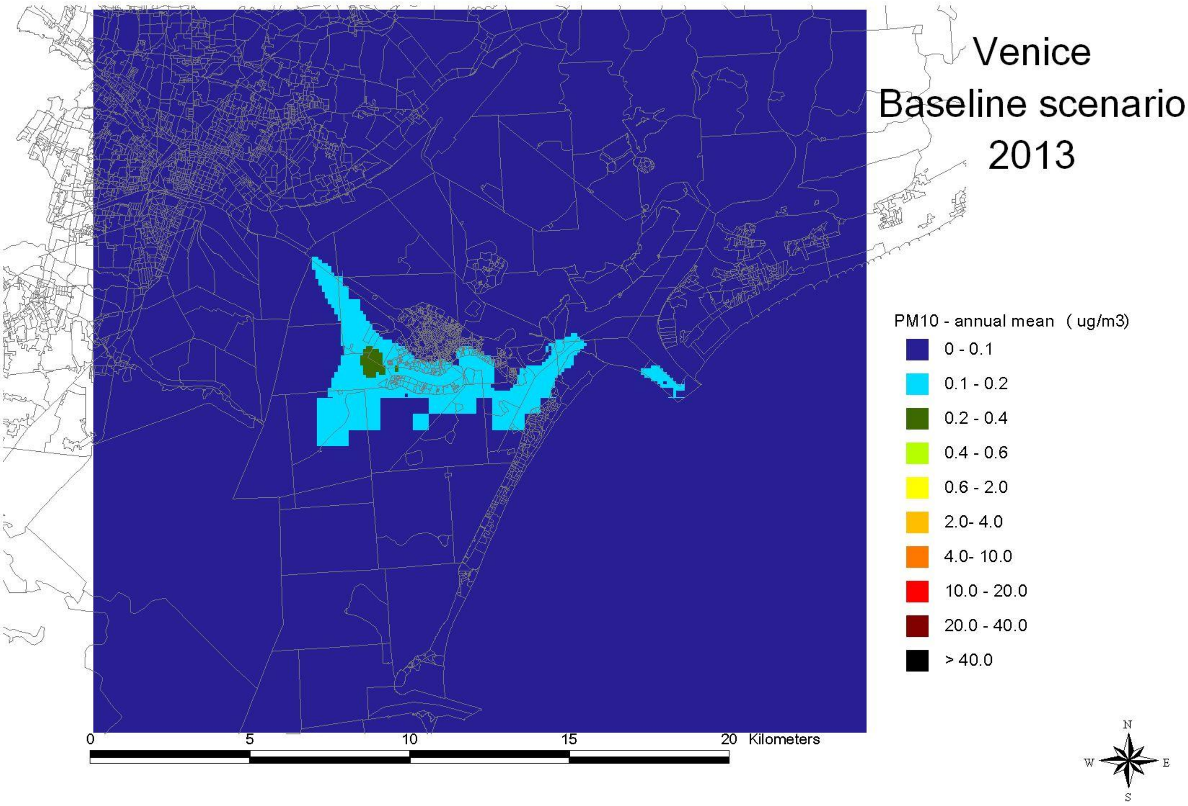


Figure 2.2.5.4. Annual $\mathbf{PM_{10}}$ concentrations for the reference year 2013.

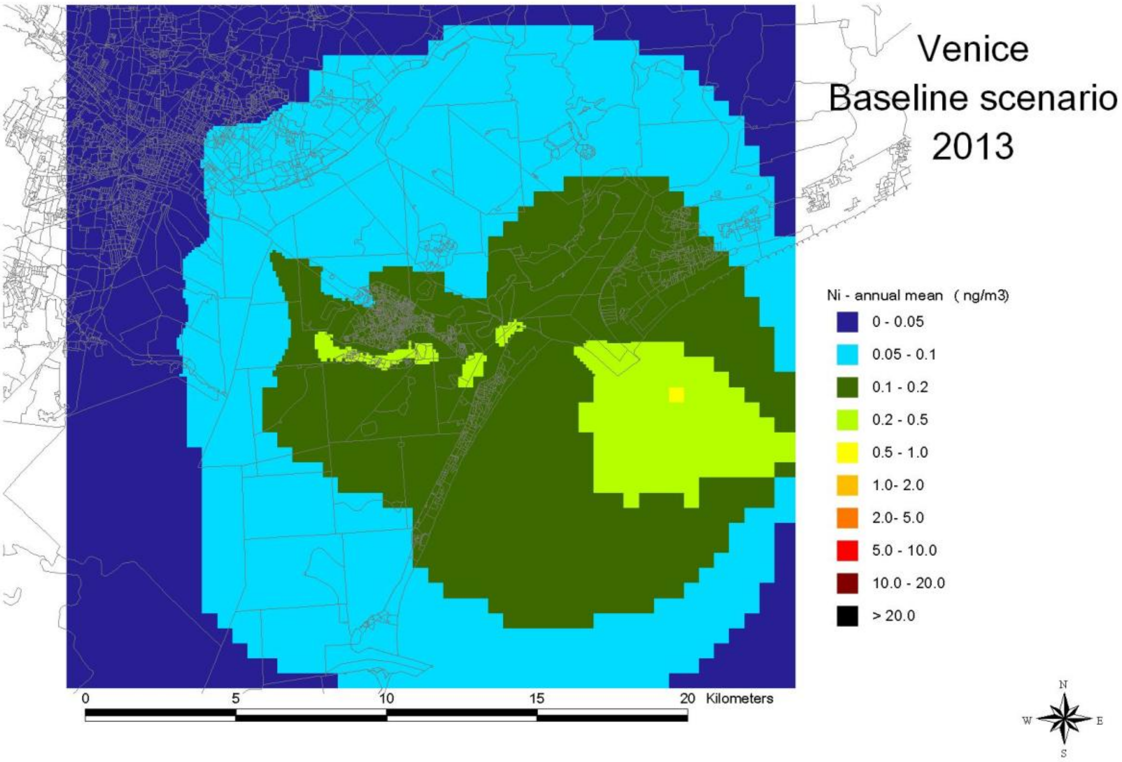


Figure 2.2.5.5. Annual **Nickel** concentrations for the reference year 2013.

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2.3. COMPARISON OF THE PORT CITIES IN TERMS OF AIR DISPERSION MODEL RESULTS FOR THE PRESENT TIME

Tables 2.3.1, 2.3.2 and 2.3.3 present the domain wide maximum values of the statistics for the long-term and short-term pollutant concentrations as simulated for each study area. As a first summary, we should highlight that the following pollutants emitted by ships can be considered of most concern with respect to their contribution to present air quality issues:

- NO_2 for Barcelona, Genoa, Marseille, Thessaloniki and Venice.
- SO_2 for Barcelona, Marseille, Thessaloniki and Venice.
- PM_{10} for Barcelona.
- Ni for Barcelona and Marseille.

Further discussion of the results are presented below, where the annual, daily and hourly values for these pollutants are detailed with respect to the exceedances of the corresponding AQL.

Table 2.3.1. Domain-wide maximum annual concentrations for the present scenario.

Pollutant (% ratio to the AQL)	Barcelona	Genoa	Marseille	Thessaloniki	Venice
NO_2 (μg/m^3)	9.24 **(23%)**	0.45 (1%)	15.08 **(38%)**	2.56 **(6%)**	3.60 **(9%)**
SO_2 (μg/m^3)	1.69 **(8%)**	0.12 (1%)	3.12 **(16%)**	0.30 (2%)	0.46 (2%)
PM_{10} (μg/m^3)	0.99 (2%)	0.03 (0%)	0.97 (2%)	0.25 (1%)	0.33 (1%)
$PM_{2.5}$ (μg/m^3)	0.99 (4%)	0.03 (0%)	0.97 (4%)	0.25 (1%)	0.33 (1%)
Pb (μg/m^3)	1.42E-05 (0%)	0.27E-05 (0%)	5.83E-05 (0%)	1.68E-05 (0%)	1.78E-05 (0%)
As (ng/m^3)	2.84E-02 (0%)	0.18E-02 (0%)	4.95E-02 (1%)	0.67E-02 (0%)	1.00E-02 (0%)
Ni (ng/m^3)	1.30 **(6%)**	0.06 (0%)	2.03 **(10%)**	0.21 (1%)	0.50 (3%)
Cd (ng/m^3)	10.8E-03 (2%)	0.19E-03 (0%)	4.72E-03 (0%)	1.28E-03 (0%)	1.43E-03 (0%)
BaP* (ng/m^3)	3.70E-03 (0%)	0.09E-03 (0%)	1.95E-03 (0%)	0.57E-03 (0%)	0.69E-03 (0%)

*BaP: Emissions according to Cooper and Gustafsson (2004).

Table 2.3.2. Domain-wide maximum values of percentiles of the daily concentration timeseries for the present scenario.

Pollutant (% ratio to the AQL)	Barcelona	Genoa	Marseille	Thessaloniki	Venice
SO_2* (μg/m^3)	5.82 (5%)	1.57 (1%)	13.26 **(11%)**	6.00 (5%)	5.20 (4%)
PM_{10}* (μg/m^3)	4.03 **(8%)**	0.13 (0%)	1.95 (4%)	0.73 (1%)	1.02 (2%)

*99.2 percentile and 90.4 percentile for SO_2 and PM_{10} respectively.

Table 2.3.3. Domain-wide maximum values of percentiles of the hourly concentration timeseries for the present scenario.

Pollutant (% ratio to the AQL)	Barcelona	Genoa	Marseille	Thessaloniki	Venice
NO_2* (μg/m^3)	260 (**130%**)	33 (**17%**)	80 (**40%**)	270 (**135%**)	174 (**87%**)
SO_2* (μg/m^3)	27 (**8%**)	13 (4%)	68 (**19%**)	24 (**7%**)	31 (**9%**)

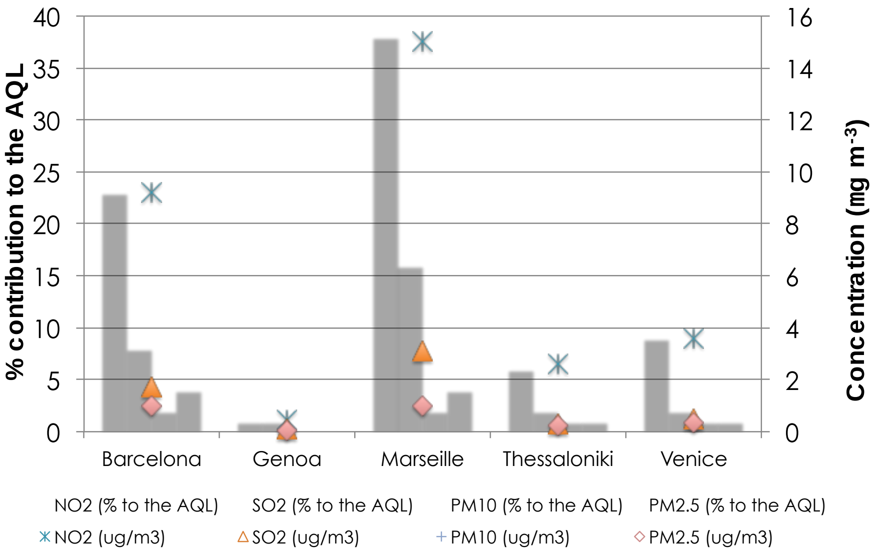
*99.8 percentile and 99.7 percentile for NO_2 and SO_2 respectively.

Figure 2.3.1 shows the percentual contribution of the domain-wide maximum macropollutant and micropollutant concentrations to the annual AQL in the different study areas. The main concern is related to the annual NO_2 levels, which exceed the 10% of the annual AQL (40 μg/m^3) in Barcelona (23%, 9 μg/m^3) and Marseille (38%, 15μg/m^3). The 5% of the annual AQL is over passed in Thessaloniki (6%, 3μg/m^3) and Venice (9%, 4 μg/m^3). As previously detailed for NO_x emissions, the ranking among the cities follows the correspondent total amount of hours spent in the various phases (and therefore, ground-level concentrations modelled are strongly related to the amount of emissions), with Barcelona and Marseilles in the highest positions because the ships arriving in these cities have generally a larger gross tonnage.

In the case of SO_2, it is Barcelona and Marseille that exceed the 5% of the AQL (20μg/m^3), with concentrations of 2 μg/m^3 and 3 μg/m^3, respectively (8% and 16% of the annual AQL).

With respect to particulate matter from cruise and passenger ships, the highest contribution from all the study areas to the annual AQL limits comes from the port of Barcelona and Marseille (4%, 1 μg/m^3), regarding the annual PM2.5 AQL (annual means should not exceed 25 μg/m^3). For the rest of the port areas, this contribution is always under 1%.

The modest contribution of regulatory micropollutants to the exceedances of the corresponding AQL has to be highlighted (under 1% of the corresponding AQL). The only pollutant to achieve relative high concentrations is a metal, Ni, that reaches 10% of the annual AQL (5 ng/m^3) in the Marseille port area (2.0 ng/m^3), and 6% in the area of the port of Barcelona (1.3 ng/m^3, Table 2.3.1 and Figure 2.3.1).



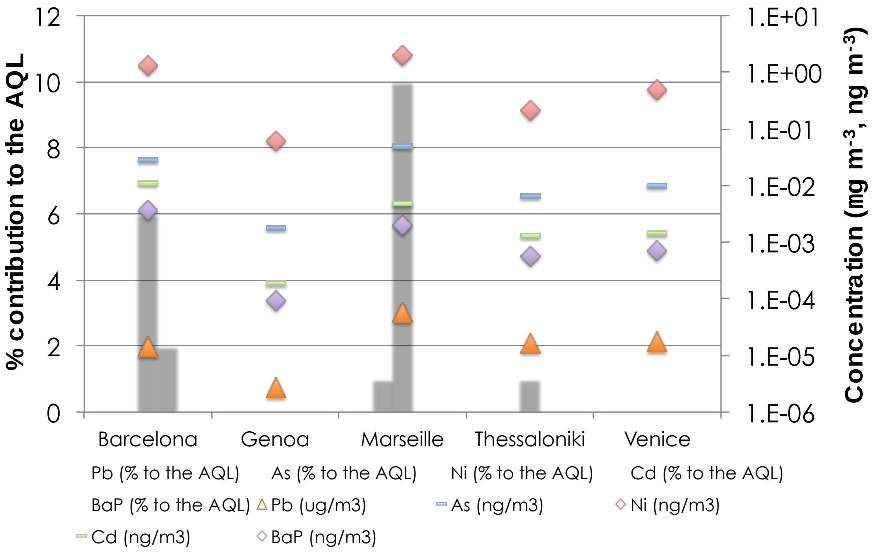


Fig. 2.3.1. Macropollutants (top) and micropollutants (bottom) domain-wide maximum percentual contribution to the annual AQL (left axis, bars)and concentrations (right axis, points) in the different study areas.

However, if daily exceedances are analysed (Table 2.3.2; Figure 2.3.2), values under 5% of the AQL (99.2 percentile of the SO_2 daily concentration timeseries should not exceed 125 µg/m^3) are always found for SO_2 daily concentrations, except in the city of Marseille, where the 10% of the daily SO_2 AQL is exceeded (13 µg/m^3). Regarding particulate matter (precisely, PM10) concentrations around 8% of the PM_{10} AQL (90.4 percentile of the daily concentration timeseries should not exceed 50 µg/m^3) are modelled for the port of Barcelona (4 µg/m^3) with the rest of the cities depicting values under 5% of the AQL for PM_{10}.

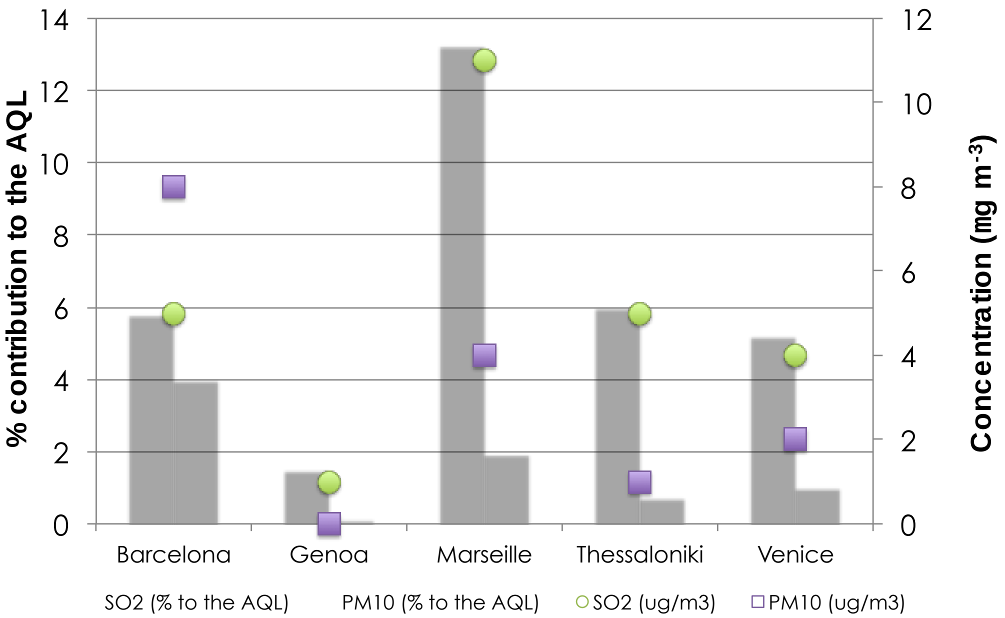


Fig. 2.3.2.SO_2 and PM_{10} domain-wide maximum percentual contribution to the daily AQL (left axis, bars) and concentrations (right axis, points) in the different study areas.

Last, regarding the domain-wide 1-hr maximum concentrations estimated for the different ports, the 100% of the hourly NO_2 AQL (99.8 percentile of hourly concentration timeseries should not be higher than the value of 200 µg/m^3) is exceeded in Barcelona (130%, 260 µg/m^3) and Thessaloniki (135%, 270 µg/m^3), the 50% is exceeded in Venice (87%, 174µg/m^3) and the 10% of the 1-hr AQL is over passed in Genoa (17%, 33 µg/m^3) and Marseille (40%, 80 µg/m^3). These concentrations are much lower for SO_2, where the 10% of the hourly SO_2 AQL is only exceeded in Marseille (19%, 68 µg/m^3), whereas the concentrations are higher than the 5% of the 1-hr AQL in Barcelona (8%, 27 µg/m^3), Thessaloniki (7%, 24 µg/m^3) and Venice (9%, 31 µg/m^3). Concentrations under the 5% of the 1-hr AQL are simulated in Genoa (4%, 13 µg/m^3).

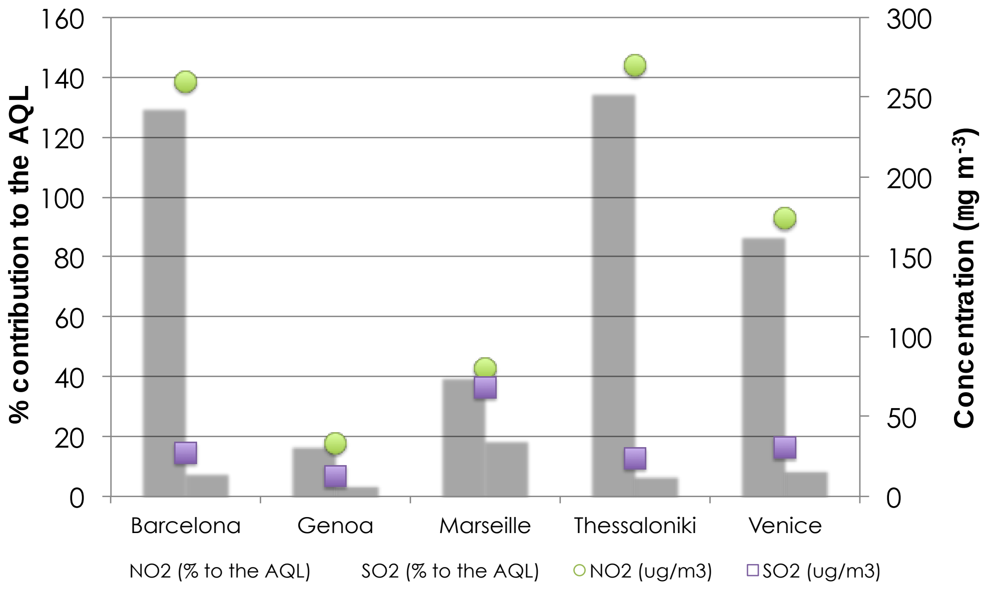


Fig. 2.3.3. NO_2 and SO_2 domain-wide maximum percentual contribution to the annual AQL (left axis, bars) and concentrations (right axis, points) in the different study areas.

3. FUTURE TREND OF POLLUTANT EMISSIONS FROM PASSENGER SHIPS

3.1. REGULATORY FUTURE SCENARIO

This Section 3.1 presents the future trend of pollutant emissions in two temporal horizons, depending on the port city (2020 and 2025). Besides the particularities of each city, which will be described in Section 3.2, there is a general regulatory scenario for future emissions that comes conditioned by upcoming regulations and legislation.

The sulphur oxides (SO_x) and, particularly, SO_2 emissions in future scenarios comes conditioned by the Directive 2012/33/EU of the European Parliament and of the Council of 21 November 2012 amending Council Directive 1999/32/EC as regards the sulfur content of marine fuels. This European Directive highlights that air pollution caused by ships at berth is a major concern for many harbor cities when it comes to their efforts to meet the Union's air quality limit values.

Emissions from shipping due to the combustion of marine fuels with high sulfur content contribute to air pollution in the form of sulfur dioxide and particulate matter, which harm human health and the environment and contribute to acid deposition. Without the measures set out in Directive 2012/33/EU, emissions from shipping would soon have been higher than emissions from all land-based sources.

In 2008, the International Maritime Organisation (IMO) adopted a resolution to amend Annex VI of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL), containing regulations for the prevention of air pollution from ships. The revised Annex VI to MARPOL entered into force on 1 July 2010.

This revised annex introduces, inter alia, stricter sulfur limits for marine fuel in SO_x Emission Control Areas (SECAs) (1.00 % as of 1 July 2010 and 0.10 % as of 1 January 2015) as well as in sea areas outside SECAs (3.50% as of 1 January 2012 and 0.50% as of 1 January 2020). Most Member States are obliged, in accordance with their international commitments, to require ships to use fuel with a maximum sulfur content of 1.00 % in SECAs as of 1 July 2010.

In order to ensure a minimum quality of fuel used by ships either for fuel-based or technology-based compliance, marine fuels whose sulphur content exceeds the general standard of 3.50 % by mass should not be allowed for use in the Union, except for fuels supplied to ships using emission abatement methods operating in closed mode.

With respect to passenger ships operating in ports or close to coastal areas, those ships are required to use marine fuel with a maximum sulfur content of 1.50 % unless stricter sulfur standards apply to all ships in territorial seas, exclusive economic zones and pollution control zones of Member States.

On the other hand, NO_x emissions are regulated by the Annex VI of the Convention for the Prevention of Marine Pollution from Ships (MARPOL 73/78) governed by the International Maritime Organization (IMO). This regulation indicates that the operation of a marine diesel engine which is installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

1. 17.0 g/kWh when n is less than 130 rpm;
2. $45 \cdot n^{(-0.2)}$ g/kWh when n is 130 or more but less than 2,000 rpm;
3. 9.8 g/kWh when n is 2,000 rpm or more.

Regarding the future scenarios defined here, Annex VI states that post-2010 vessels need to meet Tier II standards according to IMO. That is, the operation of a marine diesel engine which is installed on a ship constructed on or after 1 January 2011 is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

1. 14.4 g/kWh when n is less than 130 rpm;
2. $44 \cdot n^{(-0.23)}$ g/kWh when n is 130 or more but less than 2,000 rpm;

3. 7.7 g/kWh when n is 2,000 rpm or more.

Therefore, the application of these regulations results in 20% lower NO_x emissions for a vessel operating in the future scenarios defined below (for 2020 or 2025) than a pre-2011 vessel, as considered for the present base case scenarios.

3.2. POLLUTANT EMISSIONS OF THE PORT CITIES

3.2.1. Barcelona

Future emissions for the year 2020 have been estimated for the area of Barcelona considering the port evolution according to the activity data provided by the Barcelona Port Authority SA as well as the legislation for air pollution from the maritime transport (Annex VI of the Convention for the Prevention of Marine Pollution from Ships (MARPOL 73/78) governed by the International Maritime Organization (IMO).

According to the activity data provided by Barcelona Port Authority, no increase in the number of passenger ships and cruise ships is expected for 2020; however, the number of passengers per vessel is expected to be increased by 20%, involving then an increase in the gross tonnage of the vessels arriving at the port. That causes emissions to increase at a rate of about 2.5% per year, adding up to a 18% increase in the period 2013-2020, both for cruises and for Ro-pax vessels.

Moreover, a reduction of the sulfur content (%) of fuels used by ships in cruising mode to 0.5% m/m as well as a 5.6% reduction in the emission factors for NO_x due to the legislation of IMO (Tier II) for new vessels have been applied. More specifically, post-2010 vessels need to meet Tier II standards according to IMO legislation resulting to 20% lower NOx emissions than a pre-2011 vessel. The 5.6% reduction factor has been derived by assuming a 4% average annual replacement rate for vessels (EEA, 2013). Thus, for the year 2020, due to the ship replacements since the reference year 2013, the reduction is calculated as 7 years x 4% x 20% = 5.6% reduction.

3.2.2. Genoa

The harbor development plan by Genoa Port Authority is now under discussion and will be released at the middle of 2015. Thus, unfortunately, we were not able to access to detailed and quantitative analysis of ship traffic trends expected for the next years. Anyway we tried to define a future base scenario for the 2020 Genoa passenger ship traffic with some general considerations and on the basis of previous studies. In particular the 3-years operative plan released in 2011 and the harbor sector development forecast released in 2012 (http://www.porto.genova.it), presented the framework of Genoa harbor activities at the end of 2011 and the expectations for the next years development. A consistent decrease of ferry ship activities were encountered, mainly ascribed to the price increase, and an inversion in trend was expected. At the same time an increase in cruise ship passengers were observed and a constant positive trend was foreseen. Data extracted for the last years by Maritime Station statistics substantially confirmed the framework and trend analysis, thus we decided to consider a similar trend for the definition of the baseline future scenario. Constant factors were applied to the 2013 traffic data, distinguishing between cruise and ferry ships data. In particular a 20% increase in cruise traffic were assumed, also considering that one of the main points that, according to what presented by Genoa Port Authority, will be included in the new Regulatory Port Development Plan, will be the extension of cruise traffic capacity. A 10% increase is indeed assumed for ferries ship traffic.

3.2.3. Marseille

Future emissions have been estimated for the year 2025 using projections given by Marseille Port Authority. Data concern five large activities: container, liquid bulk, solid bulk, cargo-passenger and cruise and are given for 2020 and 2030. A linear interpolation between these dates allows an estimation of the future maritime traffic for 2025 in Marseille. A global increase of 99% is expected for 2025, split into 126% for the goods and 32% for the passengers.

As no information is available about future size of ships in Marseille or duration and location of calls, these parameters are retained constant and only the number of ships increases. To consider the future international regulations applied in 2025, a reduction in the emissions factors of NO_x is applied for the new vessels as described in the 3.1 Section.

3.2.4 Thessaloniki

Future emissions for the year 2025 were estimated for the area of Thessaloniki considering the development trend of the port as well as the legislation for the air pollution from the maritime transport (Annex VI of the Convention for the Prevention of Marine Pollution from Ships (MARPOL 73/78) governed by the International Maritime Organization).

According to the future activity data provided by the Thessaloniki Port Authority SA, a very high increase in the number of passenger and cruise ships is expected in the year 2025 with respect to the year 2013 being +284% for cruise ships and +150% for other passenger ships. In addition, the reduction of the sulfur content in fuels used by ships in the cruising mode to 0.5% m/m as well as a 9.6% reduction in the emission factors for NO_x due to the legislation of IMO for the new vessels were accounted for in the calculation of the future ship emissions. More specifically, the post-2010 vessels need to meet Tier II standards according to IMO legislation resulting in 20% lower NOx emissions than the pre-2011 vessels. The 9.6% reduction in the NOx emission factors for the year 2025 with respect to the year 2013 has been derived by assuming a 4% average annual replacement rate for vessels according to (EEA, 2013).

3.2.5. Venice

The mid term future scenario chosen for the trend analysis in Venice is the year 2020. This is a relative near scenario that allows considering realistic development hypothesis without introducing big uncertainties as those linked to a longer timescale. As a major factor of great change in the Venetian harbor development and configuration the proposal of an off-shore harbor that would come into operation certainly after year 2020.

The 2020 scenario has been estimated considering, for the passenger traffic, two different hypotheses:

- a stationary traffic for cruise ships, accordingly to the recent studied presented in the framework of the Environmental Impact Assessment procedure for the plans in response to the banning of the cruise ships from the San Marco Basin (Progetto Canale Contorta and Progetto Venice 2.0). At the basis of this hypothesis the evaluation that the housing capacity of the Venice Terminal is already almost saturated by the present number of calls in a year (and moreover during the high season). This scenario considers the hoteling of the cruise ships in the same quays as for year 2013, so for great cruise ships mainly the Marittima Terminal, and the maneuvering route as at the time being, trough the Lido entrance of the lagoon, the navigation in the San Marco Basin ant through the Giudecca Channel;
- an increase for the Ro-pax vessels due to the coming into operation of the New Terminal of the Motorway of the Sea in Fusina, able to serve up to 1,200 ferries. The development scenario has been studied for hypothesis of a doubling of the 2013 Ro-pax traffic from around 250 to 500 calls per year and a strongest development scenario of 1200 calls per year. In this scenario Ro-pax vessels are not anymore hoteling in the historical city-center of Venice (mainly Marittina, Santa Marta and San Basilio Terminals), but arrive and departure to and from the Fusina Terminal located in the inner border of the lagoon in Porto Marghera by the Malamocco entrance into the Lagoon. So, besides an increase on the Ro-pax traffic, there's also a slightly increase on the maneuvering time of each vessel since the maneuvering route is longer.

Beside the hypothesis on passenger trend traffic, the emission for the future scenario has been calculated considering the legislation that will be become effective in 2020. In particular the limit of 0.5% m/m for the sulfur content of marine fuels to be used inside Member States (MS) territorial seas from 1st January 2020 (Directive 2012/33/EU) and the Tier II standards for post-2010 vessels resulting in 20% lower NOx emissions for new engines (Annex VI MARPOL (IMO), that, for the a 7 years projection (form year 2013 to 2020) and a 4% average annual vessel replacement rate (EEA, 2013), brings to a 5.6% reduction of the NOx emission factors.

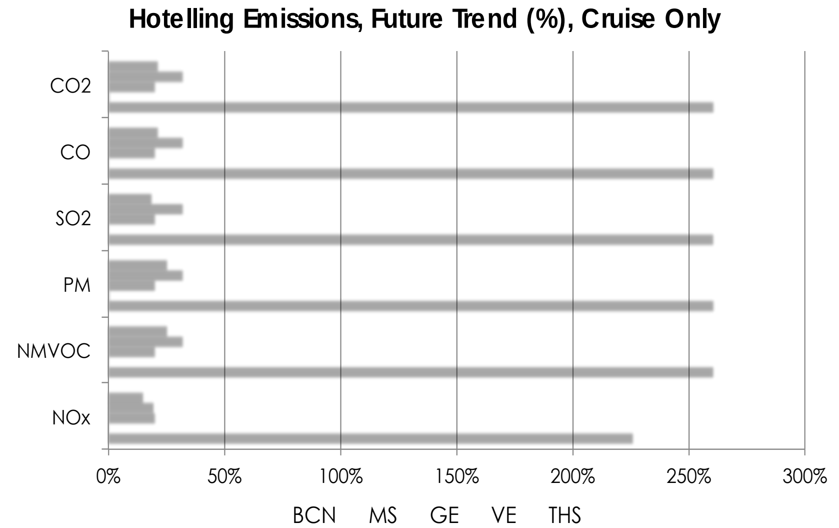
As for the effect of the sulfur limit of 0.5% m/m, in the case of Venice it's important to remind that the current emission scenario for year 2013 had been calculated considering for the cruise ships a total turn down of BFO also in maneuvering phase in order to respect the 0.1% limit for sulfur content posed by the Blue Flag 2 Agreement. Now, on the 2020 scenario, the limit of 0.5% is applied considering a BFO that will be available on the future with such a low sulfur formulation. This means that, given the no increase hypothesis on the cruise traffic trend, 2020 SO_2 emissions for cruise ships record a little rise for the maneuvering phase component, whereas for the cruise phase outside the lagoon there's a significant decrease due to the transition from the 2.7% sulfur content used for the 2013 scenario to the 0.5% of the 2020 one.

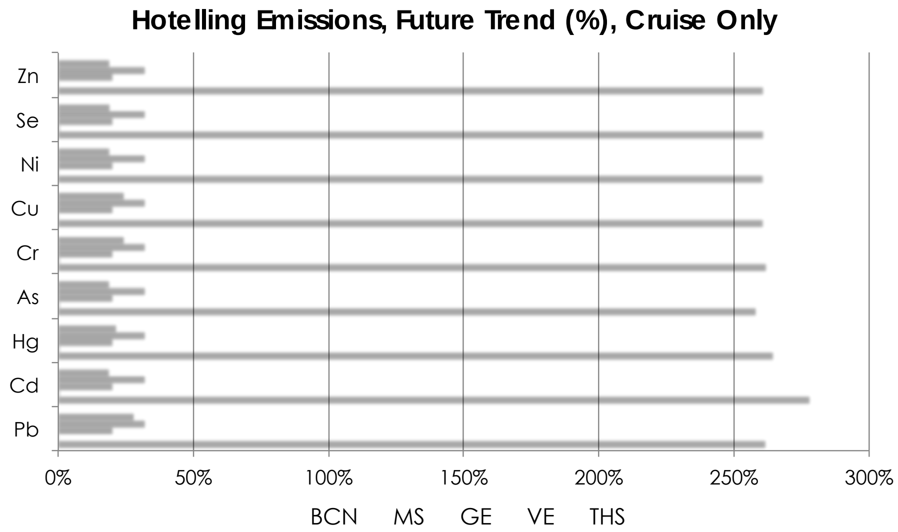
3.3. COMPARISON OF THE PORT CITIES IN TERMS OF FUTURE TIME POLLUTANT EMISSIONS

A comparison among study areas on percentage changes due to the development of future trend scenario will be presented and discussed. In the following sections, the % variation between present and future baseline scenarios will be presented for only cruises and for all passenger ships.

3.3.1. Cruise ships

For cruise ships, considering hoteling emissions the % variation of the emissions for the future baseline scenarios with respect to the present time emissions is presented in the next figures for all areas of study. Thessaloniki presents the highest increase for all pollutants (between 200-300% for almost all the pollutants considered), although this is the consequence of a much more important increase in cruise ship traffic when compared with the other areas (284% increase). Regarding the other areas, the increase in pollutant emissions during the hoteling phase is in the range 0-30% for most of the pollutants considered.





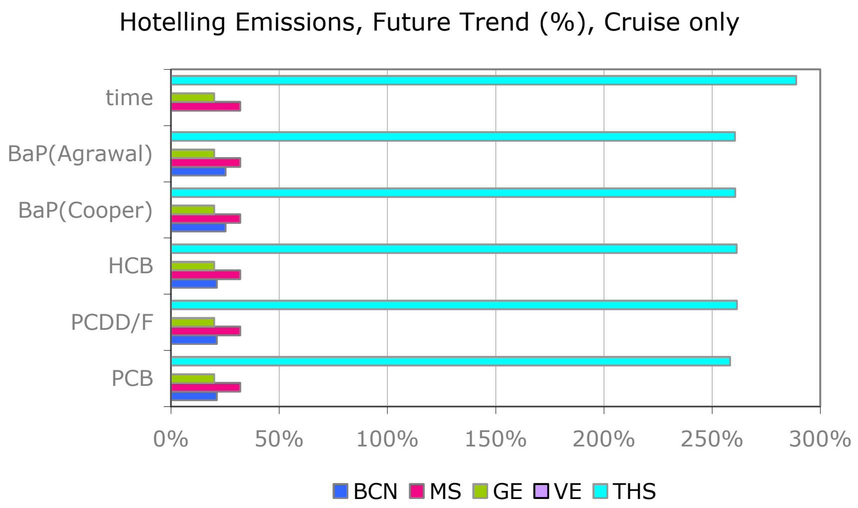
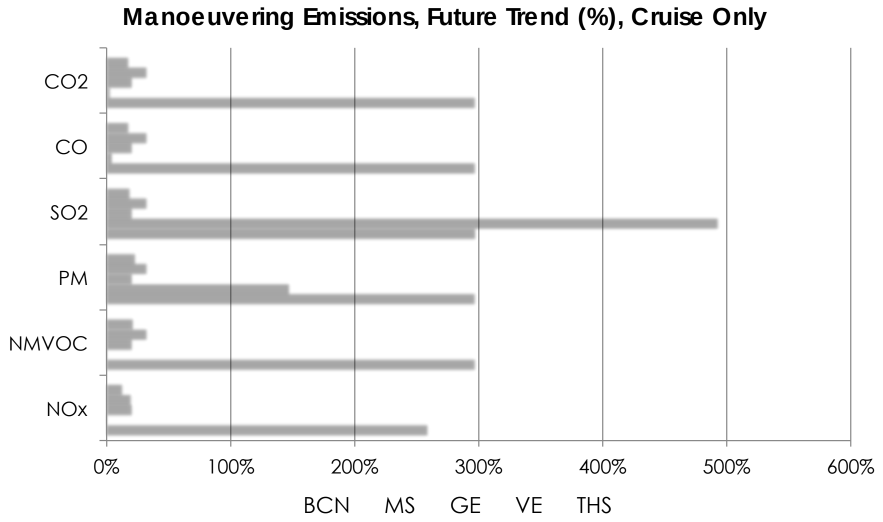
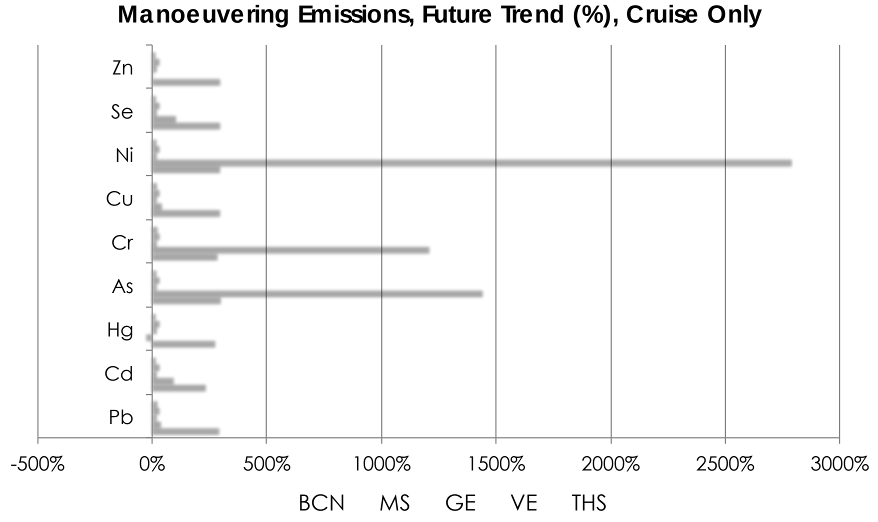


Fig. 3.3.1.1. Percentual increase in macro and micropollutant emissions for the future baseline scenarios for cruise ships during the hoteling phase in the five areas of study.





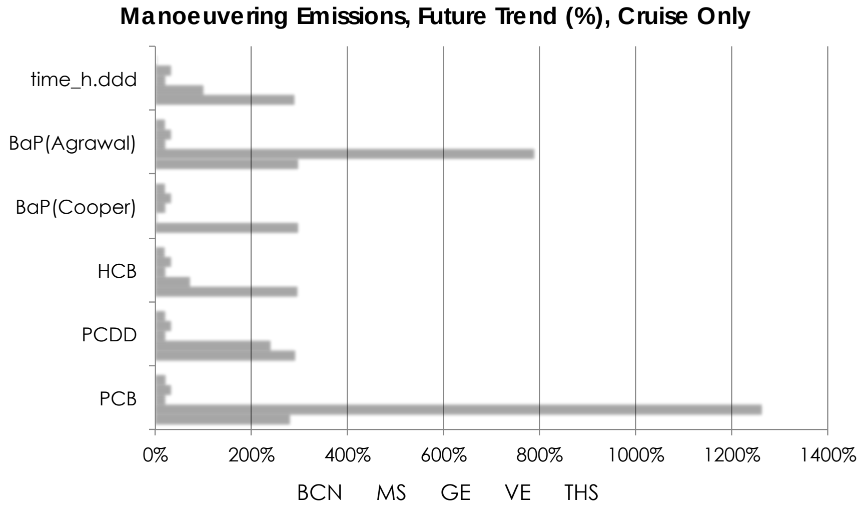
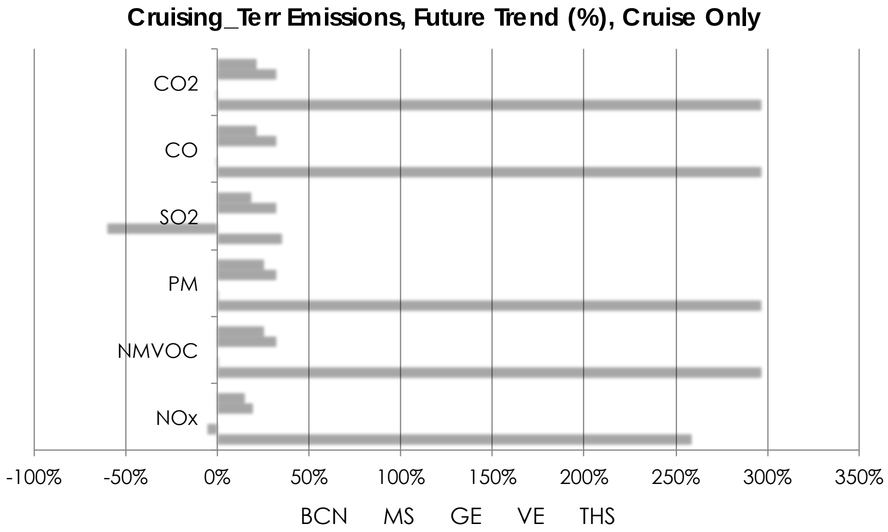
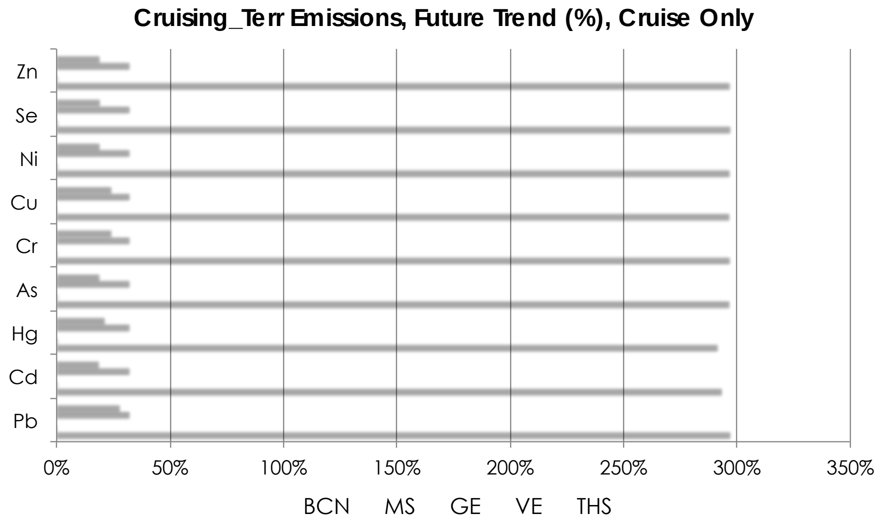


Fig. 3.3.1.2. Percentual increase in macro and micropollutant emissions for the future baseline scenarios for cruise ships during the maneuvering phase in the five areas of study.





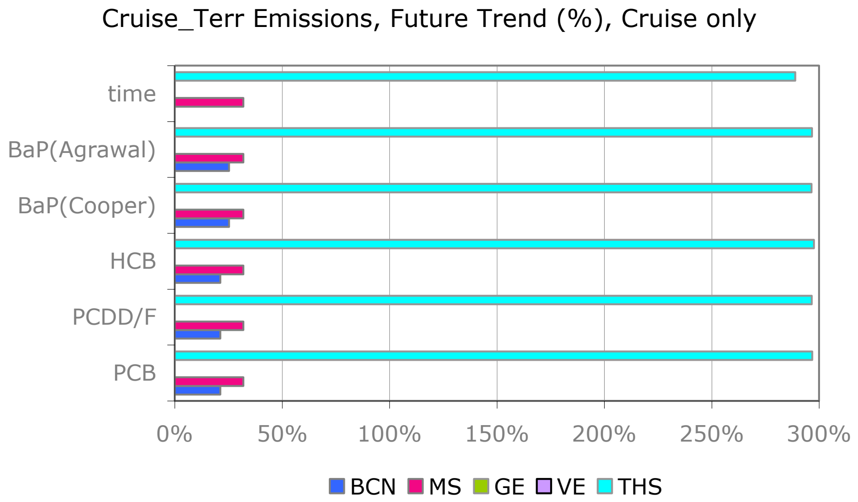


Fig. 3.3.1.3. Percentual increase in macro and micropollutant emissions for the future baseline scenarios for cruise ships during the cruising phase in the five areas of study.

When considering emission estimations during the maneuvering phase for cruise ships (Figure 3.3.1.2), higher levels were estimated for Thessaloniki in general (around 300%). Venice presented very high increases for some of the pollutants considered (SO_2, PM, Ni, Cr, As, BaP calculated as Agrawall and PCBs), because on the 2020 scenario, as already explained, the ban for BFO due to the Blue Flag 2 Agreement implemented during 2013 is supposed to not be in force. For the rest of the areas increases were between 5-30% for most of the pollutants considered.

During the cruising phase (Figure 3.3.1.3) the increase in emissions was also higher for Thessaloniki (around 300% for most pollutants considered). Barcelona and Marseille presented increases in the range 5-30% for most pollutants in general. In the case of Venice, since the number of calls for cruise ships is supposed to be unchanged, all pollutants but SO_2 and NO_x recorded no change in emissions. For this latter two pollutants a decrease is foreseen. In particular for SO_2 the decrease is of -60% for, due to the switch from a sulfur content of 1.5%, limit for all the passenger ships inside territorial waters (33/2005/EC Directive), to a sulfur content of 0.5%, future limit for all the passenger ships inside territorial waters (33/2012/EC Directive); for NOx the decrease is of 5%, due to the penetration of new vessels with IMO Tier II standard into the fleet.

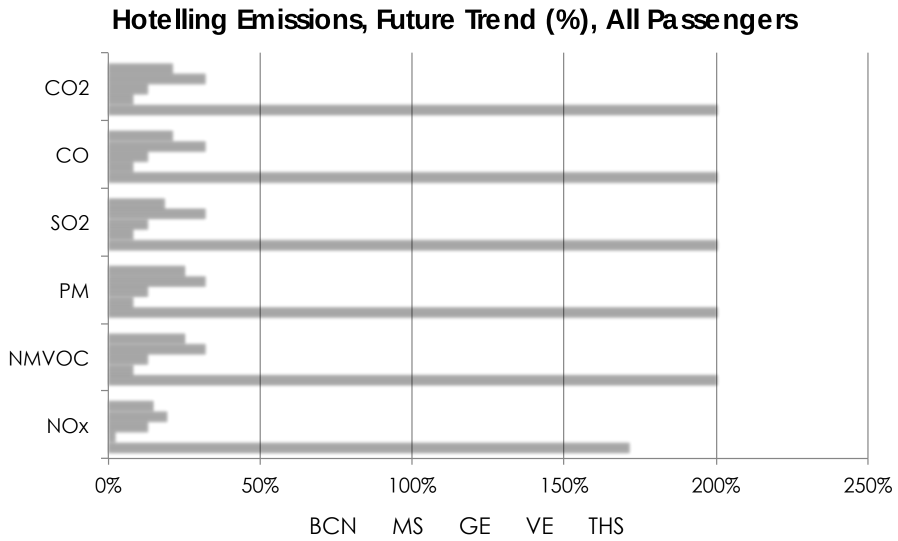
3.3.2. All passenger ships

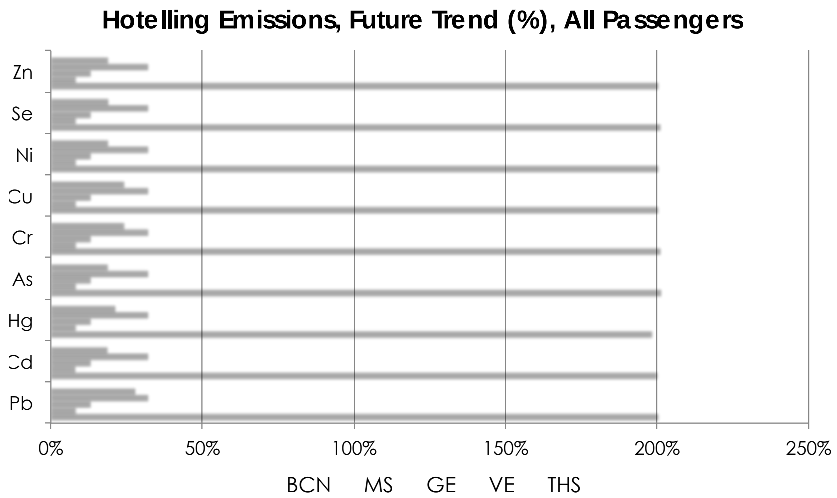
The percentual variation of the emissions for the future baseline scenarios with respect to the present time emissions during the hoteling phase and for all passenger ships is presented in Figure 3.3.1.4 for all areas of study. Thessaloniki presents the highest increase for all pollutants (200% for almost all the pollutants considered), although this is the consequence of a much more important increase in the passenger ship traffic (284% in cruise ships and 150% for Ro-pax ships). Regarding the other areas, the increase in pollutant emissions during the hoteling phase is in the range 5-30% for most of the pollutants considered. Barcelona and Marseille presented higher increases than Genoa and Venice.

When considering emission estimations during the maneuvering phase for all passenger ships (Figure 3.3.1.5), a similar trend is observed. Thessaloniki presented the highest increases in general (around 200% for all pollutants considered), while Barcelona, Marseille and Genoa presented lower increases (in the range 5-30% for all the pollutants considered). In the case of Venice important increases were observed for SO_2 and PM (around 100%). For micropollutants, in some cases the increases were even higher in Venice than in Thessaloniki (Ni, Cr, As, BaP calculated as Agrawall or PCBs).
In the case of Venice, the increase in pollutant emissions is only marginally due to the increase of Ro-pax vessels, but it is mainly owed to the change from the exclusive usage of MDO or MGO in maneuvering phase of the 2013 season for the Blue Flag2 Agreement to the mix of fuels that comprehends also BFO in a percentage given by reference statistic (EEA, 2013).

During the cruising phase (Figure 3.3.1.6) the increase in emissions was also higher for Thessaloniki (around 200%). Barcelona, Marseille and Genoa presented increases in the range 5-30% for most pollutants in general. In the case of Venice SO_2 and NO_x emissions show a reduction.

Once again for Venice the particular pattern is mainly due to the small increase of traffic supposed for Ro-pax vessels whereas cruise ships maintain the traffic of 2013 year. Moreover the Ro-pax vessels from 2013 to 2020 scenarios change their route: from the entrance into the lagoon by the northern inlet of Lido to that of Malamocco. For this reason the kilometers sailed by the single Ro-pax ship within the modeling domain are far fewer than those travelled in the 2013 year. However, considering the total amount of ro-pax vessels the greater number of ships in 2020 scenario with fewer ceilometers inside the domain balances the longer cruising route in 2013 of the less ships for the present scenario. Thanks to this balance, for the cruising phase in Venice the final results of the confrontation between 2020 and 2013 emissions is the reduction for SO2 and NOx due to the future new regulation already commented.





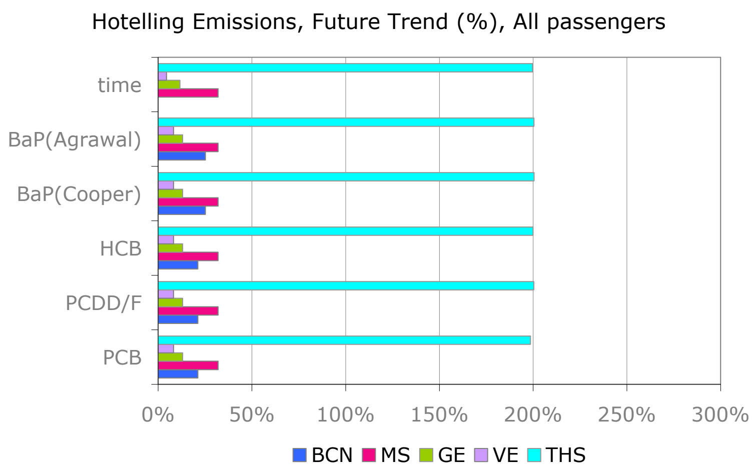
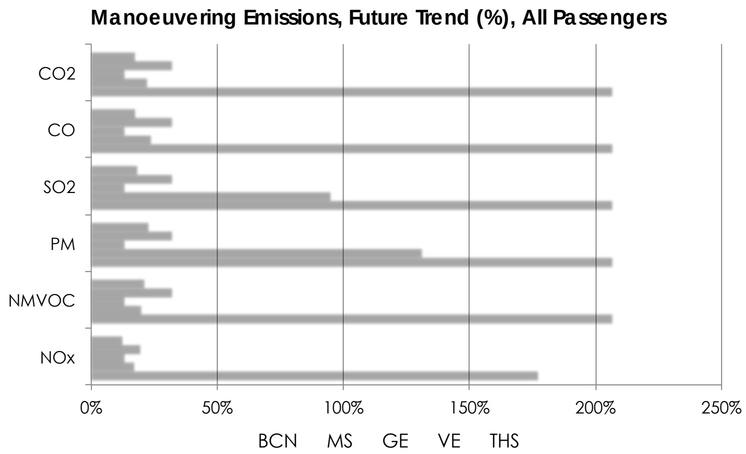
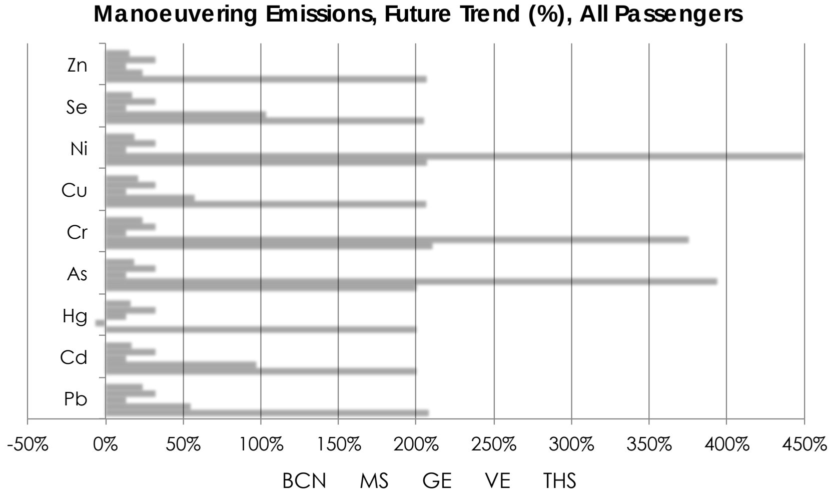


Fig. 3.3.1.4. Percentual increase in macro and micropollutant emissions for the future baseline scenarios for all passenger ships during the hoteling phase in the five areas of study.





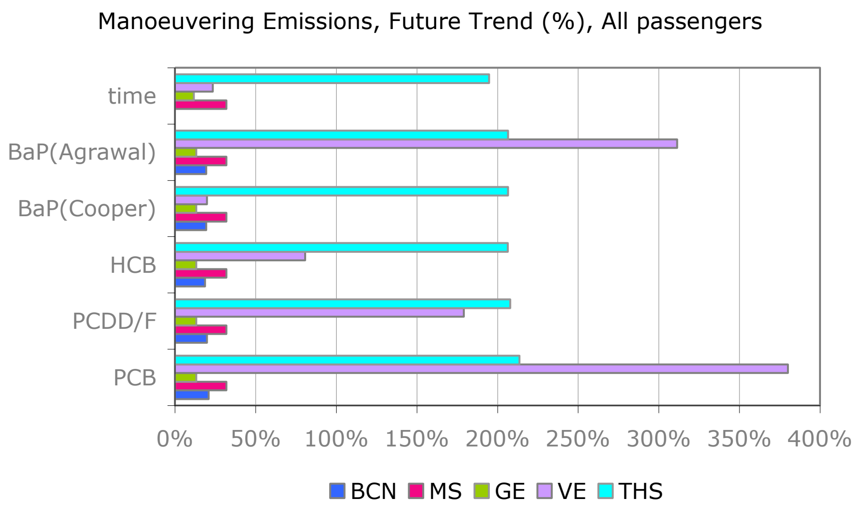
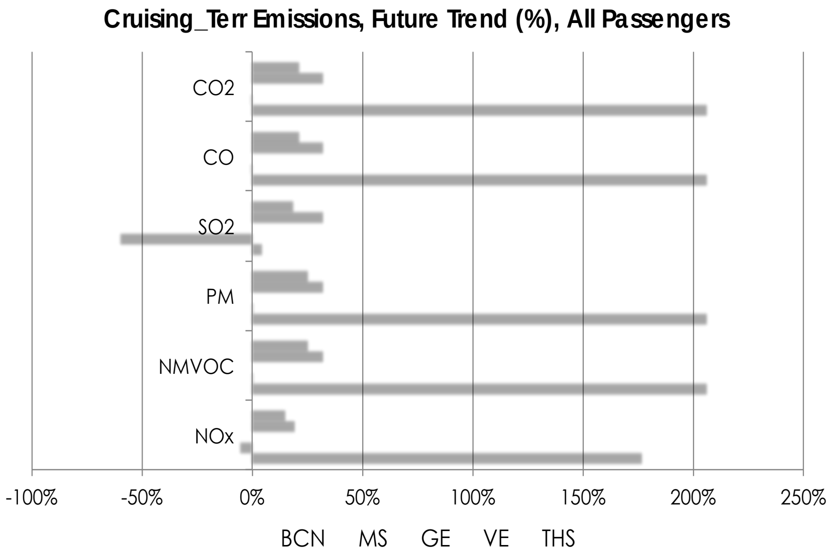
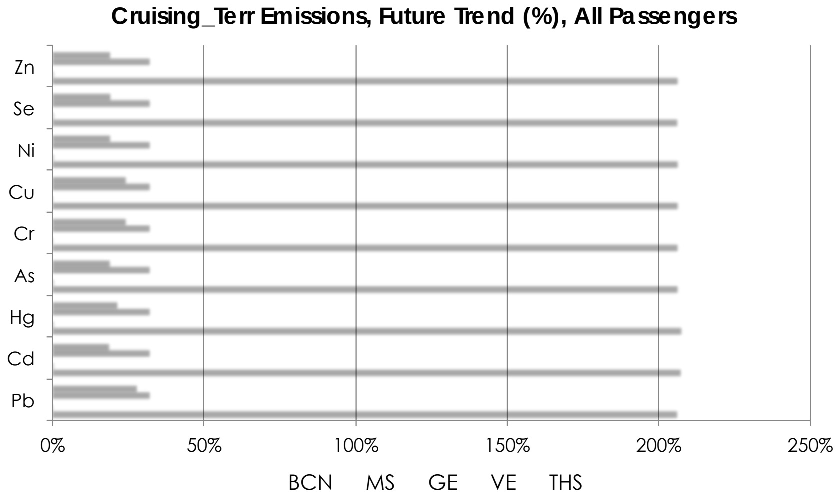


Fig. 3.3.1.5. Percentual increase in macro and micropollutant emissions for the future baseline scenarios for all passenger ships during the maneuvering phase in the five areas of study.





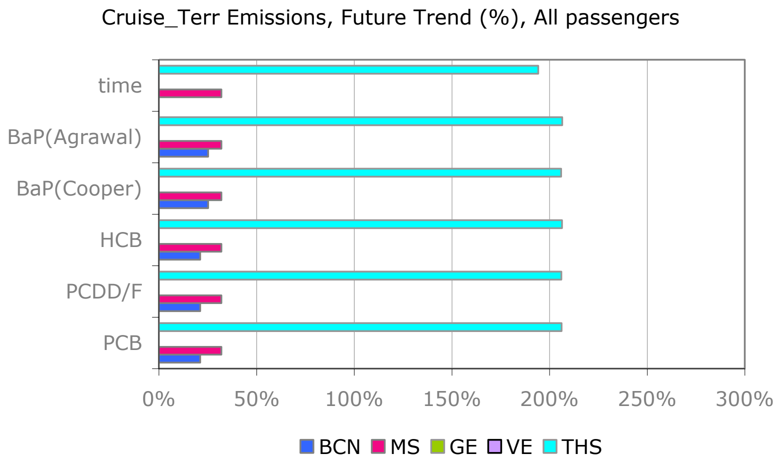


Fig. 3.3.1.6. Percentual increase in macro and micropollutant emissions for the future baseline scenarios for all passenger ships during the cruising phase in the five areas of study.

4. AIR DISPERSION MODEL APPLICATION FOR THE FUTURE BASE SCENARIO

Chapter 4 focuses on the presentation of the passenger ship plume dispersion for the future trend scenario for the study areas. The same (as for the present scenario in Chapter 2) statistical approach is followed for the assessment of the air quality impacts. The year 2020 was studied for Barcelona, Genoa and Venice while the future reference period for Marseille and Thessaloniki was the year 2025. The future time air dispersion model results are determined mostly by the following:

a) future ships' emissions which have been estimated on the basis of the development trends defined by the Port Authorities (e.g. changes in ship traffic, infrastructural interventions etc) and the legislation. More specifically, according to the International Convention for the Prevention of Pollution from Ships (MARPOL, revised Annex VI) by the International Maritime Organization (IMO) (http://www.imo.org/): i) a reduction of the sulfur content in ship fuels in the cruising and maneuvering modes to 0.5% m/m is foreseen on and after 1 January 2020 and ii) post-2010 vessels are expected to meet the Tier II standards resulting in 20% lower NO_x emissions,
b) meteorology which has been assumed to be the same as for the present time scenario (i.e. year 2013).

Tables 4.1, 4.2 and 4.3 present the domain wide maximum values of the statistics for the long-term and short-term pollutant concentrations as simulated for each study area. On the basis of these values and the criterion of confrontation with AQL, as described in Chapter 2, it can be assessed that the following pollutants emitted by ships can be considered of most concern with respect to their contribution to future air quality issues:

- NO_2 for Barcelona, Genoa, Marseille, Thessaloniki and Venice,
- SO_2 for Barcelona, Marseille, Thessaloniki and Venice,
- PM_{10} for Barcelona and Thessaloniki,
- Ni for Barcelona and Marseille.

Table 4.1. Domain wide maximum annual concentrations for the future trend scenario.

Pollutant (% ratio to the AQL)	Barcelona	Genoa	Marseille	Thessaloniki	Venice
NO_2 ($\mu g/m^3$)	10.61 (**27%**)	3.44 (**9%**)	17.32 (**43%**)	9.99 (**25%**)	3.18 (**8%**)
SO_2 ($\mu g/m^3$)	2.00 (**10%**)	0.22 (1%)	4.11 (**21%**)	0.94 (5%)	0.46 (2%)
PM_{10} ($\mu g/m^3$)	1.24 (2%)	0.11 (0%)	1.35 (3%)	0.92 (2%)	0.33 (1%)
$PM_{2.5}$ ($\mu g/m^3$)	1.24 (5%)	0.06 (0%)	1.35 (5%)	0.92 (4%)	0.33 (1%)
Pb ($\mu g/m^3$)	1.82E-05 (0%)	0.99E-05 (0%)	8.28E-05 (0%)	6.04E-05 (0%)	1.78E-05 (0%)
As (ng/m^3)	3.37E-02 (1%)	0.66E-02 (0%)	6.53E-02 (1%)	2.22E-02 (0%)	1.71E-02 (0%)
Ni (ng/m^3)	1.54 (**8%**)	0.24 (1%)	2.68 (**13%**)	0.64 (3%)	0.70 (3%)
Cd (ng/m^3)	120.92E-03 (2%)	0.69E-03 (0%)	6.22E-03 (0%)	4.83E-03 (0%)	1.43E-03 (0%)
BaP* (ng/m^3)	4.40E-03 (0%)	0.33E-03 (0%)	2.58E-03 (0%)	2.07E-03 (0%)	0.69E-03 (0%)

*BaP: Emissions according to Cooper and Gustafsson (2004).

Table 4.2. Domain wide maximum values of percentiles of the daily concentration timeseries for the future trend scenario.

Pollutant (% ratio to the AQL)	Barcelona	Genoa	Marseille	Thessaloniki	Venice
SO_2* ($\mu g/m^3$)	7.06 (**6%**)	2.19 (2%)	17.47 (**14%**)	8.08 (**6%**)	5.66 (5%)
PM_{10}* ($\mu g/m^3$)	4.43 (**9%**)	1.00 (2%)	2.70 (5%)	3.56 (**7%**)	1.02 (2%)

*99.2 percentile and 90.4 percentile for SO2 and PM_{10} respectively.

Table 4.3. Domain wide maximum values of percentiles of the hourly concentration timeseries for the future trend scenario.

Pollutant (% ratio to the AQL)	Barcelona	Genoa	Marseille	Thessaloniki	Venice
NO_2* ($\mu g/m^3$)	267 (**133%**)	310 (**155%**)	83 (**42%**)	354 (**177%**)	153 (**76%**)
SO_2* ($\mu g/m^3$)	31 (**9%**)	17 (5%)	90 (**26%**)	38 (**11%**)	28 (**8%**)

*99.8 percentile and 99.7 percentile for NO2 and SO2 respectively.

In the following subsections, the passenger ship plume dispersion results for the future trend scenario are compared with the results for the present time scenario. More specifically, maps and bar-charts are presented showing percentage differences with respect to the AQL defined as following:

Difference (%) = (Future concentration statistic – Present concentration statistic) / AQL

In section 4.1, model results and concentration differences are presented in detail for the most critical pollutants and discussed separately for each study area. In section 4.2, a synthesis is performed and the main results for all study areas are summarized and compared while conclusions about the air quality in the future due to the passenger ship traffic are drawn.

4.1. FUTURE TIME PASSENGER SHIPS PLUMES DISPERSION IN EACH PORT CITY

4.1.1. Barcelona

In order to assess future air quality and the changes of future concentrations with respect to present levels, a scenario of future emissions for the year 2020 (SC2020, formerly described in the previous chapter) was run with CALPUFF model. While future emissions change, meteorology for the year 2013 is considered invariant in order to evaluate changes in future air quality due to modifications in the emissions of cruise and other passenger ships. In the SC2020 scenario, according to the CALPUFF results, the most important pollutants regarding their impact on the air quality of Barcelona are NO_2 and SO_2.

Figures 4.1.1.1 and 4.1.1.2 represent the percentage differences in specific statistical parameters of the timeseries for the concentrations of the aforementioned pollutants between future trend and present scenarios with respect to the corresponding AQL.

Precisely, Figure 4.1.1.1 indicates the spatial distribution of the % differences in 1 hour and annual NO_2 concentrations between future trend (SC2020) and present scenario (BC2013) with respect to the NO_2 limits (200 µg/m^3 and 40 µg/m^3 for hourly and annual AQL). Here, a general increase in the NO_2 statistics (variation in the 99.8% percentile with respect to the AQL) ranging from 0.2% to 3.6% is identified in all the Barcelona metropolitan area, with the largest hourly increases in the port area and in the central part of the city (those areas closest to the port). Very similar results are found for the NO_2 mean annual values, with increases ranging from 0.06 to 3.5%. Maximum increases in the statistical value presented (future-present/AQL) are found over the port area and, in general, parallel to the coastline of the Barcelona metropolitan area.

Figure 4.1.1.2 depicts the 99.7% percentile of the hourly SO_2 concentrations timeseries, 99.2% percentile of the daily SO_2 concentrations and SO_2 mean annual value. The maximum increases for the sulfur dioxide concentrations estimated with respect to the air quality limit (350 µg/m^3, 125 µg/m^3 and 20 µg/m^3, respectively) are 1.3%, 1.1% and 1.6%. For the 1-hour value, the maximum increases are found over the track of ships approaching the port (both in cruise and maneuvering phases), while the increase of concentrations/AQL is maximized for daily and annual values in those areas close to the port, especially in the southern part of the simulation domain.

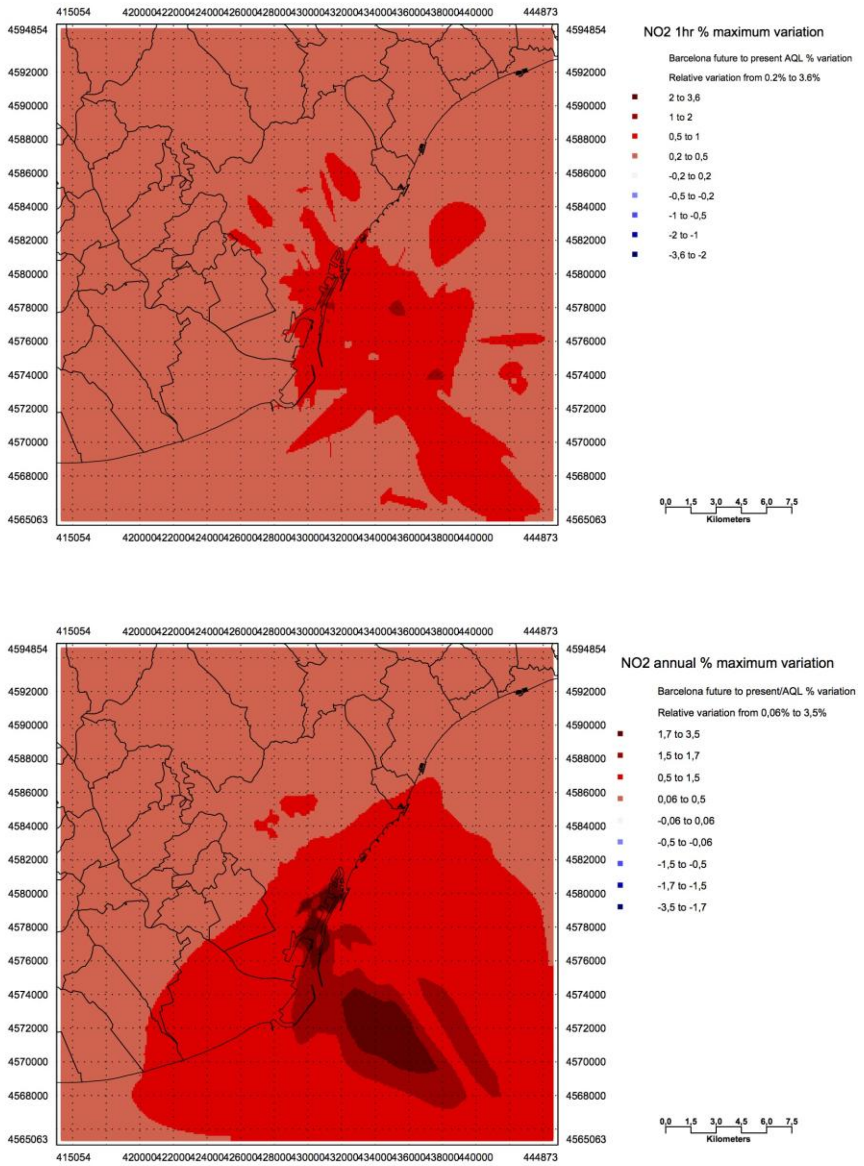


Fig. 4.1.1.1. Percentage differences relative to AQL for (top) 99.8% percentile of the 1hr NO_2 concentrations and (bottom) mean annual NO_2 concentrations between future trend and present scenarios.

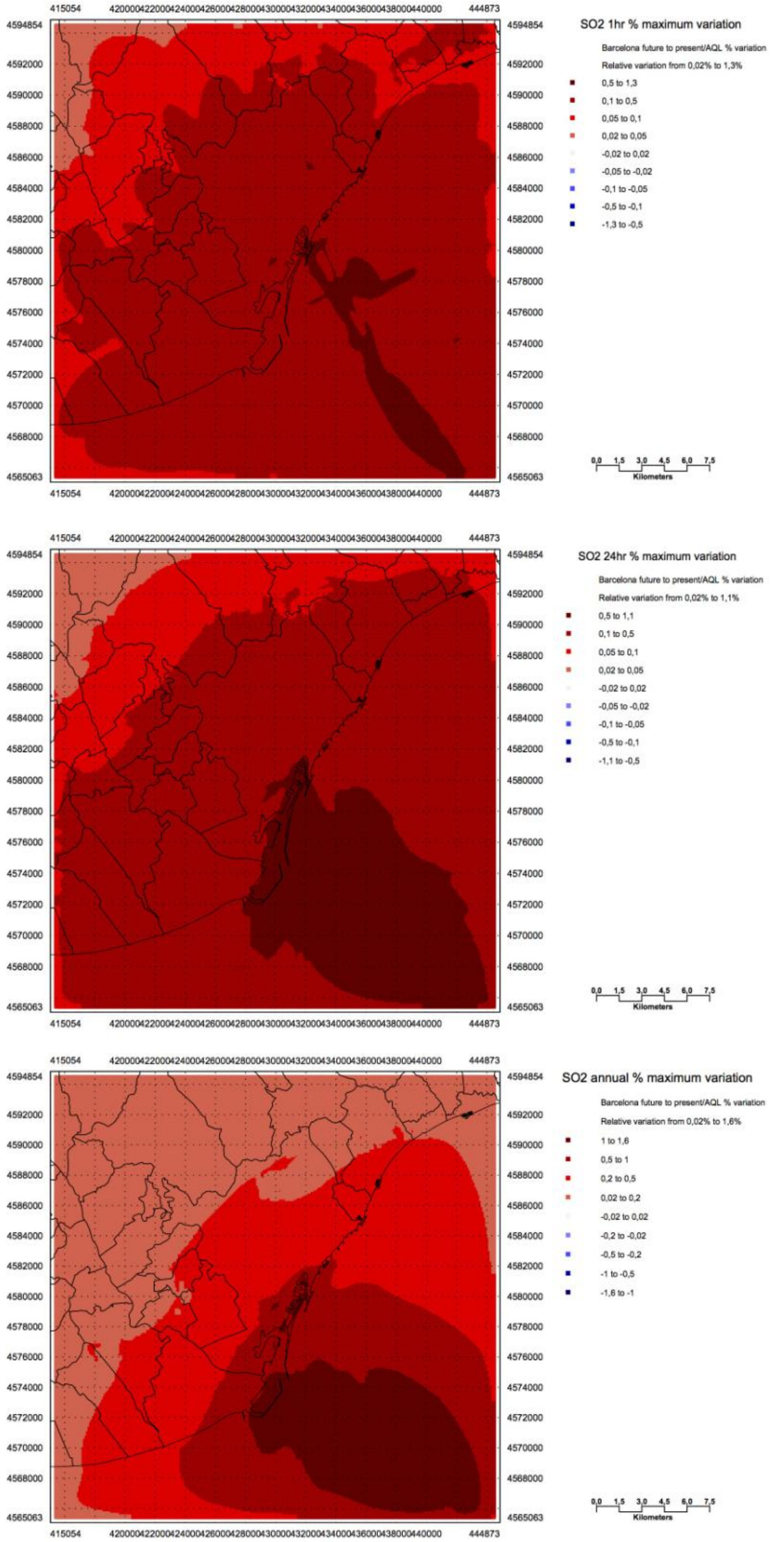


Fig. 4.1.1.2. Percentage differences relative to AQL for (top) 99.7% percentile of the 1hr concentrations; (center) 99.2% percentile of the daily concentrations and (bottom) mean annual SO_2 concentrations between future trend and present scenarios.

4.1.2. Genoa

In order to assess the air quality impact due to the future development of passenger ship traffic on Genoa area we adopted the same modeling chain structure used to perform the simulations of present time scenario (see Section 2.2.2) with the following input data:

- 2013 meteorology (unchanged with respect to present time simulations).
- 2020 emission data obtained by ARPAV-BUH program applied on 2020 database (see Section 3.2.2).

In this paragraph we will focus our attention on NO_2 concentration values, which were identified in the previous sections as the most critical ones over the Genoa area. In the following figures we report the NO_2 concentration maps obtained by simulation analysis of future baseline scenario and the percent change with respect to present time results, normalized with AQL.

The greater impact of the future baseline scenario NO_2 values from ship plumes can be observed through a further deterioration of air quality affecting of the already high values of NO_2 concentrations, reaching values of 19^{th} hourly maximum over the simulation domain equal to 310 µg/m^3 (i.e. 155% of AQL) and annual mean values equal to 3.44 µg/m^3 (i.e. 8% of AQL). The most relevant impact area is confirmed to be in the harbor area (near the touristic traffic docks) and in the partially inhabited hills above (NE side). Comparing the present time scenario and the future baseline scenario concentrations we got 14% for the spatially matched maximum increase of 99.8% percentile of hourly values and 3.4% for the spatially matched maximum increase of annual mean concentrations.

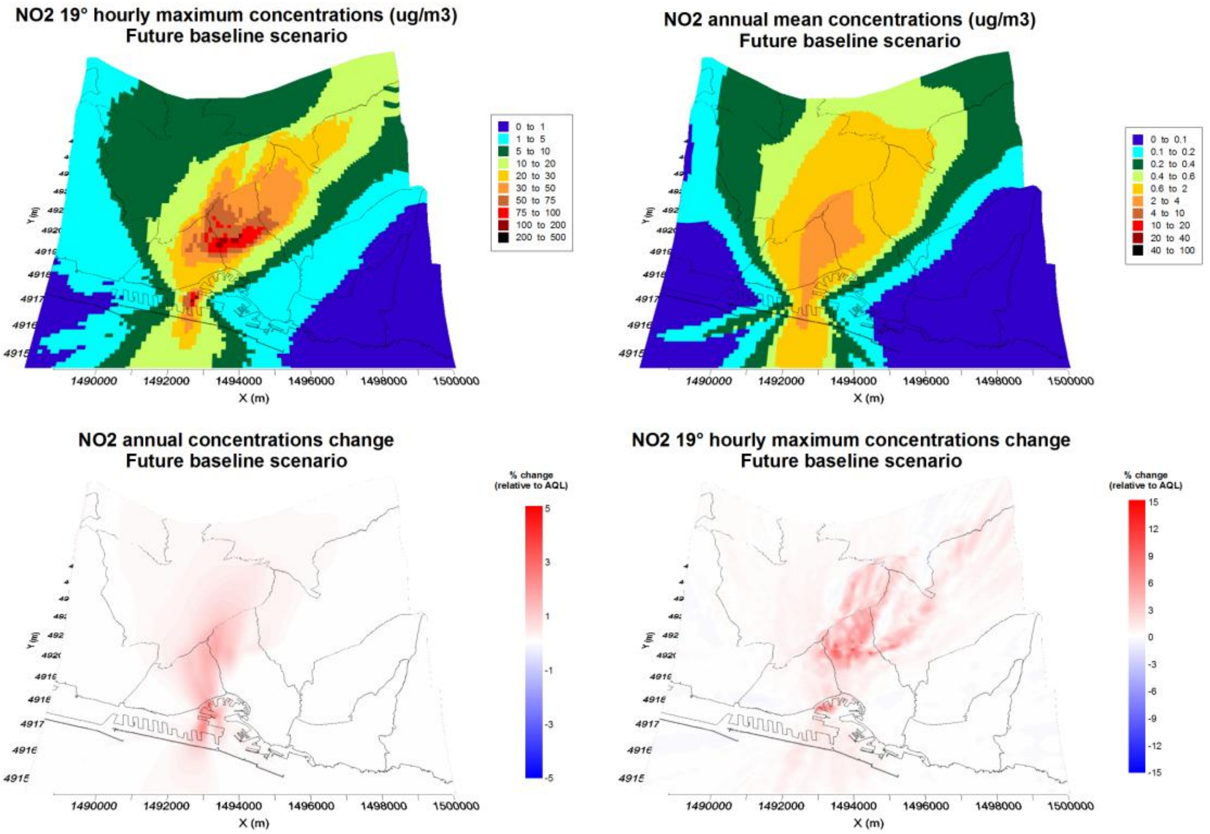


Fig. 4.2.2.1. On the left side the NO_2 19th maximum hourly values for the future baseline scenario (top: concentration values, bottom: percent change with respect to present time results normalized to AQL). On the right side NO_2 annual mean values for the future baseline scenario (top: concentration values, bottom: percent change with respect to present time results normalized to AQL).

4.1.3. Marseille

For the future baseline runs, the emissions for the year 2025 are used. They are calculated from GPMM projections. The meteorological data are similar to the present time scenario to evaluate the maritime traffic evolution only. Considering the impact of passengers/cruise ships on the air quality, SO_2, NO_2 and Ni pollutants are the main pollutants emitted over the area. Thus the results obtained for these 3 pollutants are described here and shown in Figures 4.1.3.1, 4.1.3.2. and 4.1.3.3.

Figure 4.1.3.1 shows that the 99.7 percentile of the hourly SO_2 concentrations increases in the future from +1% to 5% on the whole domain, with the maximum clearly observed along the ships trajectories and on the port. The maximum hourly SO_2 concentration in the future (90 $\mu g/m^3$) is observed on the Northern part of the port, representing 26% of the AQL value.

Fig. 4.1.3.1. Percentage differences in the SO_2 annual concentration between future trend and present scenarios with respect to the corresponding AQL (20µg/m3).

Figure 4.1.3.2 (a) shows that annual NO_2 concentrations increases in the future from +0.2% to 6% on the whole domain, with the maximum value clearly localized on the port.

Figure 4.1.3.2 (b) shows that the 99.8 percentile of the hourly NO_2 concentrations increases slightly in the future from +1% to +3% on the whole domain. The lower increase observed on the port can be explained by the fact that percentiles were already high on this point, at the present time, compared to the rest of the domain.

Figure 4.1.3.3 illustrates the percentage differences between future trend and present time obtained for the Ni annual concentrations. A maximum increase of about 3% is mainly observed in the Northern part of the port.

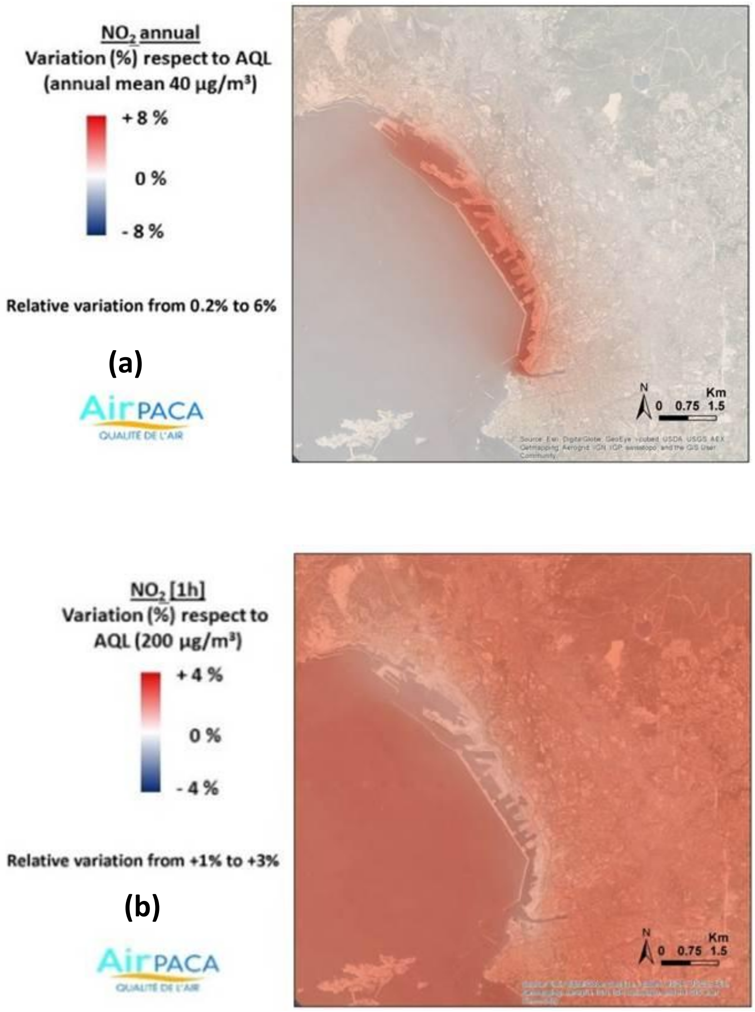


Fig. 4.1.3.2. Percentage differences in the NO_2 statistics between future trend and present scenarios with respect to the corresponding AQL [(a) annual concentration (b) 99.8 hourly percentile].

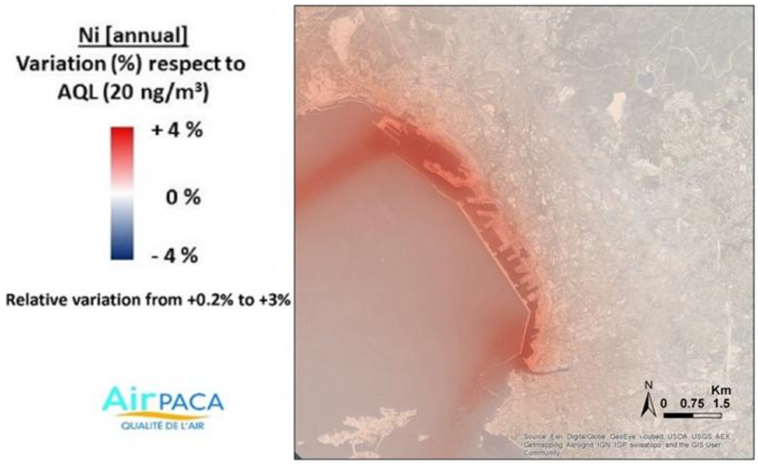


Fig. 4.1.3.3. Percentage differences in the Ni annual concentration between future trend and present scenarios with respect to the corresponding AQL (20 ng/m^3).

4.1.4. Thessaloniki

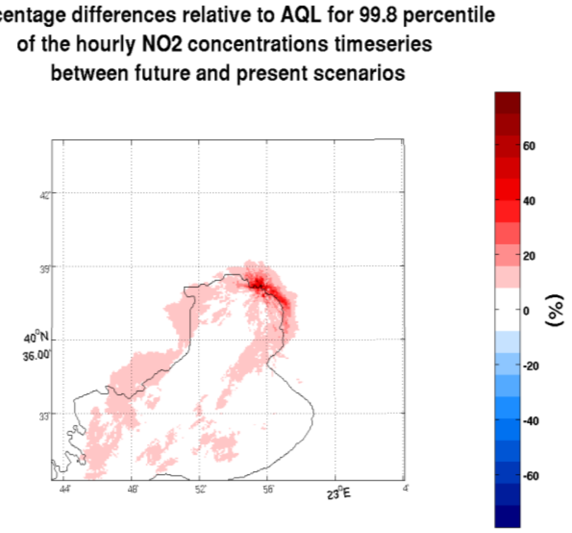
The CALPUFF model was applied while using the estimate emissions for the year 2025 described in the previous chapter and the meteorology for the year 2013 in order to identify the air pollutants levels in the study area due to plumes from cruise and other passenger ships and how the air quality is expected to change in the future with respect to the present situation. In future time, in accordance with the CALPUFF results for the present time scenario, the most important pollutants emitted from ships in terms of their impact on the air quality of Thessaloniki are NO_2 and SO_2.

Figures 4.1.4.1 and 4.1.4.2 present the percentage differences in specific percentiles of the timeseries of the hourly NO_2 and SO_2 concentrations between future trend and present scenarios with respect to the corresponding AQL. In Figure 4.1.4.1, the spatial distribution of the percentage differences in annual NO_2 values between future and present scenarios with respect to the NO_2 annual AQL is also shown.

In Figure 4.1.4.1, increases in the NO_2 statistics are identified being higher over the area of the port, the urban city center and the eastern part of the city which is closer to the port. The maximum variation in the 99.8 percentile of the hourly NO_2 concentrations timeseries compared to the AQL is up to about +80%. The maximum difference in the NO_2 annual values with respect to the NO_2 annual AQL is up to about +20%.

Figure 4.1.4.2 shows that along the coastal areas the 99.7 percentile of the hourly SO_2 concentrations timeseries is mostly increased in the future. The maximum increase is estimated very close to the port and represent 4% of the SO_2 hourly AQL.

(a)



(b)

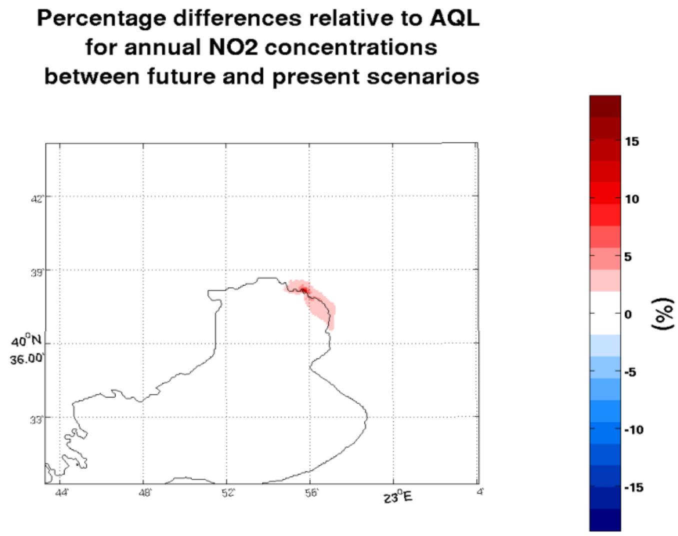


Fig. 4.1.4.1. Percentage differences in the NO_2 statistics between future trend and present scenarios with respect to the corresponding AQL for hourly (a) and annual (b) averaging times.

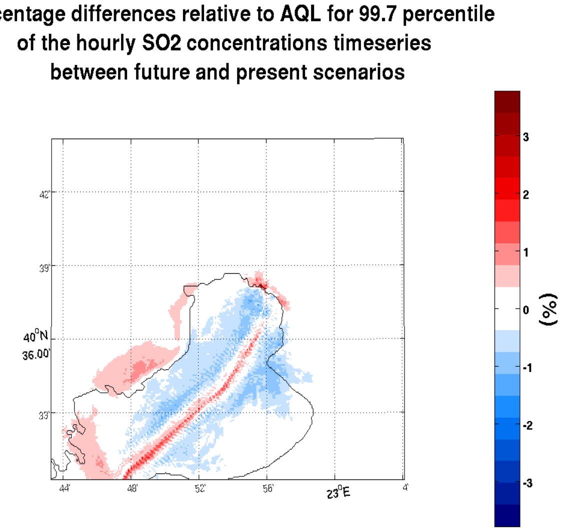


Fig. 4.1.4.2. Percentage differences in the statistic for the SO_2 hourly values between future trend and present scenarios with respect to the AQL.

4.1.5. Venice

Future emissions estimated for the 2020 trend scenario of passenger ships in Venice are input on the same CALMET-CALPUFF modeling chain in order to assess how the impact on the air quality, due to the future estimated passenger ship traffic, is expected to change with respect to the present situation.

While the meteorological input is the same used for the 2013 base run, the future 2020 scenario, obviously, takes into consideration for the Ro-pax vessels, the displacement of the terminal from Venice city center to Fusina, in Porto Marghera, as well the changed maneuvering route by the Malamocco entrance of the lagoon.

The difference between 2020 and 2013 concentrations are mapped on the following figures as percentage differences with respect to the corresponding AQL. Red areas, with increasing intensity, mean an increase in concentrations whereas blue areas correspond to a decrease. Figures 4.1.5.1 presents the changes in NO_2 concentrations: (a) for the 19th rank of the hourly concentrations in respect to the AQL of 200 μg/m^3 of which are allowed 18 exceedances in a year; (b) for the annual mean in respect to the AQL of 40 μg/m^3. Figures 4.1.5.2 presents the changes in SO_2 concentrations for the 25th rank of the hourly concentrations in respect to the AQL of 350 μg/m^3 of which are allowed 24 exceedances in a year.

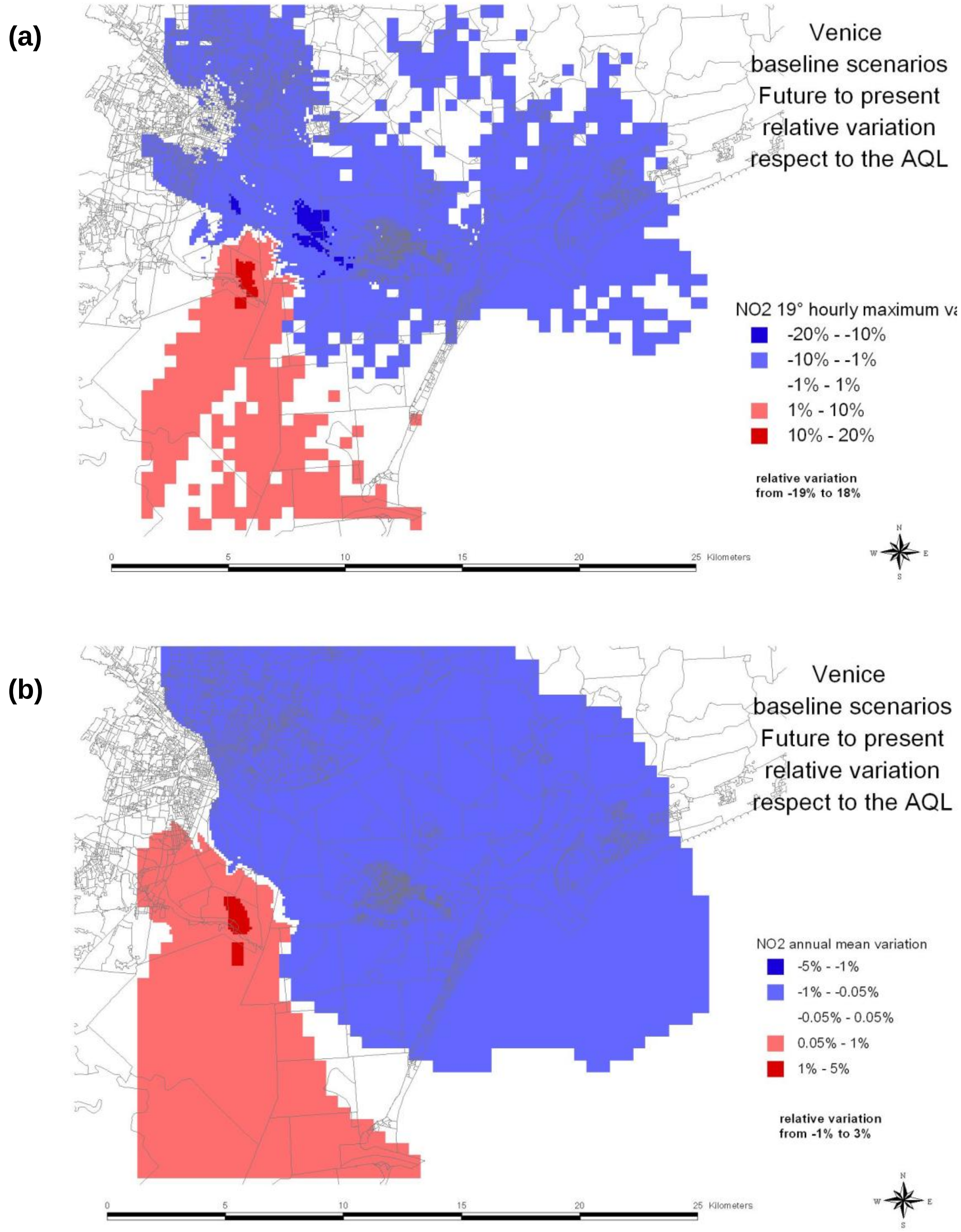


Fig. 4.1.5.1. Percentage differences in the NO_2 statistics between future trend and present scenarios with respect to the corresponding AQL. a) 19th highest hourly values, b) annual mean.

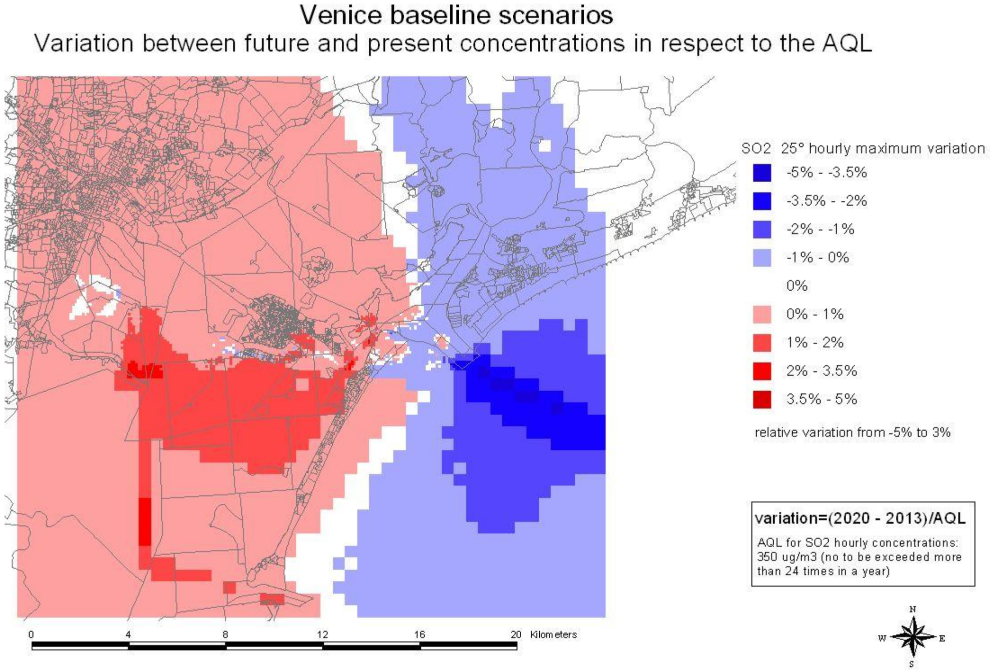


Fig. 4.1.5.2. Percentage differences between future trend and present scenarios for the 25th highest hourly SO_2 concentration with respect to the AQL.

As for NO_2 (Fig. 4.1.5.1), both the hourly and annual concentration maps of the future 2020 scenario record a decrease over the historical city center of Venice and the northern part of the lagoon and an increase on the southern part of the lagoon and the southern area of Porto Marghera. The relative changes are stronger for the hourly concentrations than the annual ones, with a range form -19% to + 18% for the first one in respect to the range from -1% to 3% for the annual averages. This pattern is mainly due to the displacement of Ro-pax vessels from the Marittima terminal in Venice city center to the Fusina terminal in Porto Marghera and the maneuvering route by the Malamocco entrance into the lagoon. A minor contribution to the decrease is due to the fleet renewal foreseen by IMO legislation.

SO_2 hourly concentrations (Fig. 4.1.5.2) show a general increase over quite all the lagoon, with the exception of the northern-eastern part and a decrease outside the lagoon. The relative changes lie between -5% to +3%. On the most populated areas of both Venice city center and Mestre a slight relative increase is recorded from + 1% to + 2%. The maximum decrease is along the cruise route outside the lagoon.

Differently to NO_2, even if in 2020 scenario the Ro-pax vessels are moved to the Fusina terminal in Porto Marghera, over the ancient city and over the central lagoon till the Lido entrance a slight increase is foreseen. This pattern is due to the change for the cruise ships from fuels respecting the 0.1% limit for sulfur content in maneuvering phase, as established by the Blue Flag 2 Agreement in 2013 year, to the 0.5% sulfur content limit for the fuels used in all European territorial waters set by the 2012/33 EU Directive.

So, whereas inside the lagoon there's an increase from the 0.1% to 0.5% limits considered for the cruise ships, outside the lagoon there's the decrease from the 2.7% used in the 2013 scenario as fuel average composition for the navigation mode (see 1.1 paragraph) to the 0.5% limit. The decrease outside the lagoon is also due to the missing component of the cruise phase by Ro-pax vessels approaching the port of Venice by the Malamocco entrance in 2020 scenario. On the map in Fig. 4.1.5.2 the greater decrease along the cruise route is in fact evident.

4.2. COMPARISON OF THE PORT CITIES IN TERMS OF AIR DISPERSION MODEL RESULTS FOR THE FUTURE TIME

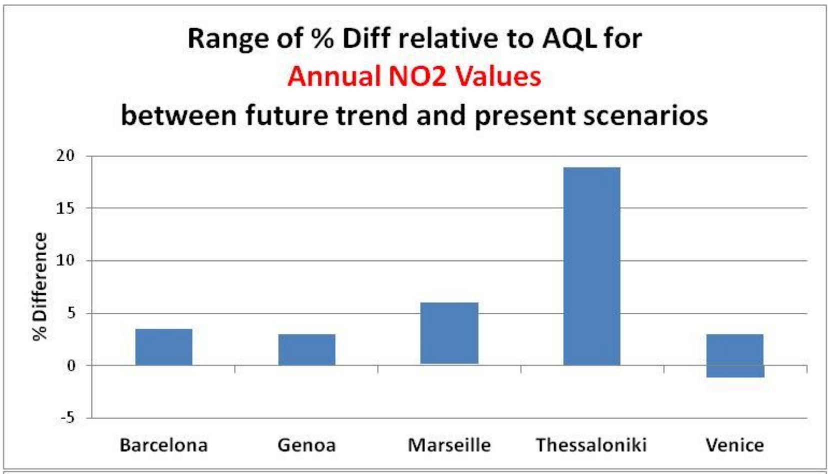
In the previous descriptions of chapter 4.1, it has been identified that the pollutants emitted by ships which are expected to be critical for the future air quality of the study areas are NO_2 and SO_2. Ni is also of concern, but only in Marseilles, considering the spatially matched differences. In this city, the passenger ship emissions are expected to impact the future atmospheric concentrations of Ni over generally extended parts of the modeling domains, covering the port and/or the adjacent maritime areas. The absence of PM_{10} from the maps, even for the ports with high enough absolute values, is due to the small coverage area, generally located near the terminals.

Figures 4.2.1 and 4.2.2 summarizes the range (i.e. minimum and maximum values) of the percentage differences in the long-term and short-term NO_2 and SO_2 concentration statistics between future trend and present scenarios with respect to the corresponding AQL (the same differences have been presented in the maps of the previous subsections of chapter 4). In addition, the percentage differences in the domain wide maximum long-term and short-term NO_2 and SO_2 concentration statistics between future trend and present scenarios with respect to the corresponding AQL are also presented (Figures 4.2.1c and 4.2.2d).

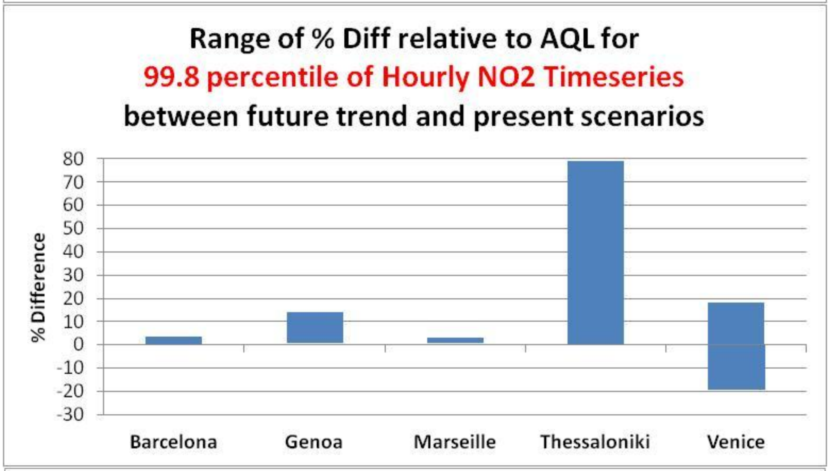
Figure 4.2.1a and b reveals that high percentage increases in NO_2 levels with respect to the AQL are expected in the future in Thessaloniki due to the cruise and other passenger ship traffic (about +20% and +80% for the long-term and short-term concentration statistics respectively). These increases are the highest compared to those for the other study areas. This result is in line with the highest increase in the passenger ship traffic foreseen for the port of Thessaloniki where the present time passenger ship traffic is low. Moderate percentage changes in the NO_2 short-term values with respect to the AQL have been estimated for Venice (about ±20%) and Genoa (about +15%). Percentage increases in NO_2 levels are projected for Barcelona and Marseille being though low compared to the AQL (about +5% or less).

As for the domain wide maximum NO_2 values, increases have been estimated in the future in all study areas except for Venice (Figure 4.2.1c). For most cities, the changes in maximum short term NO_2 values statistics when compared to the AQL are more pronounced compared to those in annual values. More specifically, the changes in the maximum short term NO_2 statistics represent a high share of the AQL in Thessaloniki (+42%), a moderate share in Genoa (+20%) and Venice (-10%) and are low in Barcelona and Marseille when compared to the AQL (less than +3.5%).

(a)



(b)



(c)

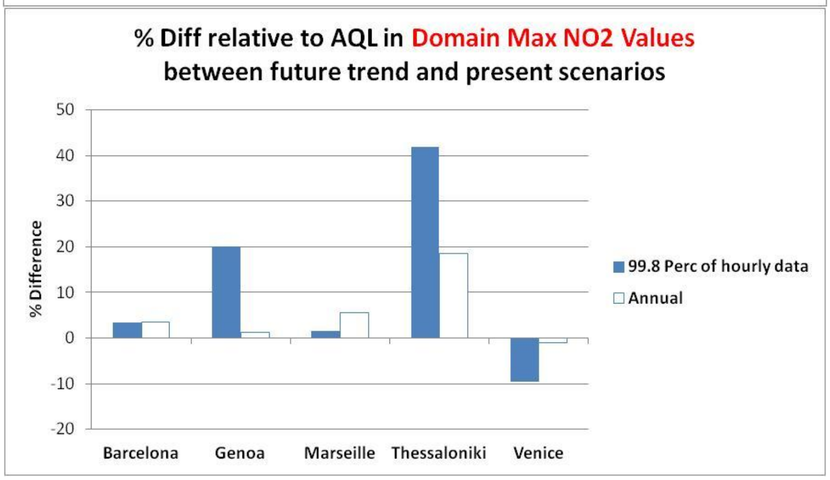


Fig. 4.2.1. (a) and (b): Range of the % differences in the long-term and short-term NO_2 concentration statistics between future trend and present scenarios with respect to the corresponding AQL. (c): % differences in the domain wide maximum long-term and short-term NO_2 concentration statistics between future trend and present scenarios with respect to the corresponding AQL.

Figure 4.2.2a, b and c shows that the percentage changes in long-term and short-term SO_2 concentration statistics with respect to the AQL are expected to be small (up to ± 5%) in the future in all study areas. In Barcelona, Genoa and Marseille, the changes refer to increases over the whole modeling domains of the study areas. In Venice and Thessaloniki, both increases and decreases in SO_2 values are expected, the latter though mostly over the sea or over parts of the domain which are less populated.

Increases have been estimated in the future for the domain wide maximum values of the long-term and short-term SO_2 concentration statistics in all study areas. These increases represent though small percentage values when compared with the corresponding AQL; up to +6% for Marseille, up to +4% for Thessaloniki, less than +2% for the other study areas (Figure 4.2.2d).

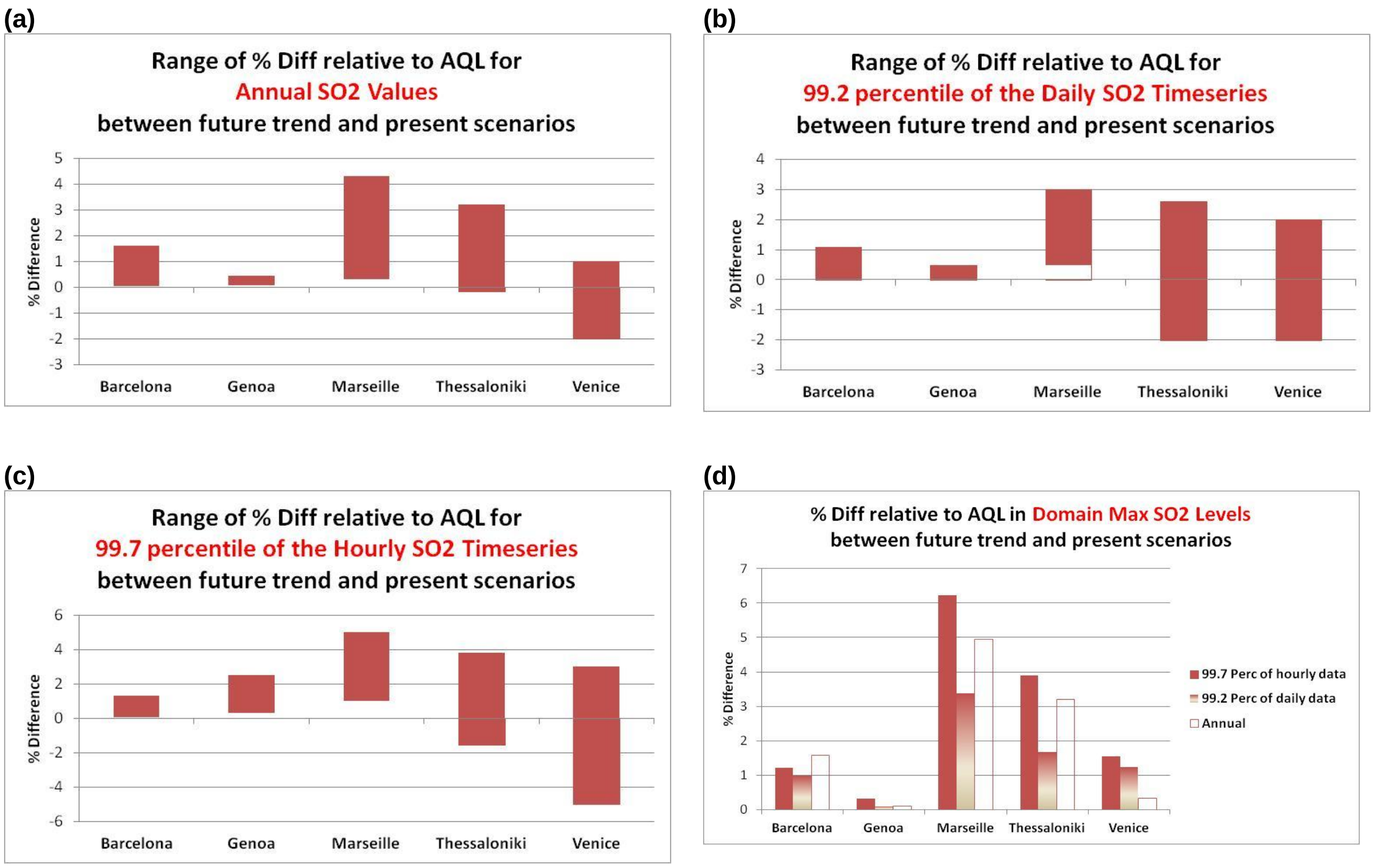


Fig. 4.2.2. (a), (b) and (c): Range of the % differences in the long-term and short-term SO_2 concentration statistics between future trend and present scenarios with respect to the corresponding AQL. (d): % differences in the domain wide maximum long-term and short-term SO_2 concentration statistics between future trend and present scenarios with respect to the corresponding AQL.

It is also interesting to notice that when, for both NO_2 and SO_2, increases have been estimated in long-term and short-term concentration statistics between future trend and present scenarios and compared to the corresponding AQL, then the percentages derived are higher for NO_2 than for SO_2 suggesting a more effective control of SO_2 concentrations due to passenger ship traffic in the future.

5. EMISSION MITIGATION MEASURES FOR SUSTAINABLE DEVELOPMENT STRATEGIES RELEVANT WITH THE PASSENGER SHIPS TRAFFIC

5.1. THE COMMON LNG SCENARIO

A common LNG emission scenario has been implemented in all hrbours. This emission scenario includes the use of Liquefied Natural Gas (LNG) as a fuel used by ships. LNG is considered as a clean fuel (no sulfur) and it therefore leads to the removal of SO_2 and PM emissions. According to the report of IMO (2009), LNG has higher hydrogen-to-carbon ratio compared with oil-based fuels leading to 20% lower CO_2 emissions. Finally, the reduced peak temperatures in the combustion processes result to 90% reduction of NO_x emissions for four-stroke engines.

Thus, the following reduction factors were applied on the future trend scenario (2020/2025) emissions for the year 2020/2025:

- SO_2 and PM: 100% reduction. This reduction has also been applied to metals and POPs.
- NO_x: 90% reduction
- CO_2: 20% reduction

5.2. DESCRIPTION OF THE MITIGATION SCENARIOS AND THEIR IMPACT ON FUTURE POLLUTANT EMISSIONS AND AIR QUALITY IN EACH PORT CITY

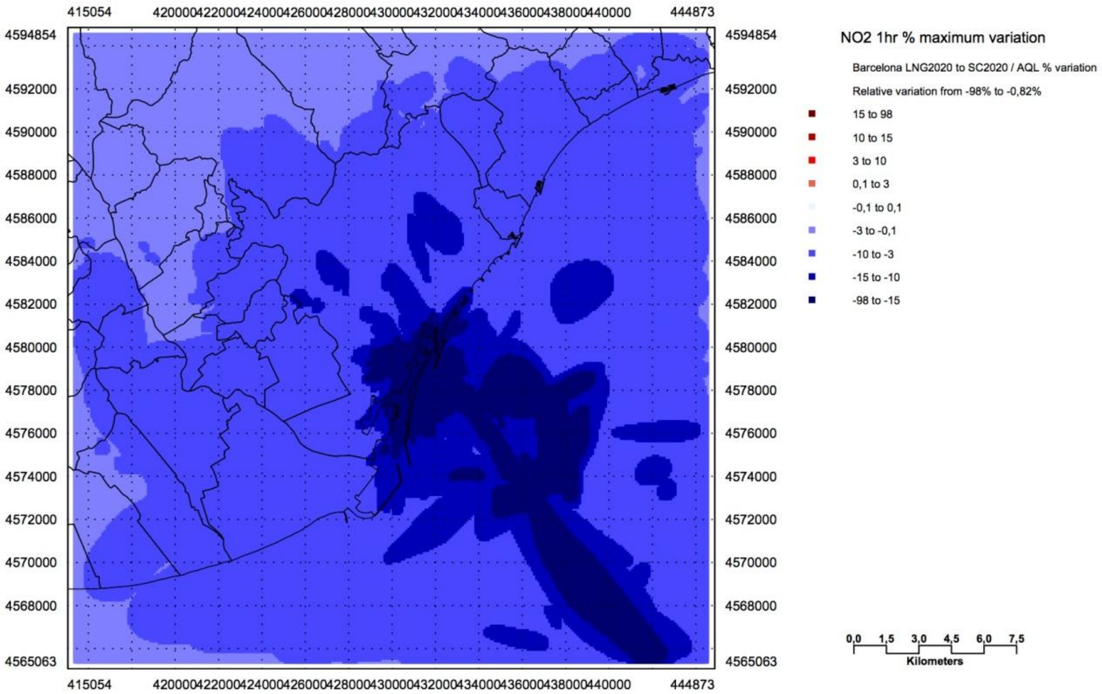
5.2.1. Barcelona

For the area of Barcelona, the common LNG emission scenario has been implemented (LNG2020). Application of the LNG2020 scenario on future trend leads to a reduction of emissions around -78% on NO_2 emissions with respect to BC2013 and zero SO_2/PM/micropollutants/metals emissions. Since LNG is applied to all navigation phases, this percentage is similar in hoteling, maneuvering and cruising. Therefore, here we will focus mainly on NO_2. The analysis will be carried out through percentage differences between future trend (SC2020) and mitigation scenario (LNG2020).

Regarding the atmospheric concentrations of pollutants, simulated with CALPUFF for LNG2020, the results indicate that for NO_2 hourly values reductions range from -90% to -73% when considering LNG2020 vs. SC2020 for the entire modelling domain. For annual values, these reductions range from -89% to -83%; in both cases, the maximum percentual reduction is found in background areas, where the NO_2 concentrations is close to zero (or very small) in the LNG2020 scenario. On the other hand, the lowest reductions –despite important- are found over the dock area (Addosat and Barcelona docks) and especially in the northern and southern buoys where the cruise phase of the vessels ends and the maneuvering phase begins. For SO_2, results are not shown since the reduction is -100% (SO_2 emissions and concentrations are considered zero for LNG).

When the results are expressed relative to the AQL (calculated as LNG2020-SC2020/AQL), the largest reductions for NO_2 (Figure 5.2.1.1) are found on the flanks of vessels' track (a similar pattern is also seen for SO_2 in Figure 5.2.1.2). The highest reduction found for hourly NO_2 with respect to the AQL (200 $\mu g/m^3$) (-98%) is located at the entrance of the vessels in the port (north and south buoys), increasing continuously towards the port. For the rest of the domain, reductions represent -10% of the AQL. Especially close to the boundaries, the low reductions can be related with the low concentrations of the future trend scenario (around -0.1%). All the above are also evident on the SO_2 1-hr variations (Figure 5.2.1.2). However, reductions here range from -0.1 to -8.9% since of the much lower values of this pollutant with respect to its AQL (350 $\mu g/m^3$).

For the annual values, the region with the highest reductions both for NO_2 and SO_2 is oriented on the centre and south of the port. The extended central part can be attributed on hoteling phase (-25% for annual NO_2, -11% for annual SO_2), covering a smaller area. However, important reductions of the concentrations expressed with respect to the AQL are also found during the cruising phase (decreases of -10% for NO_2 and -6% for SO_2). Again, low reduction values can be related with the lowest part of the concentrations, since they are far from the AQL used as reference.



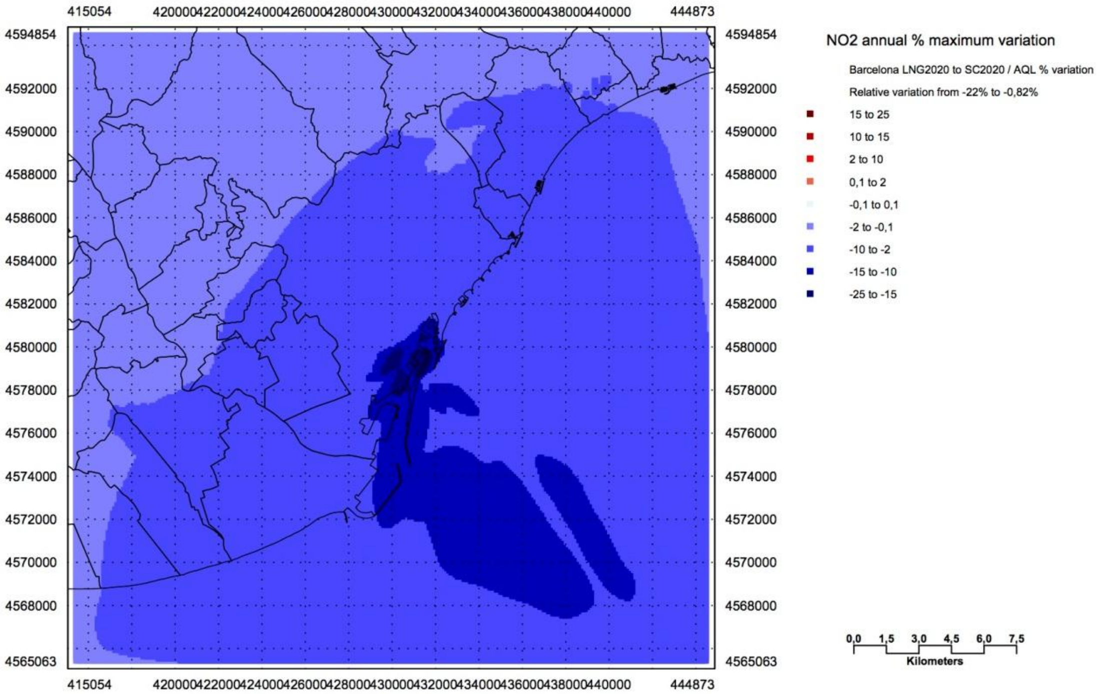


Fig. 5.2.1.1. Percentage differences relative to AQL for NO_2 (top) 99.8% percentile of the 1hr concentrations and (bottom) mean annual concentrations between LNG2020 and SC2020.

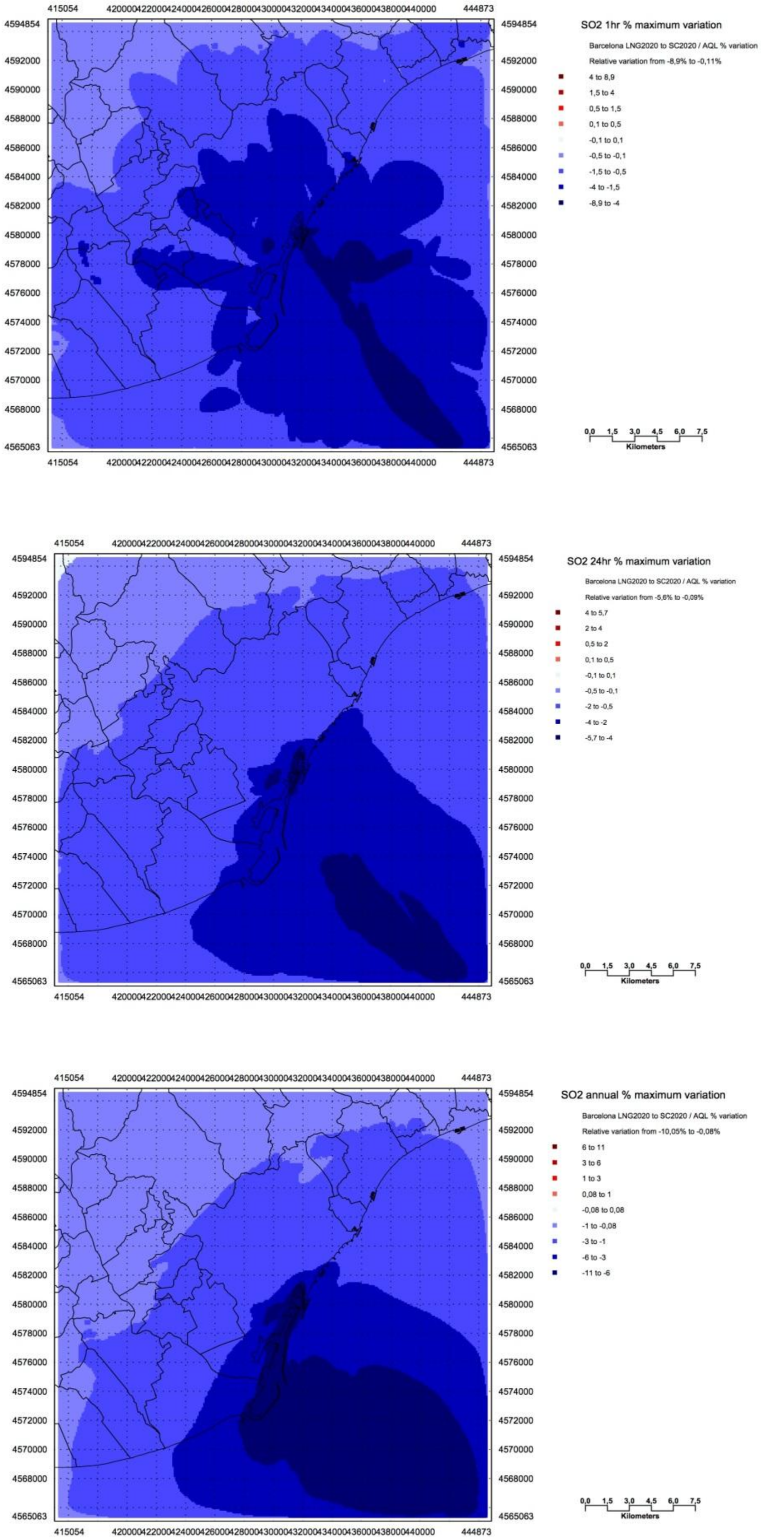


Fig. 5.2.1.2. Percentage differences relative to AQL for SO_2 (top) 99.7% percentile of the 1hr concentrations; (centre) 99.2% percentile of the daily concentrations and (bottom) mean annual concentrations between LNG2020 and SC2020 scenarios.

5.2.2. Genoa

Two mitigation scenarios were studied for the Genoa area:

- LNG scenario;
- On-shore Power Supply (OPS) scenario.

The modeling approach was similar to what adopted for the future baseline scenario:

- 2013 meteorology (unchanged with respect to future baseline scenario simulations).
- emission data obtained applying overall scaling factors (for LNG and OPS scenarios) to the 2020 future baseline scenario inventory (see Section 5.1 for the description of LNG emission reduction factors and Section 3.2.2 for the future baseline emission evaluation, the factors applied to define OPS scenario are described in the following).

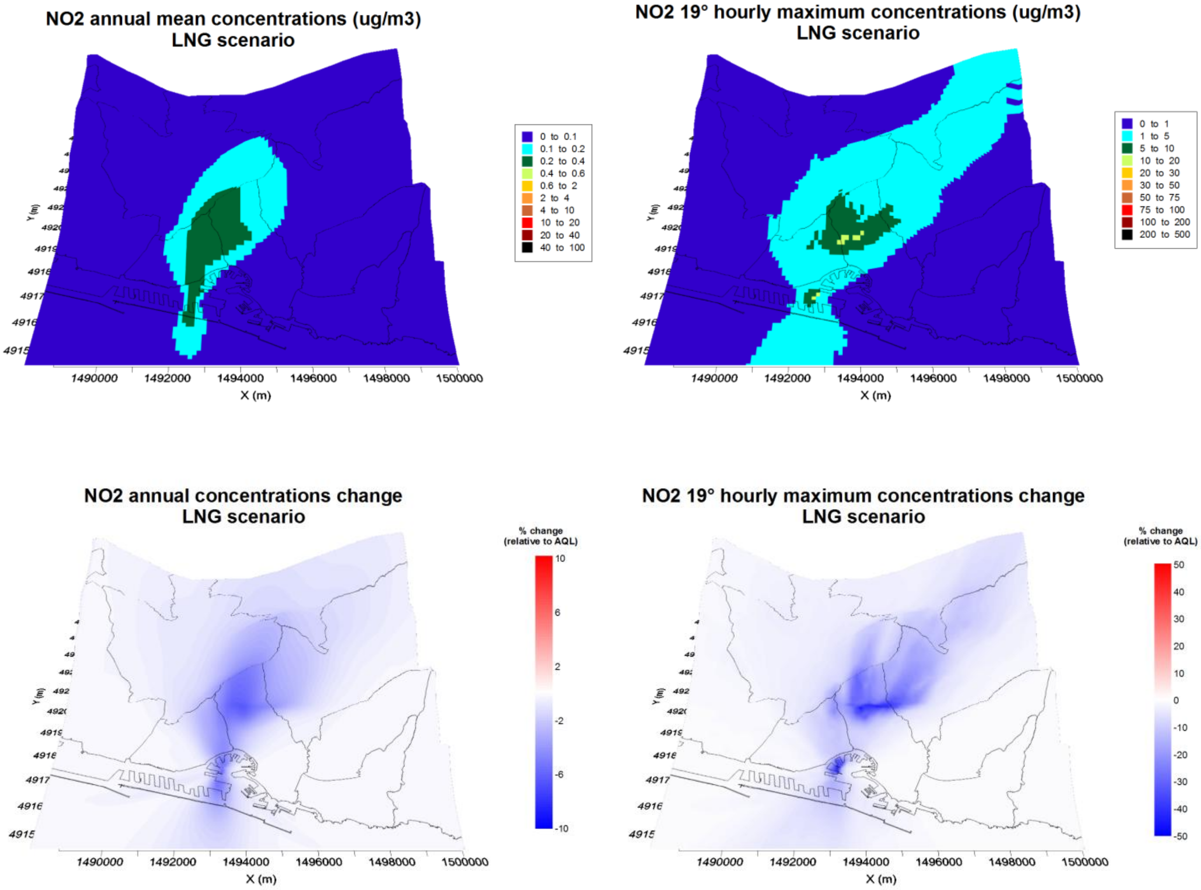


Fig. 5.2.2.1. On the left side the NO_2 19th maximum hourly values for the LNG scenario (top concentration values, bottom percent change with respect to future baseline results normalized to AQL). On the right side NO_2 annual mean values for the LNG scenario (top concentration values, bottom percent change with respect to future baseline results normalized to AQL).

LNG scenario was fixed as a common mitigation action to be studied within CAIMANs.
The highly positive effect on Genoa framework of the introduction of LNG fuel for passenger ship is evident when comparing the results of NO_2 19th hourly maximum (top-right of Figure 5.2.2.1) with for the future baseline scenario results reported in Figure 4.2.2.1. In fact no area within the simulation domain is close to AQL anymore and for most of the analyzed region we observe values lower than 5% AQL. The two maps at the bottom of Figure 5.2.2.1 show the NO_2 concentration percent reduction normalized to AQL, respectively for annual mean values (left) and for 99.8 percentile of hourly values (right).

In addition to the common LNG scenario, the mitigation action considered for the Genoa area was the introduction of OPS for passenger (cruises and Ro-pax) ships in the hoteling phase. In fact, according to the study commissioned by Liguria Region on the possible mitigation actions to be adopted for the Liguria Ports (Savona, Genoa and La Spezia), even if some significant infrastructure intervention would be needed to implement it, the OPS can be considered as one of the most convincing mitigation actions to reduce the impact of harbor activities on urban air quality. In the same study a global evaluation was performed of the emission reduction obtained with the application of OPS in different harbor sectors, focusing in particular on the effects on container and cruise terminal (where some intervention for infrastructural adaptation has been already started by Genoa Port Authority). For the calculation of the emission input for the Cold-Ironing scenario we applied the percentage reduction factors calculated for different cruises and ferries terminal. In particular for the cruises terminals we had about 80% NO_x, PM and SO_2 reductions, while for Ro-pax terminals we had about 90% NO_x, PM and SO_2 reductions. In Figure 5.2.2.2 we report the emission percent reduction calculated over the total emission amount (hoteling phase + maneuvering phase) for both Ro-pax and cruises.

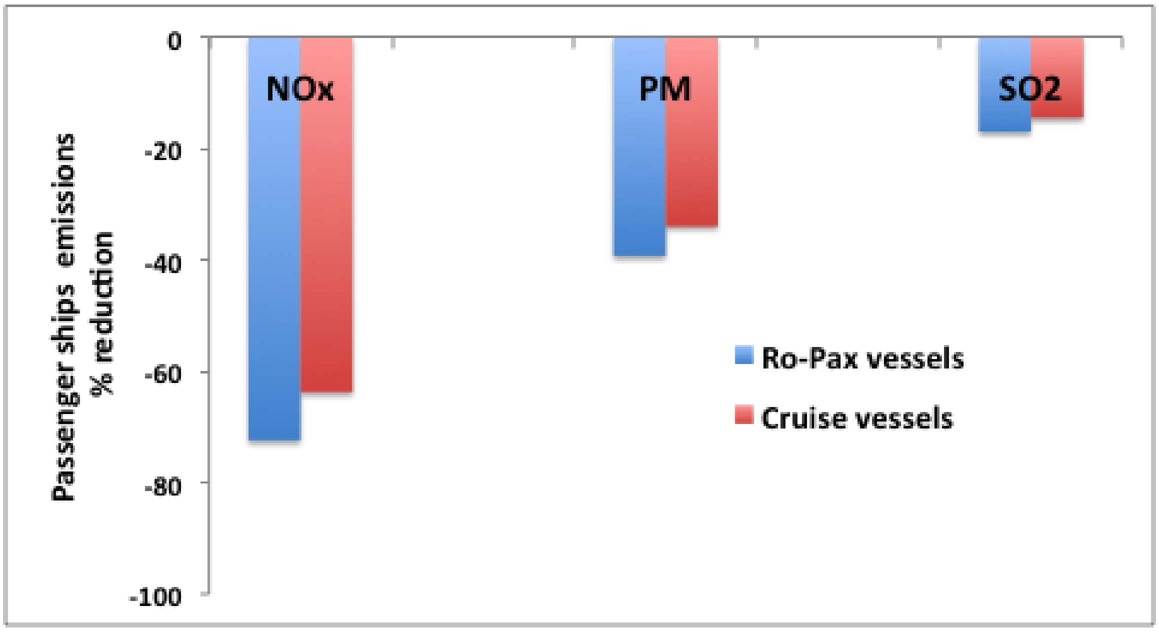


Fig. 5.2.2.2. Percentage reduction of total emissions (hoteling and maneuvering phases) obtained applying OPS to Ro-pax and Cruises terminals.

The global impact decrease, if compared to the total harbor emissions, was evaluated in a range of 3% - 14% for NO_x emissions, 6% - 11% for PM emissions and 4% -14% for SO_2 emissions.

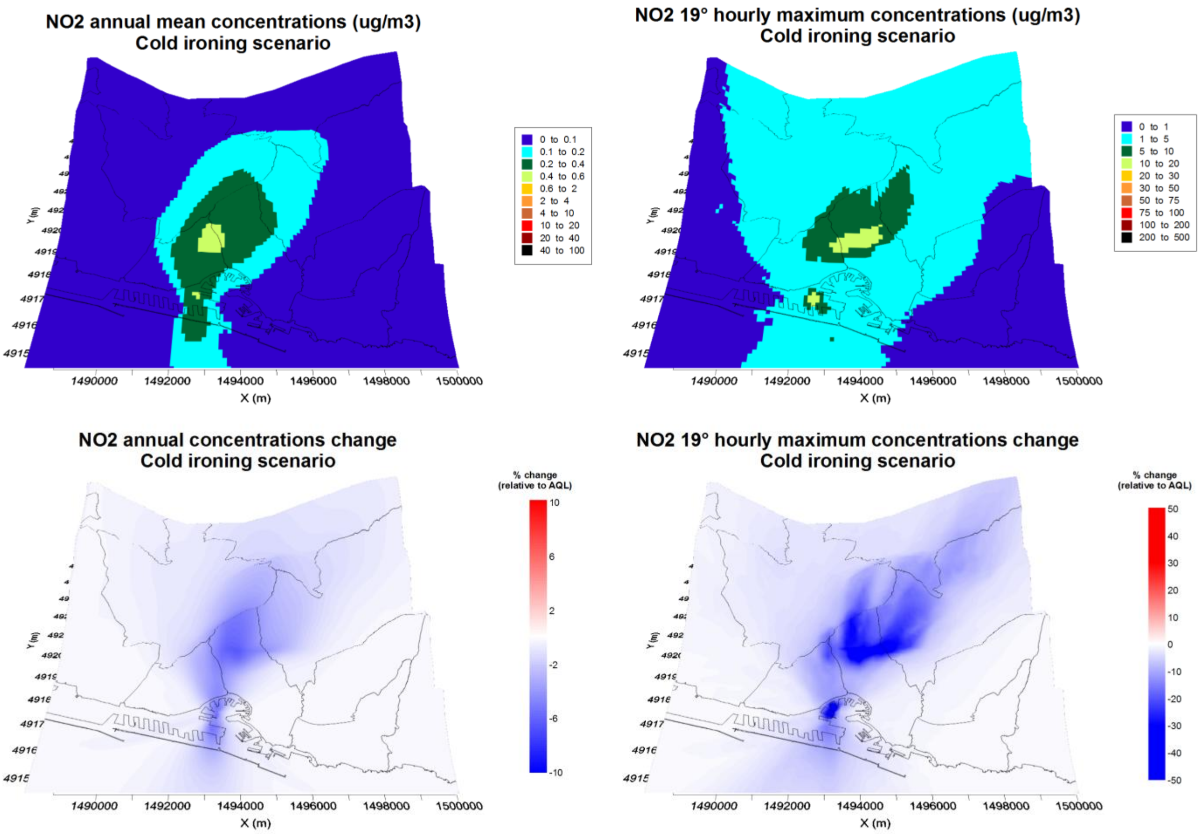


Fig. 5.2.2.3. On the left side the NO_2 19th maximum hourly values for the OPS scenario (top concentration values, bottom percent change with respect to future baseline results normalized to AQL). On the right side NO_2 annual mean values for the OPS scenario (top concentration values, bottom percent change with respect to future baseline results normalized to AQL).

In Figure 5.2.2.3 we report the results of the OPS scenario simulations for NO_2 concentrations. Similarly to what observed for LNG, the OPS mitigation action has a relevant positive effect on the impact of passenger ship traffic on Genoa air quality, reducing NO_2 concentration values. Also in this case the highest mitigation effect is obtained on hourly concentration values, with percent reduction of the 19^{th} hourly maximum ranging between -0.03% and -49% over the simulation domain.

The above analysis shows that we can obtain good results for the Genoa area from both the mitigation actions studied, LNG fuel introduction and OPS for passenger ships. The effects of the two actions on NO_2, which were identified as the most critical pollutant related to passenger ships traffic by the analysis of present and future trend scenario, are comparable, with concentration reduction ranging from less than 1% to about 50%

of AQL. Moreover in both the analyzed scenarios we found no area within the simulation domain with NO_2 concentration values close to AQL anymore.

5.2.3. Marseille

In the area of Marseille, only the common LNG mitigation scenario, as described in paragraph 5.1, has been studied. The cold ironing scenario was studied in the framework of APICE and lead to successful actions, because since June 2015, 3 OPS have been operating in the Port of Marseille.

To simulate the LNG scenario in 2025, the meteorological data of 2013 and the emissions factors as described in paragraph 5.1 were used. Since no more emissions of SO_2 and Ni are expected, only the relevant results on the NO_2 pollutant are shown here.

By applying this LNG scenario, it is shown in Figure 5.2.3.1 that annual NO_2 concentrations decrease from -1 % to -38 %, with the maximum value clearly observed close to the port. The maximum annual concentration for the LNG scenario is of about 2 μg/m^3, which represents around 5% of the annual AQL.

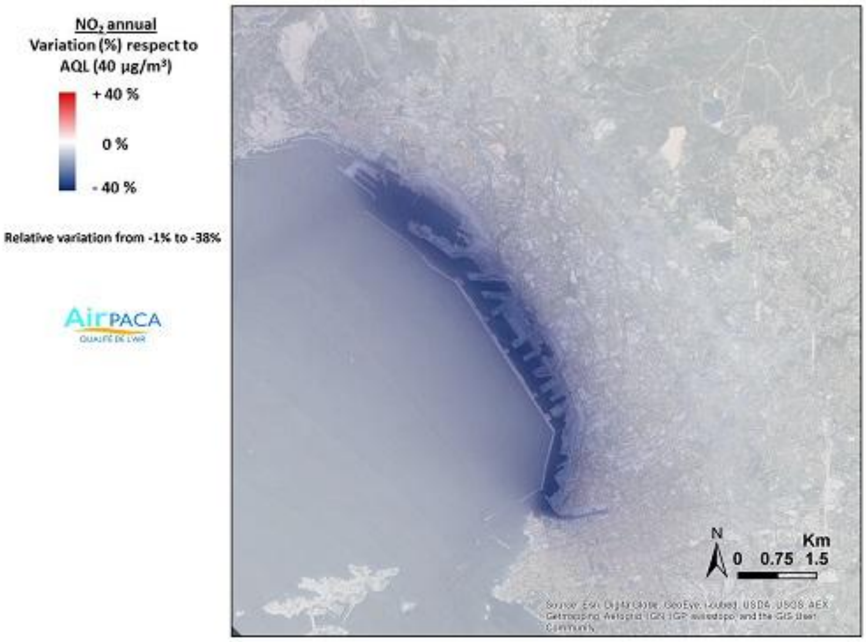


Fig. 5.2.3.1. Percentage differences in the NO_2 annual mean between LNG mitigation and future trend scenarios with respect to the corresponding AQL.

Figure 5.2.3.2 presents the percentage differences in the 99.8 percentile of the hourly NO_2 concentrations time series between the LNG mitigation and future trend scenarios with respect to the corresponding AQL. A significant variation from -17 % to -29 % is obtained, with respect to the AQL. This variation concerns the whole domain. Furthermore, the maximum 99.8 percentile value (about 26.3 µg/m^3) obtained for this LNG scenario is localized close to the port and represents only 13 % of the hourly AQL.

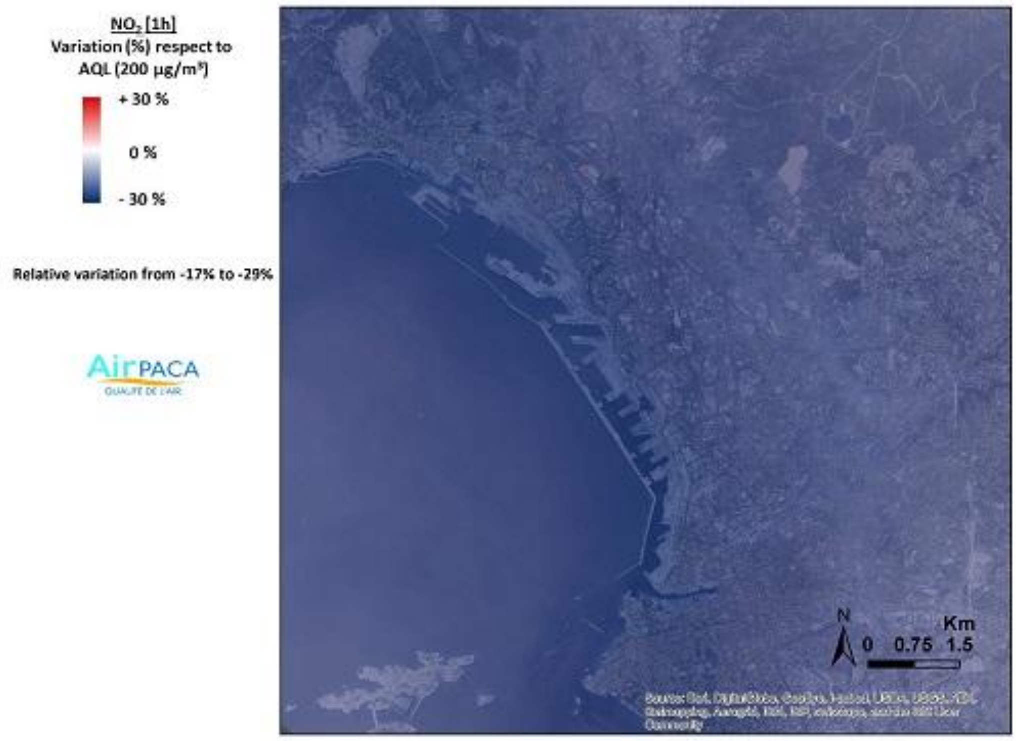


Fig. 5.2.3.2. Percentage differences in the NO_2 hourly statistics between LNG mitigation and future trend scenarios with respect to the corresponding AQL.

These results show an evident mitigation of air pollution thanks to LNG use, that leads to a huge reduction of the NO_2 pollution and a removal of PM and SO_2 pollution from ships.

5.2.4. Thessaloniki

For the area of Thessaloniki, two mitigation emission scenarios were examined in the framework of the project: a) the use of LNG as ship fuel and b) the cold ironing.

In the case of the LNG scenario, the above mentioned percentage reductions were applied on the future trend scenario emissions of the year 2025 to account for the use of LNG as passenger ship fuel (cf. paragraph 5.1).

The 2nd mitigation scenario concerned the implementation of cold ironing i.e the electrification of ships during hoteling mode. Thus, future trend scenario emissions were forced to zero for the hoteling mode for all the studied pollutants.

Fig.5.2.4.1 illustrates the percentage differences between the 2nd mitigation scenario (cold ironing) and the future trend scenario emissions for: a) all passenger ships and b) cruise ships only. The differences shown in Fig. 5.2.4.1 refer to total emissions from all ship operation modes, i.e. cruising, maneuvering and hoteling. In both plots, macropollutant and CO_2 future emissions present a reduction of around -30% when cold ironing is implemented, except for PM and SO_2. For these pollutants the estimated reductions are smaller (-18% and -10%respectively) due to the lower sulphur content of fuel used by ships in hoteling mode resulting in lower emissions in that mode compared to those in cruising and therefore in a lower impact of the cold ironing scenario on the reduction of total PM and SO_2 emissions. Concerning micropollutant emissions, Hg emissions present the largest reduction of -35% because of the larger emission factor in hoteling mode. BaP2 (i.e. BaP estimated using emission factors from Agrawall et al., 2010) emission reduction is very low; around -4%.Emission factors of Cr and Ni are also very low in hoteling mode and therefore the cold ironing scenario has a negligible impact on their emissions. For the remaining micropollutants, the emission reductions range from around -13% for PCDD/Fs to -30% for BaP1 (i.e. BaP estimated using emission factors from Cooper and Gustafsson, 2004) and Zn.

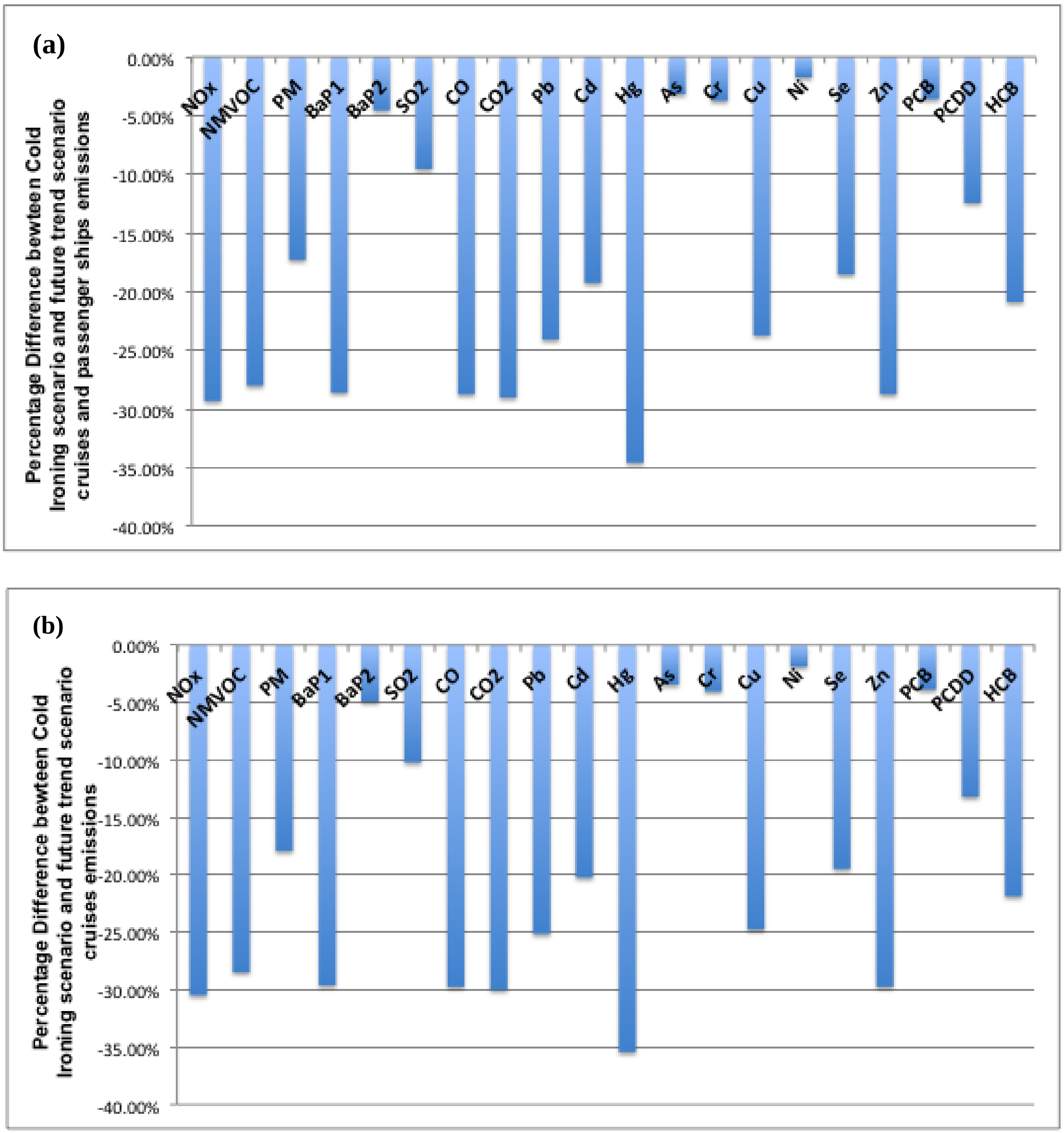


Fig. 5.2.4.1. Percentage difference between the cold ironing mitigation scenario and the future trend scenario emissions for: a) cruise and passenger ships and b) only cruise ships for the year 2025.

The CALPUFF model was applied while using the pollutant emissions of the two mitigation scenarios described above and the meteorology for the year 2013 so as to assess the effectiveness of the emission abatement measures. Following, the response of NO_2 surface concentrations to the applied emission reductions is investigated. In the analysis, more emphasis is put on NO_2 which has been revealed as a critical pollutant the concentrations of which are most affected by the passenger ship traffic.

Figure 5.2.4.2illustratesthe percentage differences in the 99.8 percentile of the hourly NO_2 concentrations timeseries and in the NO_2 annual values between the mitigation and future trend scenarios with respect to the corresponding AQL.

In Figure 5.2.4.2a, the 99.8 percentile of the hourly NO_2 concentrations timeseries is reduced over the maritime and coastal areas of the modeling domain due to the use of LNG as ship fuel. Over the greater part of these areas, the decreases are up to -20% with respect to the AQL. The reductions are more pronounced over the central and eastern parts of the city which are closer to the port and over the passenger terminal where the percentile values can be reduced by more than -40% with a maximum decrease value of -147%. These high reductions appear on urban areas with high population density and a reduction on human health impact is expected due to the cut-off of the ship emissions. Figure 5.2.4.2b present reductions in annual NO_2 values over the port area and city center representing up to about -22% of the NO_2 annual AQL.

As shown in Figure 5.2.4.2c and d, the differences in NO_2 statistics for the cold ironing scenario are less spatially extended compared to the LNG scenario. In fact, NO_2 levels are affected mostly over the area of the port where the maximum reduction of the 99.8 percentile of the hourly NO_2 concentrations timeseries represents about -120% of the NO_2 hourly AQL (reduction lower by -27% compared to the corresponding maximum reduction for the LNG scenario). Figure 5.2.4.2d shows that the reductions in annual NO_2 values over the port due to cold ironing represent up to about -23% of the NO_2 annual AQL (maximum impact comparable with that for the LNG scenario). Among the other pollutants, it is the SO_2 levels that are most affected by the cold ironing scenario. More specifically, the maximum reduction in the 99.7 percentile of the hourly SO_2 concentrations timeseries with respect to the SO_2 hourly AQL is about -6.6%

The above analysis suggests that the LNG scenario is more efficient than cold ironing in terms of air quality impact in the study area because it eliminates SO_2, PM (including BaP and metals) emissions and results in higher and more extended reductions in NO_2 levels.

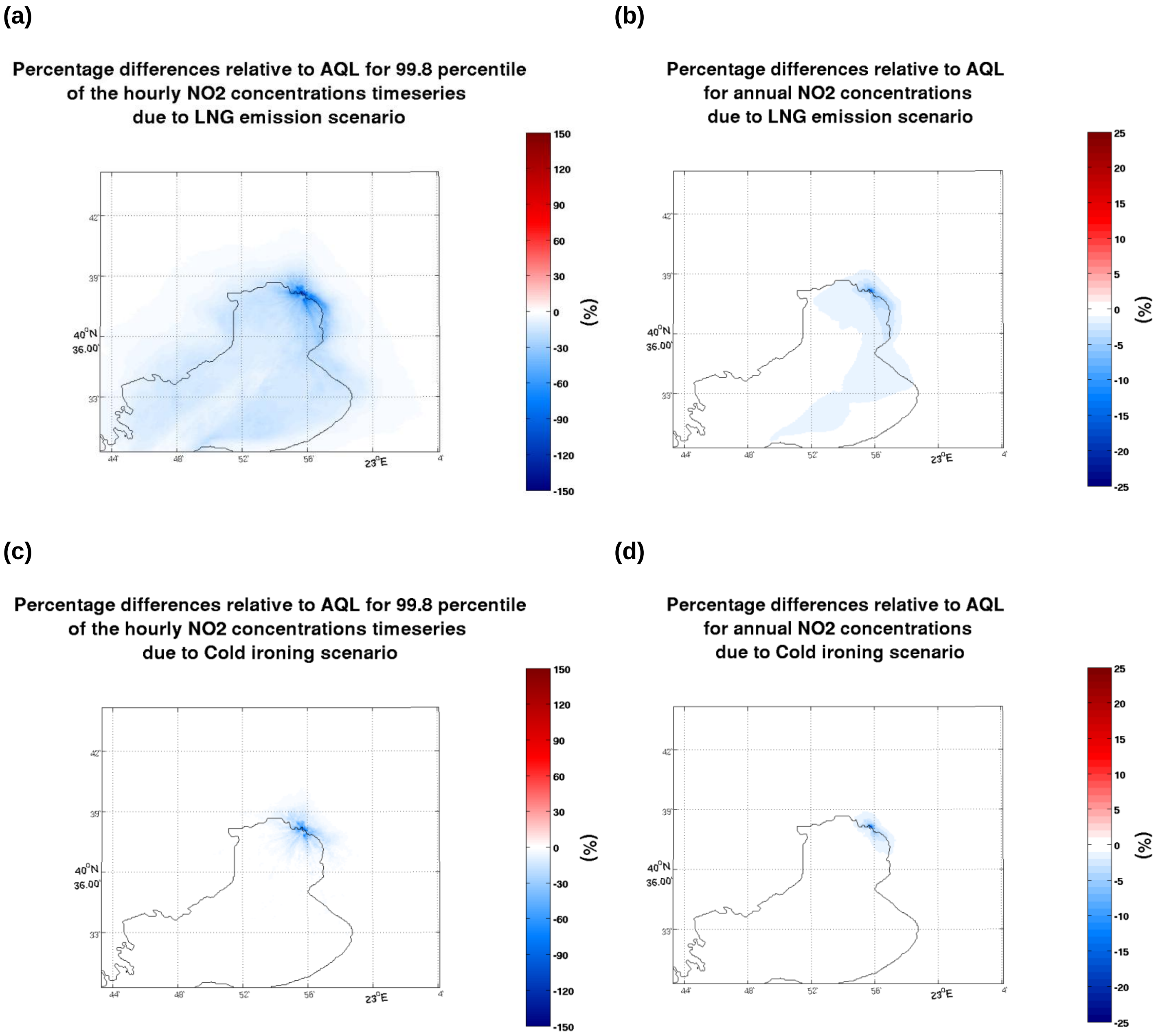


Fig. 5.2.4.2. Percentage differences in the NO2 statistics between mitigation and future trend scenarios with respect to the corresponding AQL (a and b plots for the LNG scenario; c and d plots for the cold ironing scenario).

5.2.5. Venice

For the port of Venice, four mitigation emission scenarios have been studied: beside the common LNG emission scenario and the cold ironing ones, analysed also in the other pilot areas, two additional hypothesis have been investigated concerning two different projects under discussion as an answer of the pending ban in Venice, since 2012, for the sailing in the San Marco basin and in the Giudecca Channel by ships over 40’000 gross tonnage (GT)(Ministerial Decree no. 79 of 12/3/2012 by Ministry of Infrastructure and Transport; this ban is currently suspended whilst awaiting an alternative solution for the manoeuvring route).

The first project, the so-called "Contorta-Sant'angelo Channel", proposes digging a 5 kilometres channel in the depths of the lagoon to let the cruise ships entering by the Malamocco lagoon entrance and hoteling on the same Martittima Terminal currently used (http://www.va.minambiente.it/it-IT/Oggetti/Info/1486).

The second project, the so-called "Venice Cruise 2.0 terminal", proposes a totally new terminal for the cruise ships at the border of the lagoon entrance of Lido in Punta Sabbioni area, just outside the MOSE mobile flood barriers under construction (http://www.va.minambiente.it/it-IT/Comunicazione/DettaglioNotizia/283).

It's worth noting that the two mentioned local projects have been investigated, starting from the information available at the time of the implementation of CAIMANs, but the outcomes here presented can't be considered as a substitute of the Environmental Impact Assessment Study required by the legislation. Especially for the project of a new terminal at the Lido entrance only preliminary and partial information were available so the assessment performed has to be considered as an initial rough analysis. Nevertheless, the assessment by the CAIMANs methodological approach also of these two local projects has been considered a useful analysis to be delivered to the Venetian discussion.

In order to assess the effectiveness of each of the four scenarios, the correspondent emissions are input on the same CALMET-CALPUFF modeling chain used for the 2013 and 2020 scenarios and the differences between the mitigation scenario and the future 2020 scenario are analysed in percentage scale in respect to the various air quality limits (AQLs). The meteorology is once again the 2013 one.

The LNG scenario has been implemented in the Venetian study, as on the other pilot areas, considering a total replacement of the passenger ships (cruise ships included) by a fleet fuelled by Liquefied Natural Gas (LNG). The reduction factors applied on the 2020 future trend scenario emissions are described in paragraph 5.1.

In Figures 5.2.5.1 and 5.2.5.2 the variation of NO_2 concentrations between LNG scenario and future scenario are shown in percentage scale in respect to the AQL limits. Figures 5.2.5.1 shows the annual average case, whereas Figures 5.2.5.2 the 19th highest hourly value.

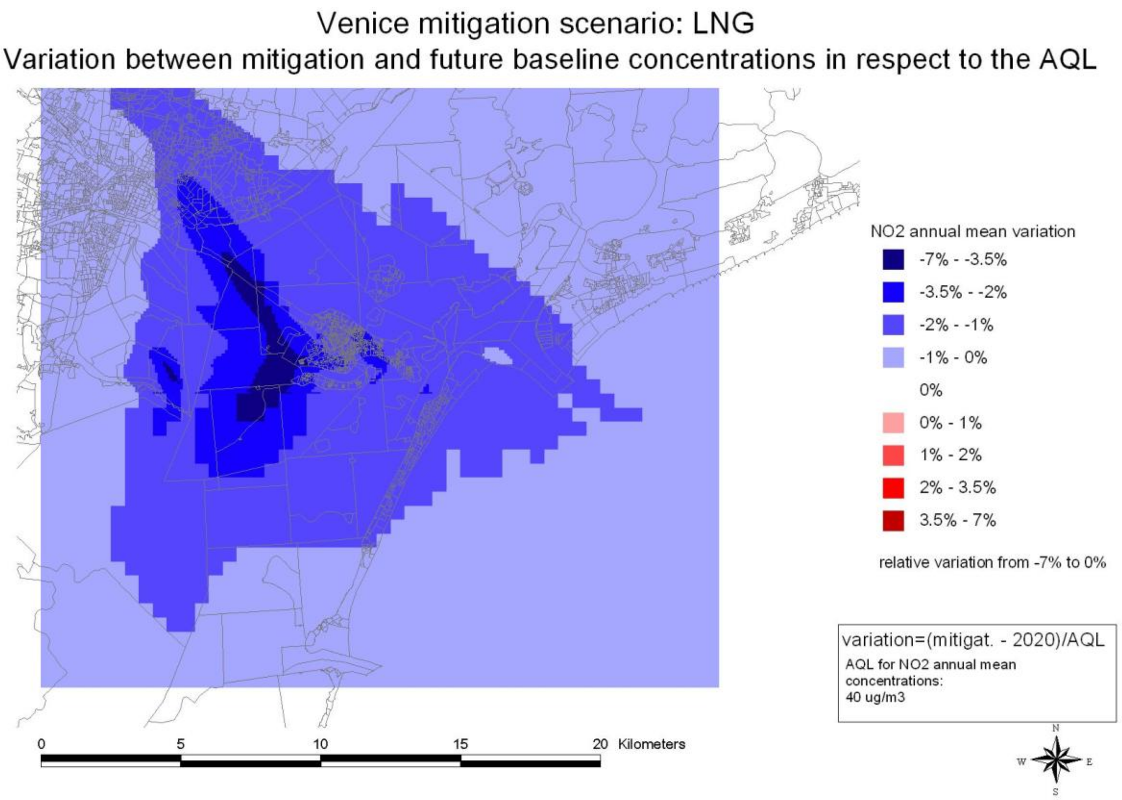


Fig. 5.2.5.1. Annual NO_2 concentrations; percentage differences in respect to AQL, applying LNG scenario.

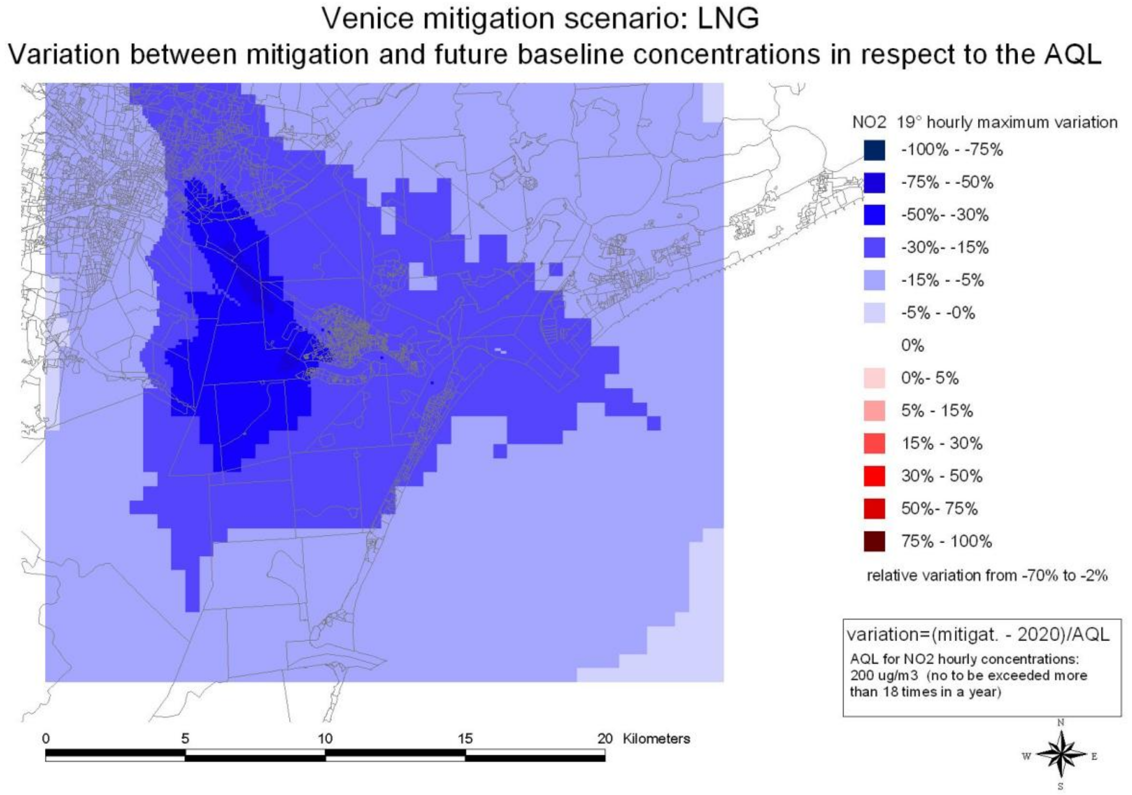


Fig. 5.2.5.2. 19th highest hourly NO_2 concentrations: percentage differences in respect to AQL, applying LNG scenario.

The highest decrease for the annual values is around -7% in the area behind and in front of the Marittima terminal where the future 2020 scenario recorded the maximum concentrations around the 5% of the AQL. With the LNG scenario all the annual NO_2 concentrations remain below 0.4 μg/m^3, that is below the 1% of the AQL of 40 μg/m^3.

The maximum decrease for the 19th highest hourly concentrations reach -70% of the AQL again very close to the Marittima terminal. With the LNG scenario no area exceeds any more the AQL as it happened for the 2020 scenario and in all the domain forecasted concentrations remain below 20 μg/m^3, that is below the 10% of the AQL of 200 μg/m^3.

The On Shore Power Supply (OPS) scenario (so-called “cold ironing”), has been implemented in Venice analysis only for the cruise ships. The OPS scenario has considered a reduction of emissions taken from a specific project that studied the feasibility of the installation of four electrified quays for delivering electricity to cruise ships hoteling in Marttima Terminal (APV, 2011 in Gissi e Quaglia, 2013).

The four electrified quays would supply around 6200 hours of power in a year, that is around the 90% of total hoteling hours of the cruise ships over 40'000 GT and the 73% of the hoteling hours of all the cruise ships, smaller ones included.

Given this data, in Figure 5.2.5.3. the percentage differences between OPS scenario and 2020 future scenario emissions are shown for the various air pollutants and in respect to the three following groups: cruise ships (in blue), all passenger ships (in red) and all ships, commercial ones included (in green). All the percentage decreases has been calculated considering the three navigation phases: hoteling, maneuvering and cruise outside the lagoon (about 10 km of route).

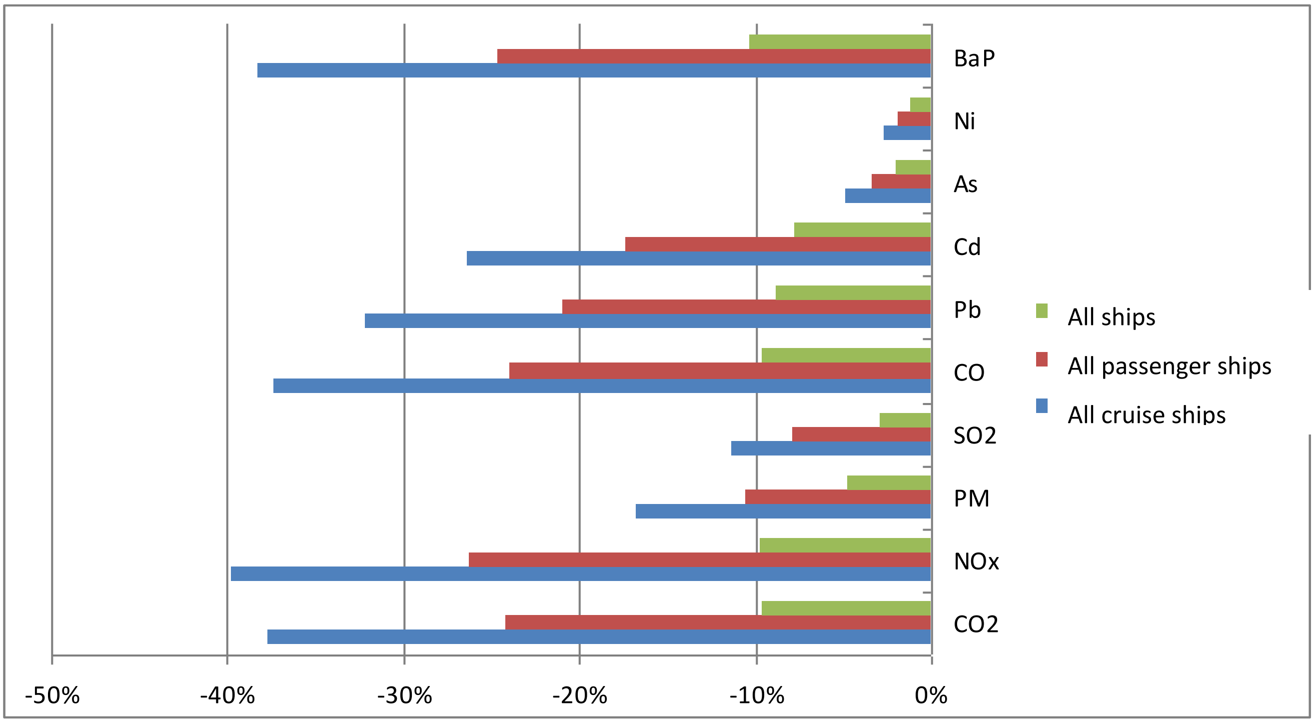


Fig. 5.2.5.3. Percentage difference in emissions
between the OPS mitigation scenario and the future trend 2020 scenario.

Ni is the pollutant that records the lowest decrease, since it is mostly emitted in maneuvering and cruising phases, where BFO is the predominant fuel used. SO_2 emission reductions are few as well, since the hoteling phase is not contributing much to the total emissions, given the ban during hoteling phase of fuels exceeding the 0.1% limit for sulphur content in effect since 2010 (2005/33 EU Directive). The reduction for NO_x emissions is around the 40% in respect to all the emissions by cruise ships summing up all the phases (hoteling, maneuvering and cruise phases), that corresponds to about 10% of all the emissions by all the ships calling in Venice in a year.

From Figure 5.2.5.4 to Figure 5.2.5.8 the variation of NO_2 and SO_2 concentrations between OPS scenario and future scenario are shown in percentage scale in respect to the correspondent AQL limits.

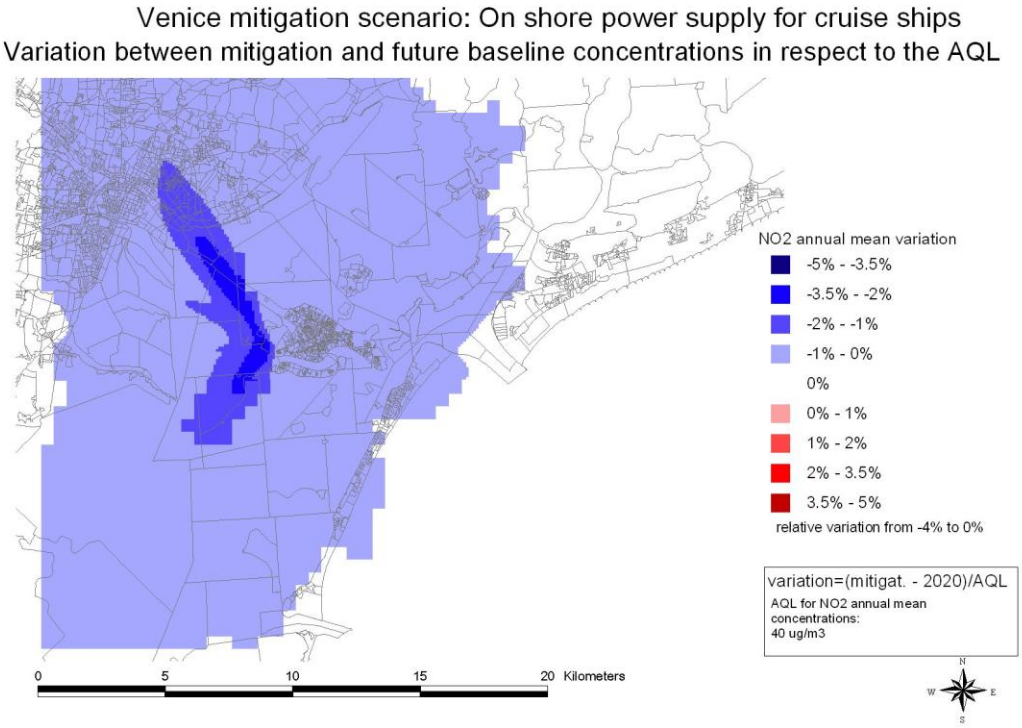


Fig. 5.2.5.4. Annual NO_2 percentage differences in respect to AQL, applying OPS scenario.

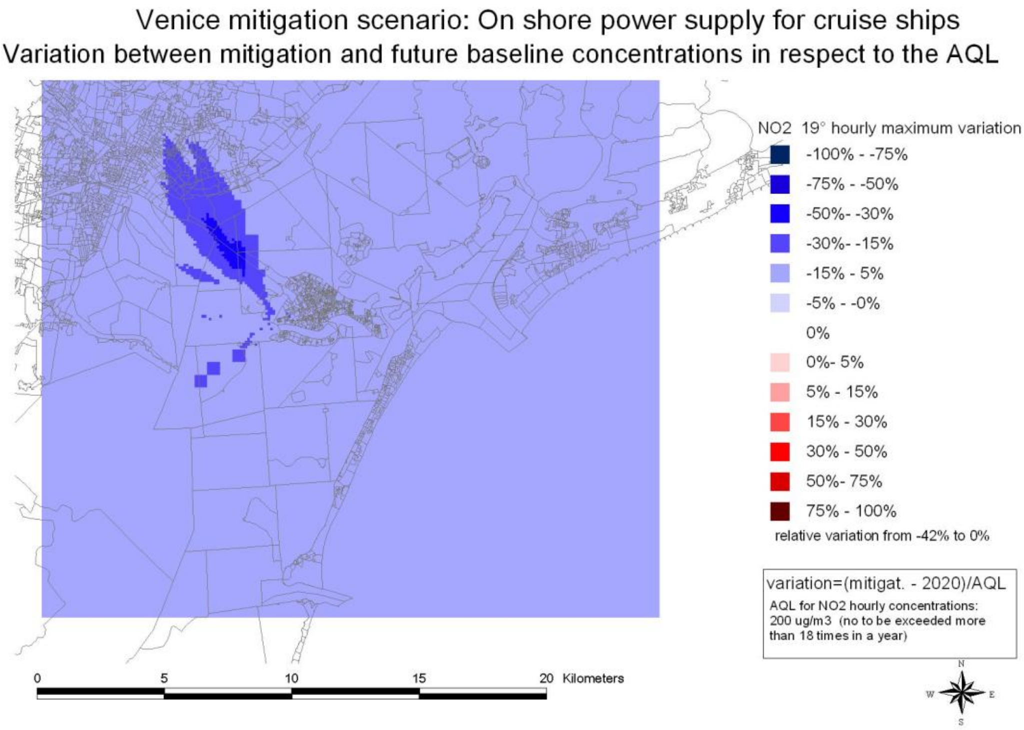


Fig. 5.2.5.5. 19th highest hourly NO_2 percentage differences in respect to AQL, applying OPS scenario.

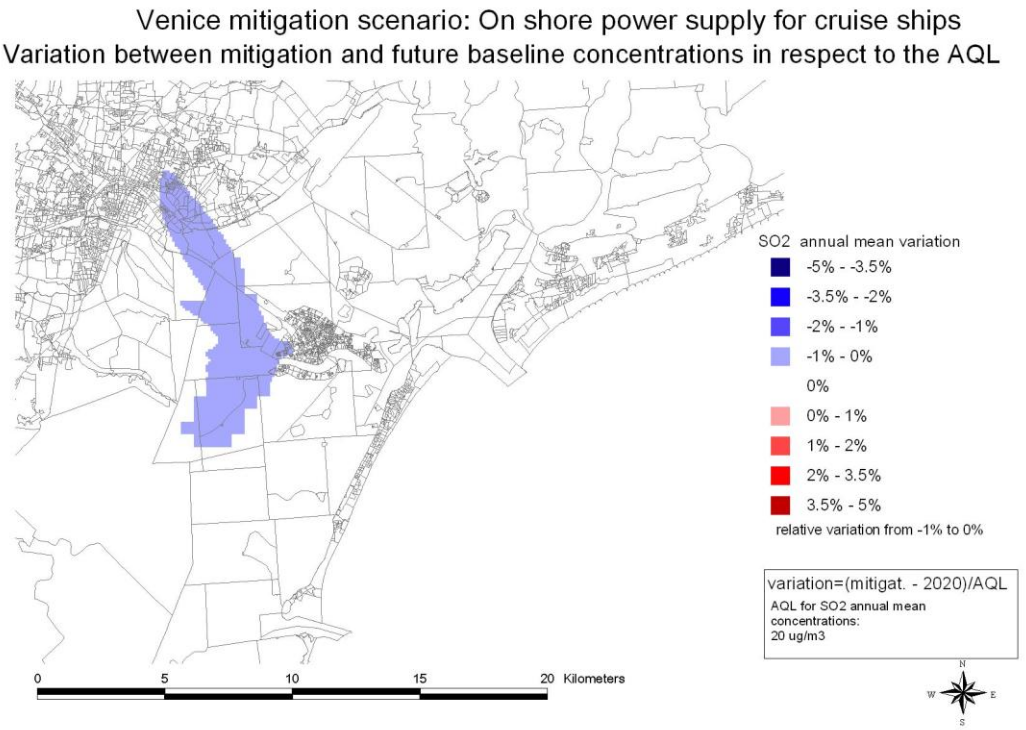


Fig. 5.2.5.6. Annual SO_2 concentrations: percentage differences in respect to AQL, applying OPS scenario.

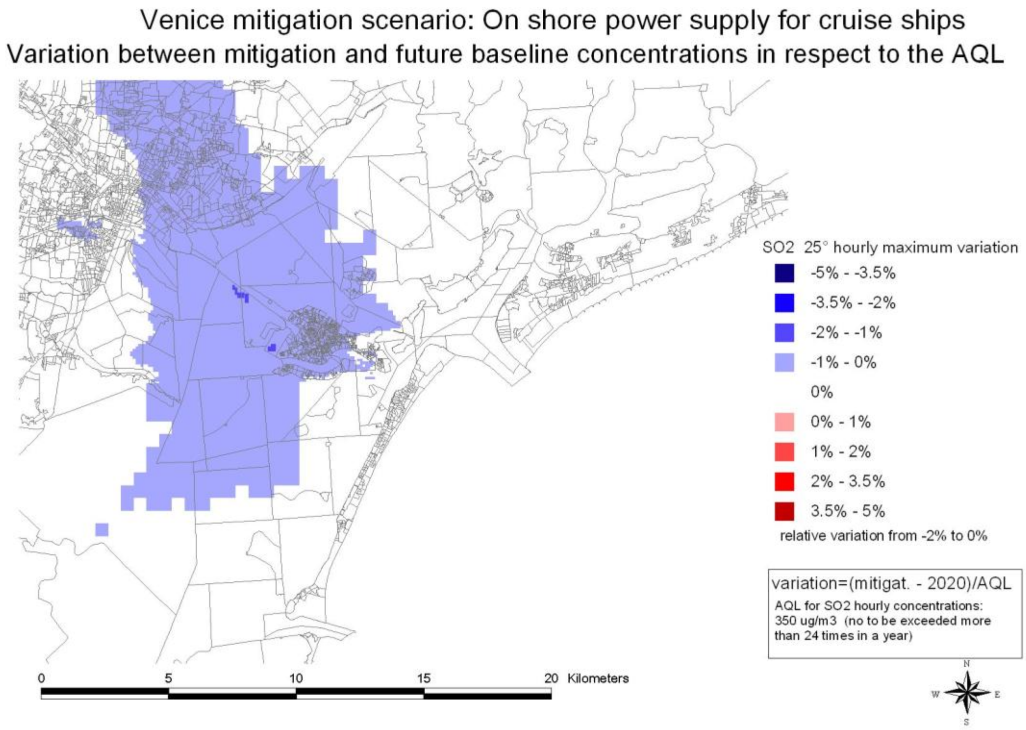


Fig. 5.2.5.7. 25th highest hourly SO_2 concentrations: percentage differences in respect to AQL, applying OPS scenario.

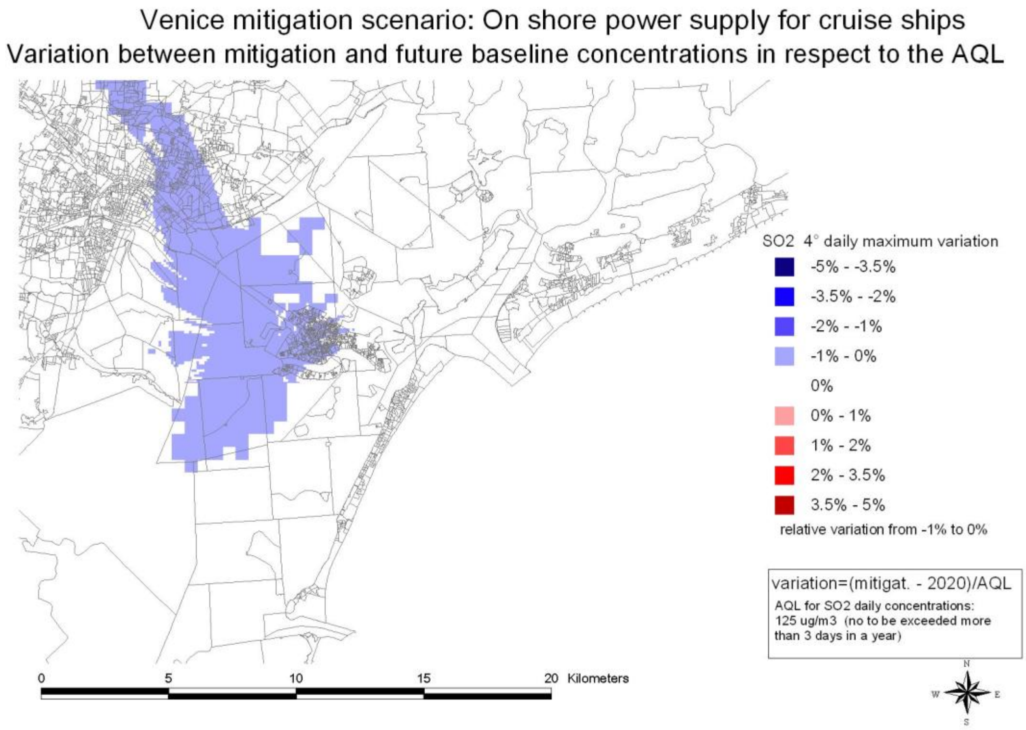


Fig. 5.2.5.8. 4th highest daily concentrations: percentage differences in respect to AQL, applying OPS scenario.

The greatest decrease is obviously recorded in front and behind the Martittima terminal, where the 4 quays would be installed. The most important effect of OPS is for NO_2, with relevant concentration reductions especially estimated for the short term statistics (up to 40% in respect the AQL).

Air pollutant emissions for the “Contorta” scenario have been estimated considering for all the cruise ships over 40’000 GT a stationary traffic, already supposed for the 2020 scenario, and the increase of the maneuvering phase due to the longer route by the Malamocco entrance into the lagoon and the sailing along the Malomocco-Marghera channel and then the Contorta-Sant’Angelo ones. In this scenario the future legislation with the limit of 0.5% m/m for the sulphur content (33/2012/EU Directive) and the decrease of NO_x emissions for post-2011 engines (IMO) are considered as well, whereas there’s no application of any voluntary agreement on the usage of distillate also in maneuvering phase, similar to the Blue Flag 2 Agreement of the 2013 year.

In Figure 5.2.5.9 the percentage differences between “Contorta” scenario and 2020 future scenario emissions are shown for the various air pollutants and in respect to the three following groups: emissions of all the cruise ships in maneuvering phase (in blue), emissions of all the cruise ships in maneuvering and hoteling phases (in green), emissions of all the passenger ships in maneuvering and hoteling phase (in red).

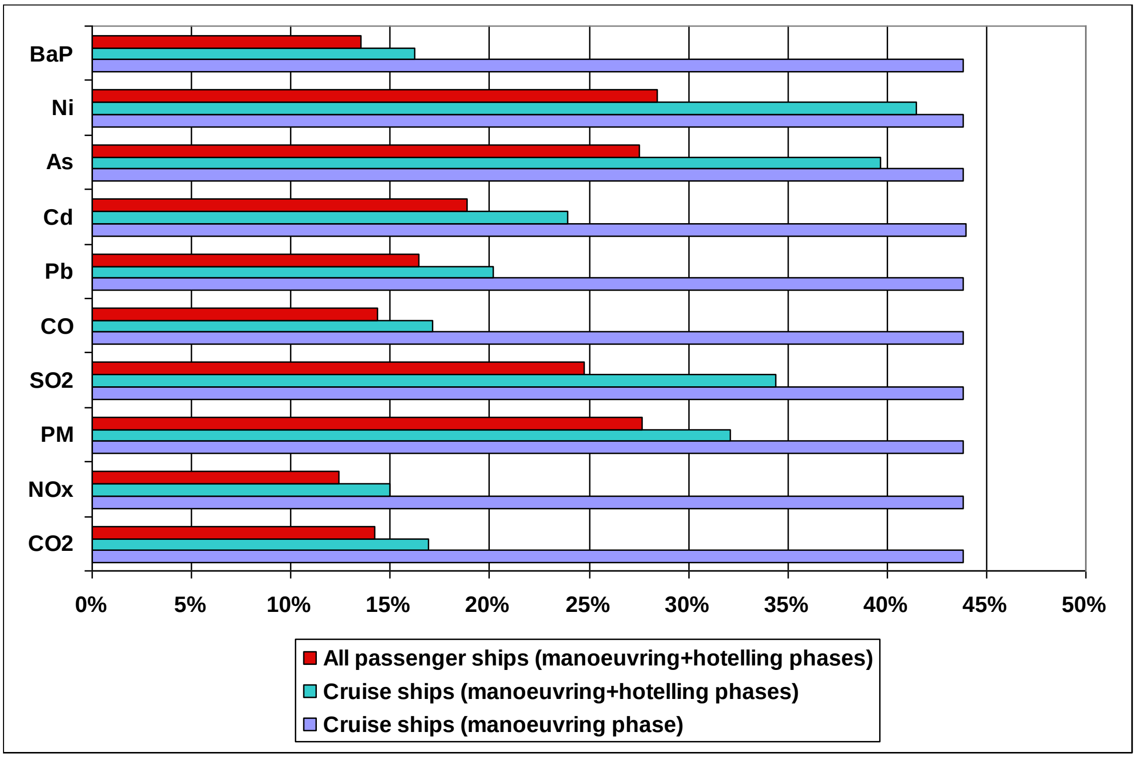


Fig. 5.2.5.9.Percentage difference in emissions between the "Contorta" scenario and the future trend 2020 scenario.

In respect to the 2020 scenario, in the "Contorta" ones only the maneuvering phase emissions increase in proportion to the longer maneuvering phase. So, in respect to the maneuvering phase emissions themselves, the relative increase is the same for all the pollutants and it is about 44% (blue bars in Figure 5.2.5.9). Extending the analysis to the sum of the emissions by maneuvering and hoteling phase always for cruise ships (green bars in Figure 5.2.5.9), the increase obviously became relatively less important and shows different percentages depending on the pollutants: the highest increase is for Ni, with about 42%, since, as already commented, it is mainly due to BFO consumption not used in hoteling phase, whereas the lowest (15%) is for NO_x whose emissions, in the annual balance, are in majority due to the hoteling phase. Enlarging further the comparison to all the emissions, both in maneuvering and in hoteling phases, of all the passenger ships (red bars in Figure 5.2.5.9), the percentage increase of the "Contorta" scenario in respect to the 2020 one, ranges from +12% (NO_x) to + 28% (As and PM). From Figure 5.2.5.10 to Figure 5.2.5.14 the variation of NO_2 and SO_2 concentrations between "Contorta" scenario and future scenario are shown in percentage scale in respect to the correspondent AQL limits.

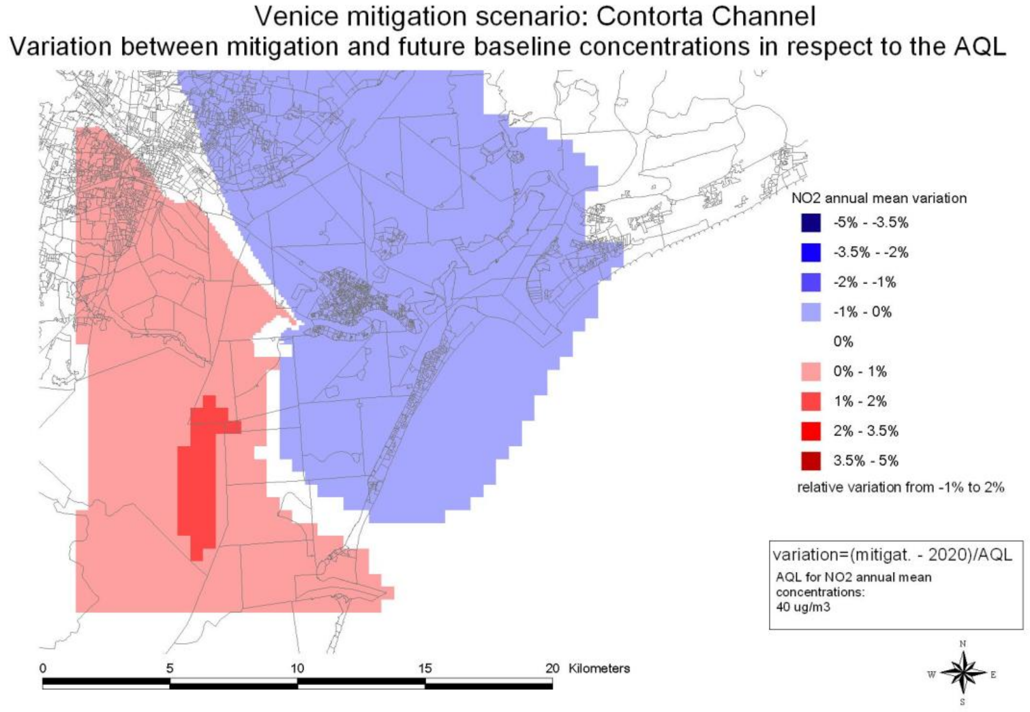


Fig. 5.2.5.10. Annual NO_2 concentrations; percentage differences in respect to AQL, applying "Contorta" scenario

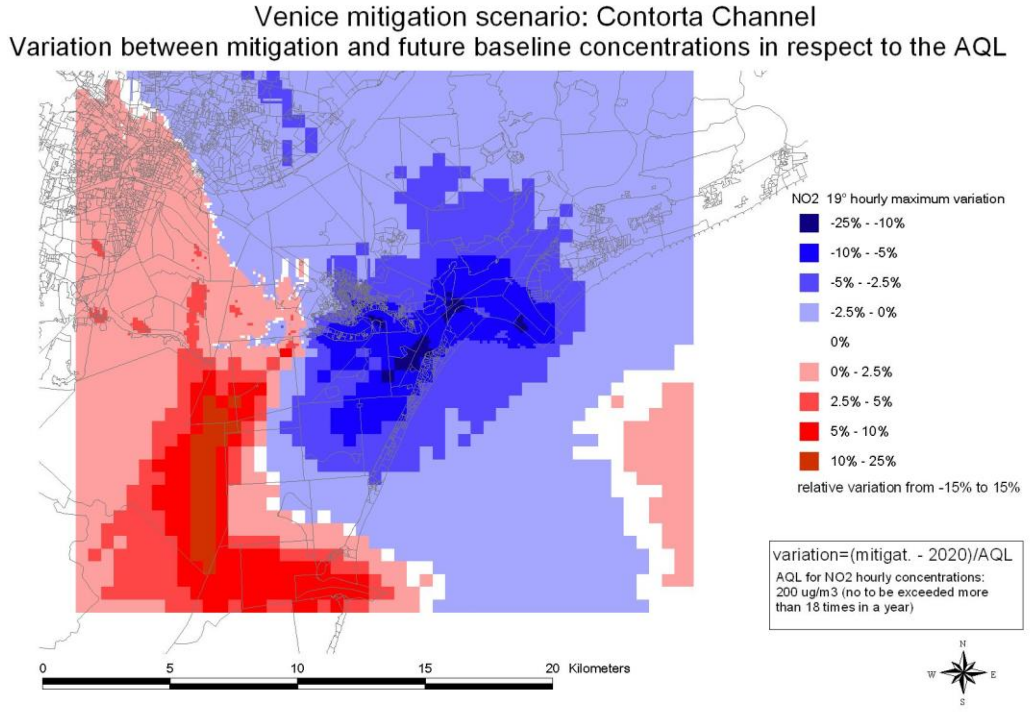


Fig. 5.2.5.11. 19th highest hourly NO_2 concentrations: percentage differences in respect to AQL, applying "Contorta" scenario.

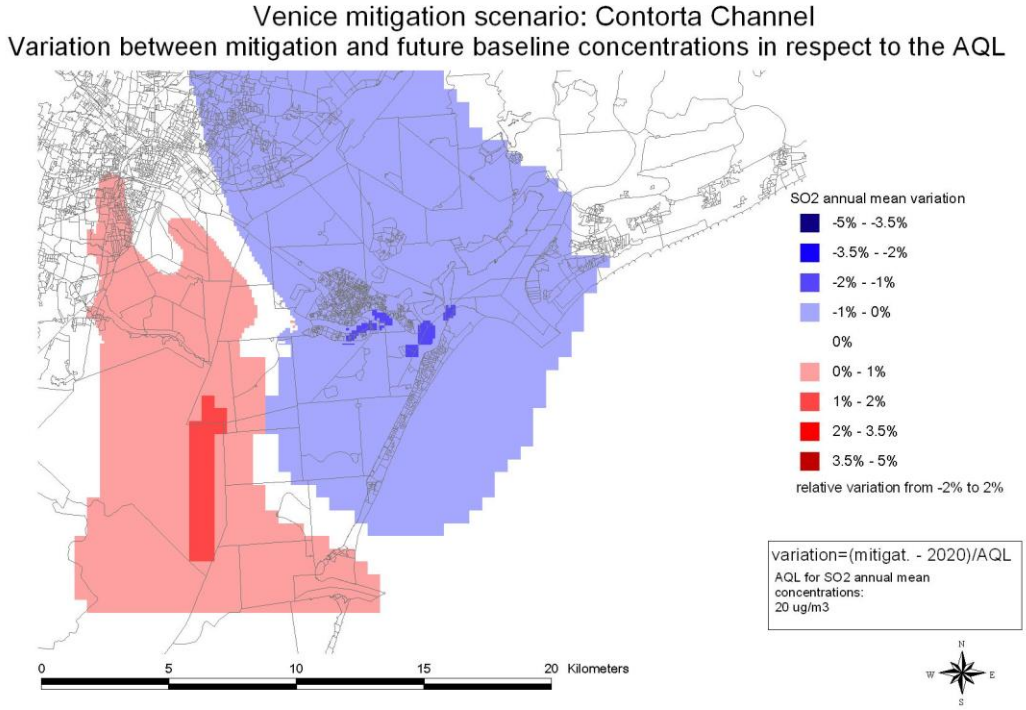


Fig. 5.2.5.12. Annual SO_2 concentrations; percentage differences in respect to AQL, applying “Contorta” scenario.

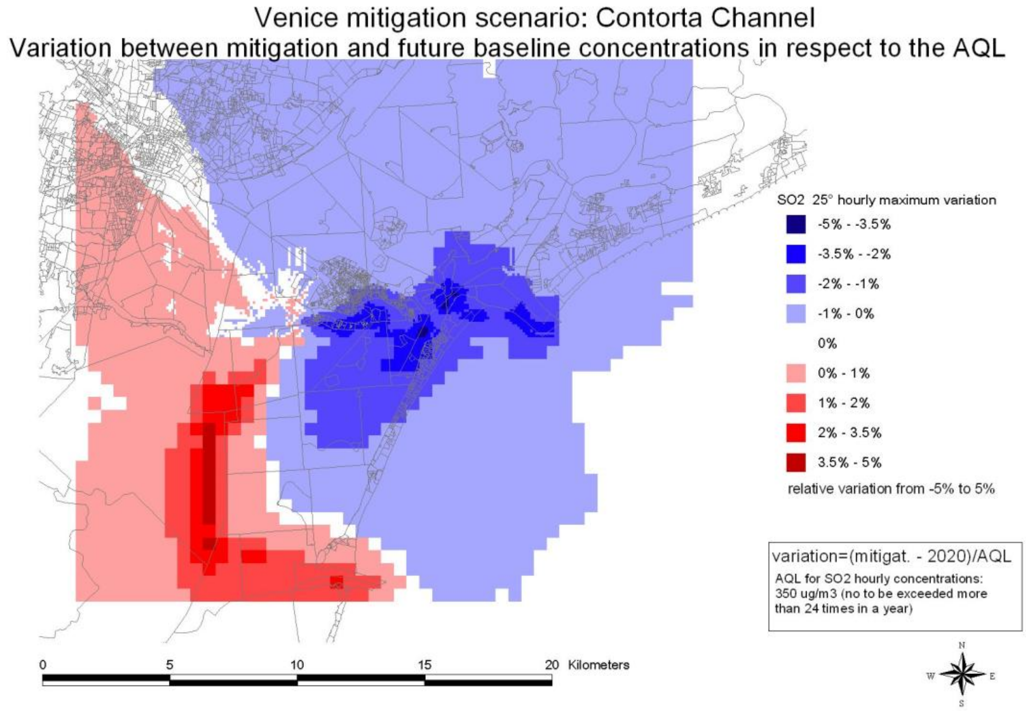


Fig. 5.2.5.13. 25th highest hourly SO_2 concentrations: percentage differences in respect to AQL, applying “Contorta” scenario.

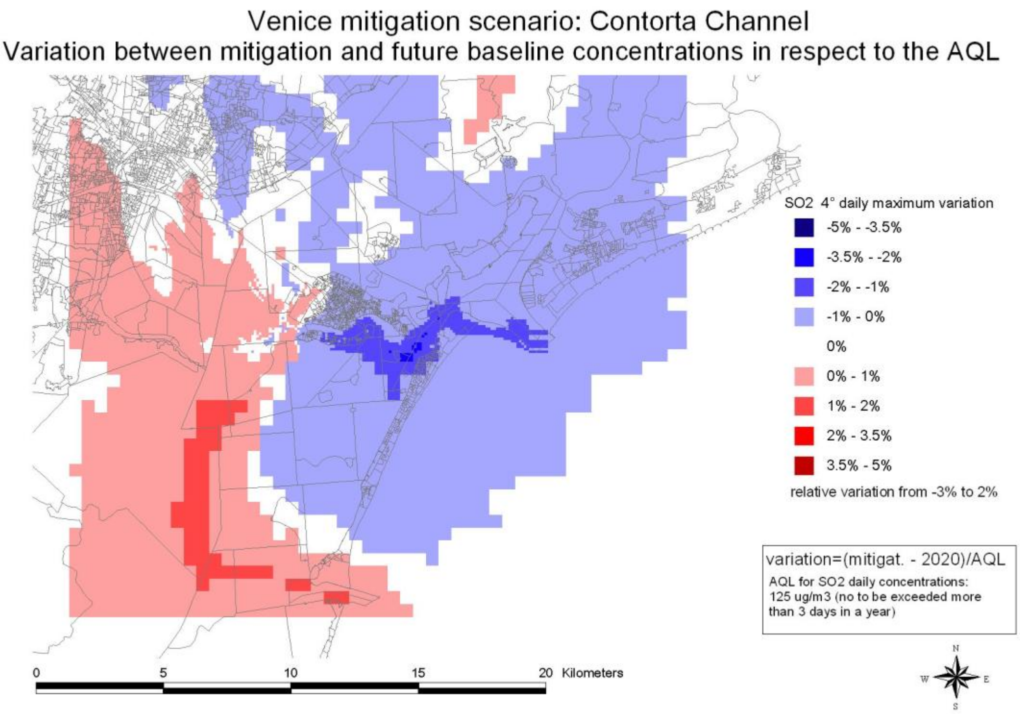


Fig. 5.2.5.14. 4th highest daily SO_2 concentrations; percentage differences in respect to AQL, applying "Contorta" scenario.

In spite of the increase of all the emissions of the "Contorta" scenario, in almost all the maps the Venice historical city centre belongs to the area in which is forecasted a decrease in concentrations. The decrease is more evident along the Lido-Marittima route and outside the Lido entrance since the manoeuvring route of the cruise ships over 40'000 GT is displaced in the "Contorta" scenario on the Malamocco-Contorta channels, where, in the same maps, is evident an increase.

Going into more details for the various pollutants and statistics linked to the different AQLs, the ranges of the percentage differences between the "Contorta" scenario and the 2020 scenario, in respect to the correspondent AQL, are the following:

- from -1% to + 1% for the NO_2 annual mean;
- from -15% to +15% for the 19th highest hourly NO_2 concentrations;
- from -2% to + 2% for the SO_2 annual mean;
- from -5% to +5% for the 25th highest hourly SO_2 concentrations;
- from -3% to +2% for the 4th highest daily SO_2 concentrations.

Air pollutant emissions for the “Punta Sabbioni” scenario, the completely new terminal proposed at the Lido entrance of the lagoon for larger cruise ships, have been estimated considering for all the cruise ships over 40’000 GT: a stationary traffic, already supposed for the 2020 scenario, a shortest maneuvering phase beside the new terminal and a decrease of 6200 hours of hoteling time, with a correspondent decrease in emissions, thanks to the integrated proposal of four electrified quays that would be installed on the new terminal. The scenario, that focused on cruise ships only, doesn’t consider the additional traffic by smaller ships that would brings the tourists of the cruise-tours calling Venice till the “Riva 7 Martiri” terminal, nor the remaining traffic on the Giudecca channel and the San Marco Basin of ships dedicated to transfer the passengers to and from the Marittima Terminal, still used as logistic terminal for the cruise-tours in home port in Venice, or the additional traffic for transferring supplies and luggage. All these elements have not been considered, since the preliminary project available at the time of the CAIMANs studies, reported information not sufficiently detailed.

In Figure 5.2.5.15. the percentage differences between “Punta Sabbioni” scenario and 2020 future scenario emissions are shown for the various air pollutants and in respect to the four following groups: emissions of all the cruise ships in hoteling phase (in yellow), emissions of all the cruise ships in maneuvering phase (in blue), emissions of all the cruise ships in maneuvering and hoteling phases (in green), emissions of all the passenger ships in maneuvering and hoteling phase (in red).

Differently to the “Contorta” scenario, the “Punta Sabbioni” one records a decrease in emissions, both for the hoteling phase, thanks to the cold ironing integrated project, and for the maneuvering phase, since the cruise ships shouldn’t enter anymore into the lagoon. For this scenario, as already reminded, additional emissions by other than cruise ships are not computed. For this reason the percentage decrease shown in Figure 5.2.5.15 should be considered as an upper limit estimation.

Considering only the cruise emissions for all the pollutant the percentage differences between “Punta Sabbioni” scenario and 2020 future scenario is of – 73% for the hoteling phase (yellow bars in figure 5.2.5.15) and around -62% for the maneuvering emissions (blue bars in figure 5.2.5.15). Summing up hoteling and maneuvering emissions of the cruise ships the percentage differences varies from the smallest differences of -62% for Nickel to the greatest of – 69% (green bars in figure 5.2.5.15). Considering all the passenger ships, the percentage decrease ranges from -42 to – 50% (red bars in figure 5.2.5.15).

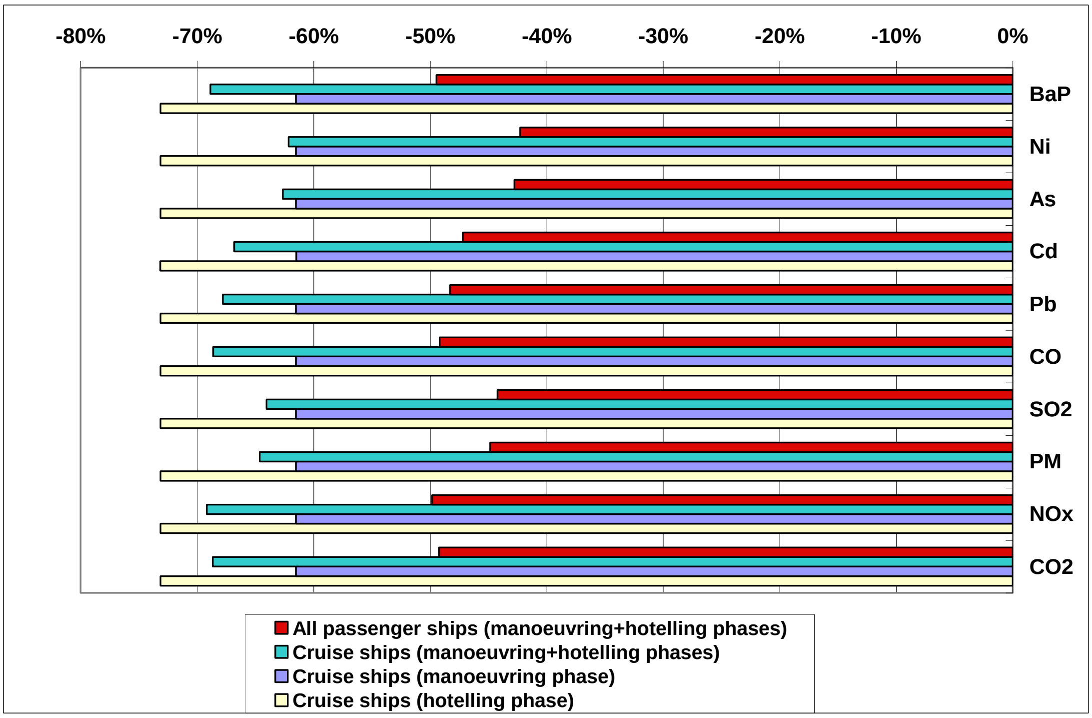


Fig. 5.2.5.15. Percentage difference in emissions between the "Punta Sabbioni" scenario and the future trend 2020 scenario.

From Figure 5.2.5.16 to Figure 5.2.5.20 the variation of NO_2 and SO_2 concentrations between "Punta Sabbioni" scenario and future scenario are shown in percentage scale in respect to the correspondent AQL limits.

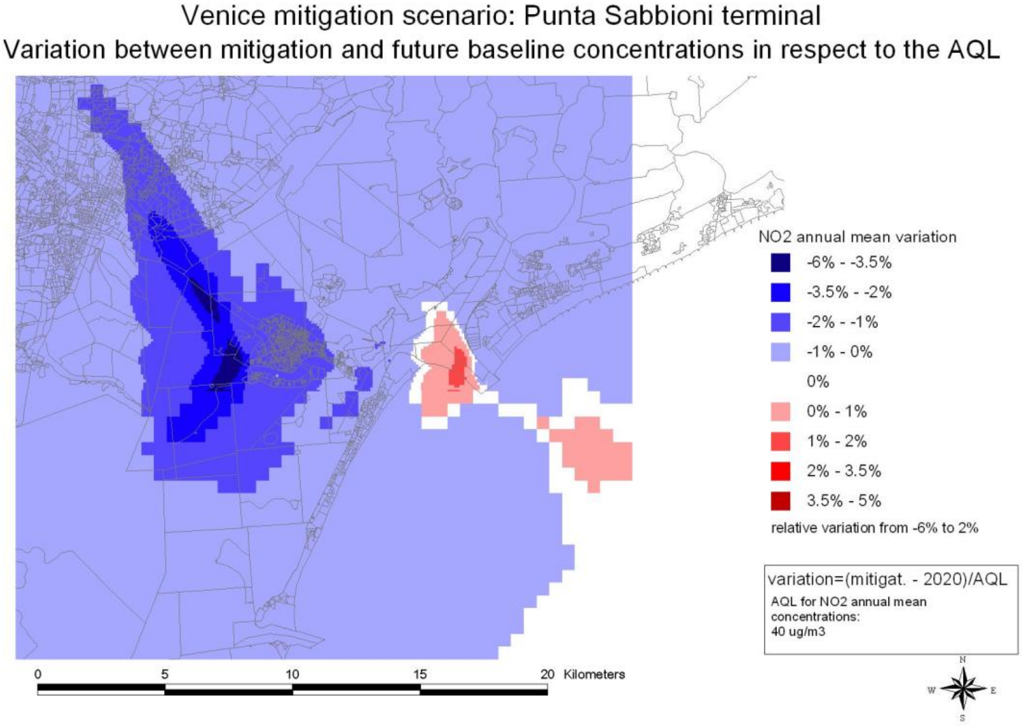


Fig. 5.2.5.16. Annual NO_2 concentrations; percentage differences in respect to AQL, applying "Punta Sabbioni" scenario.

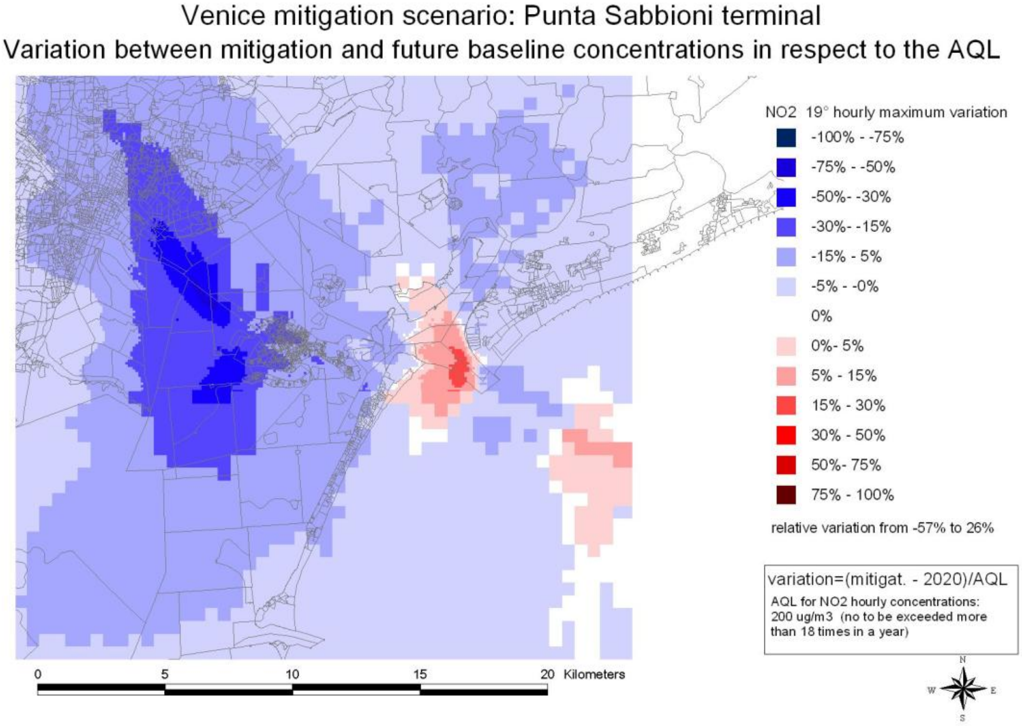


Fig. 5.2.5.17. 19th highest hourly NO_2 concentrations: percentage differences in respect to AQL, applying "Punta Sabbioni" scenario.

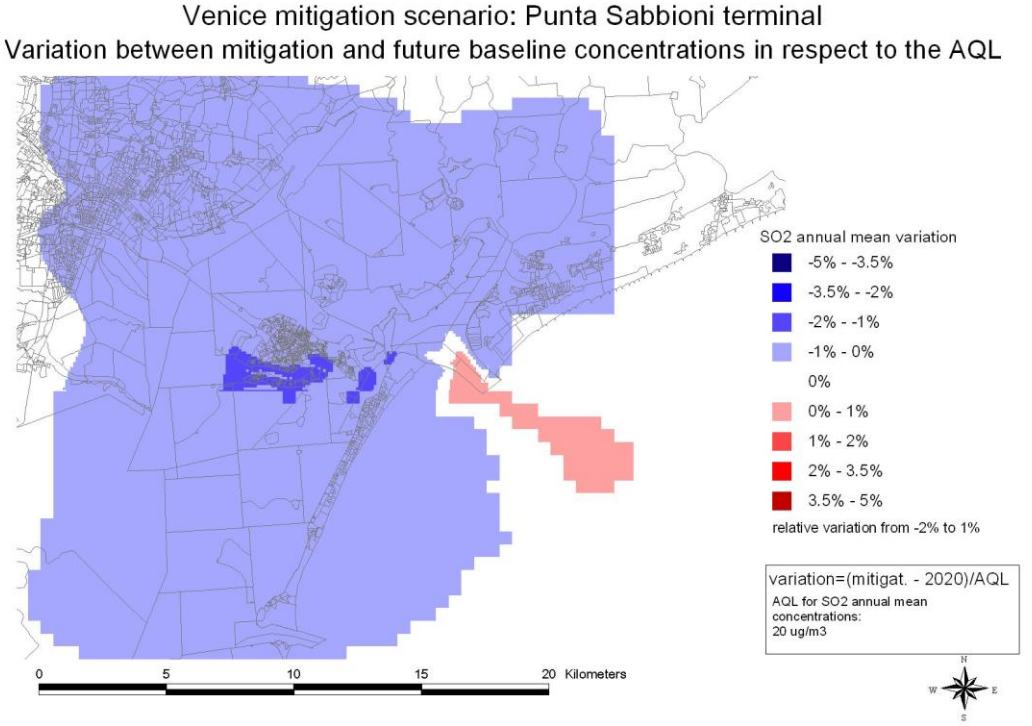


Fig. 5.2.5.18. Annual SO_2 concentrations; percentage differences in respect to AQL, applying "Punta Sabbioni" scenario.

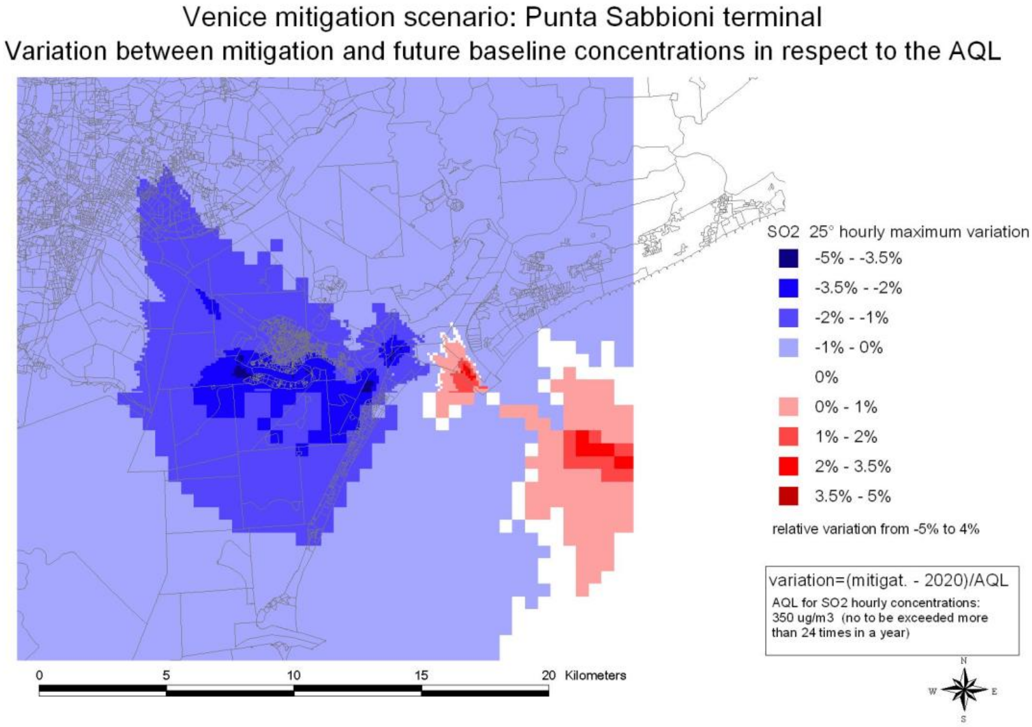


Fig. 5.2.5.19. 25th highest hourly SO_2 concentrations: percentage differences in respect to AQL, applying "Punta Sabbioni" scenario.

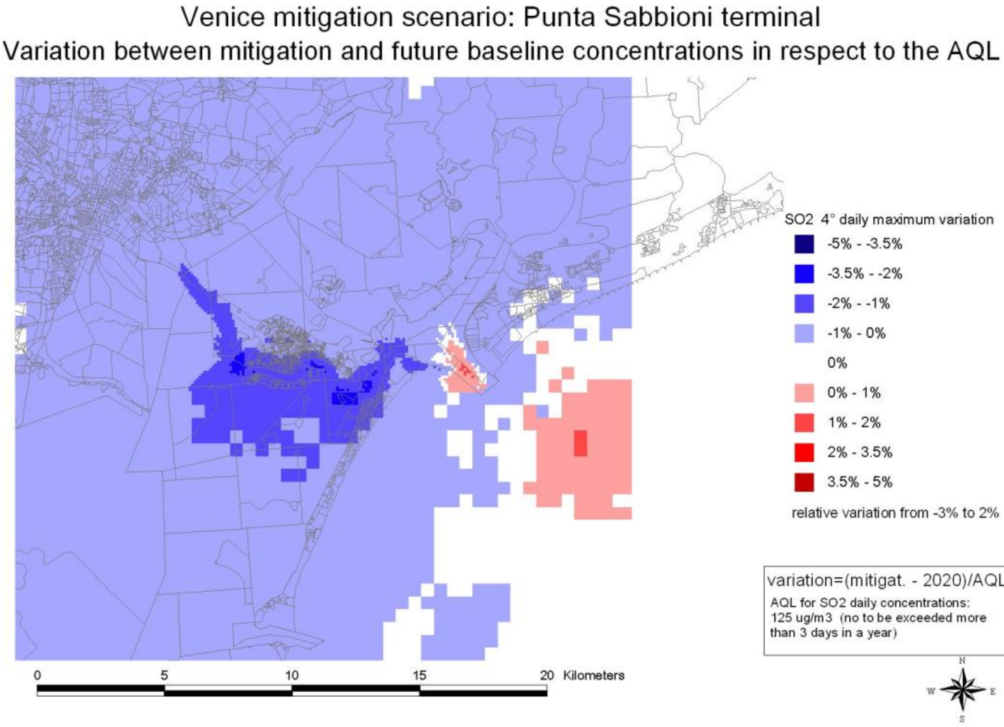


Fig. 5.2.5.20. 4th highest daily SO_2 concentrations; percentage differences in respect to AQL, applying "Punta Sabbioni" scenario.

Thanks to the switching off of all the emissions by cruise ships over 40'000 GT inside the lagoon, all the maps show a decrease in concentration over all the lagoon area. Highest decreases are forecasted where on the 2020 emission scenario have been estimated the greatest concentrations: that is mainly in front and behind the Marittima Terminal. In front of the new terminal of Punta Sabbioni and along the cruise route outside the lagoon there is, instead, an increase due to the residual emissions in hoteling phase of the cruise ships (the 4 electrified quays are not serving all the hoteling time of all the cruise ships) and the contribution of the maneuvering phase.

Going into more details for the various pollutants and statistics linked to the different AQLs, the ranges of the percentage differences between the "Punta Sabbioni" scenario and the 2020 scenario, in respect to the correspondent AQL, are the following:

- from -6% to + 2% for the NO_2 annual mean;
- from -57% to +26% for the 19^{th} highest hourly NO_2 concentrations;
- from -2% to + 1% for the SO_2 annual mean;
- from -5% to +4% for the 25^{th} highest hourly SO_2 concentrations;
- from -3% to +2% for the 4^{th} highest daily SO_2 concentrations.

5.3. COMPARISON OF THE PORT CITIES IN TERMS OF EFFECTIVENESS OF THE EMISSION MITIGATION MEASURES

Figure 5.3.1 and 5.3.2 show an intercomparison of the impact of the LNG and OPS scenarios on the NO_2 concentrations, among the 5 harbors.

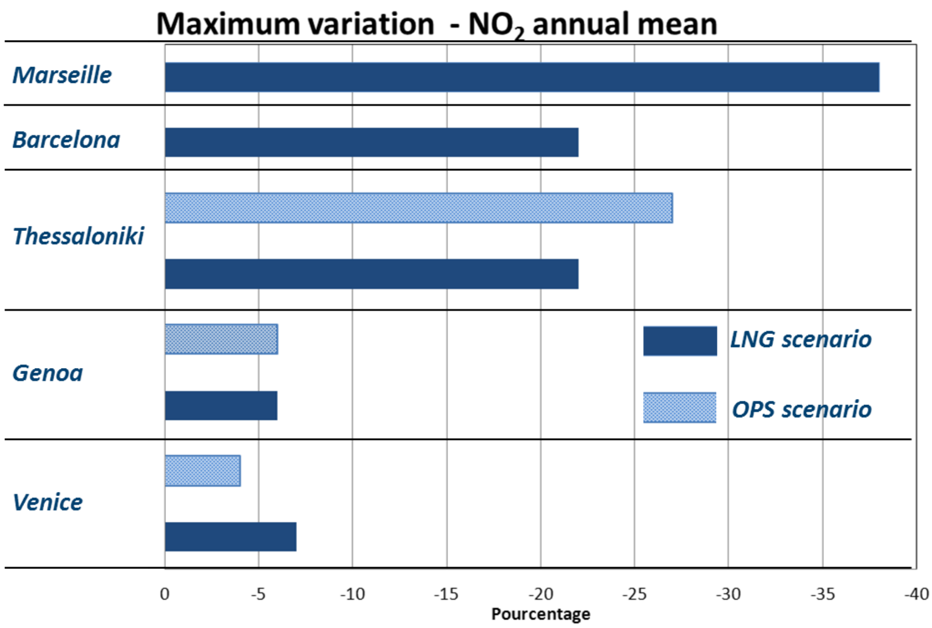


Fig. 5.3.1. Maximum variation percentage (relative to AQL) obtained for the NO_2 annual mean.

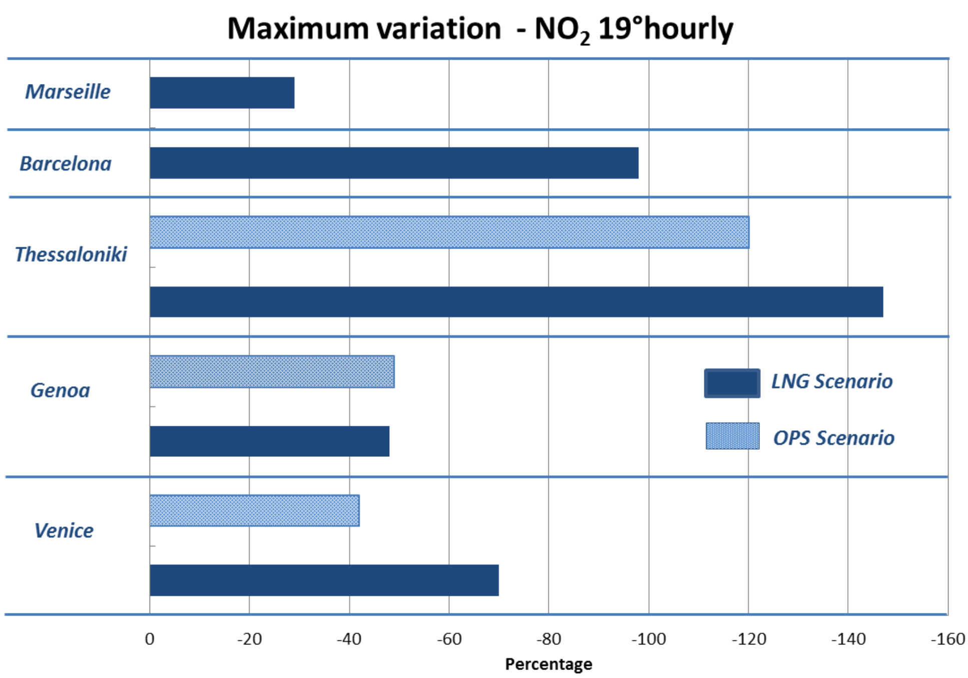


Fig. 5.3.2. Maximum variation percentage (relative to AQL) obtained for the NO_2 hourly statistics.

All the studied scenarios show beneficial impact over each area for both short and long term statistics. The LNG action shows a strong improvement in each port, with a maximal decrease of -38%, relative to AQL, for the NO_2 annual in Marseille and -150%, relative to AQL, for the NO_2 hourly statistics in Thessaloniki.

For the OPS action, a direct comparison is less evident as the number of ships connected depends on local hypothesis assumede. However, this action shows a strong impact, comparable to the LNG scenario's one.

For both kinds of scenarios, an adaptation is necessary to use LNG or electric quays by ships. These adaptations will have an economic impact for ship companies which will be profitable on condition that these solutions would be shared among a large number of ports all around the Mediterranean Sea.

6. POPULATION EXPOSURE TO POLLUTANT CONCENTRATIONS FROM THE PASSENGER SHIPS TRAFFIC

6.1. THE METHODOLOGY ADOPTED

As outlined in the previous chapters, the assessment of passenger ship contribution to air pollution has been carried out starting from the hourly emissions calculated on the basis of the ship movements scheduled or recorded in each port city involved in the project. Then, by means of air pollution dispersion models, the hourly concentration fields related to these hourly emissions have been calculated. Population exposure to air pollution concentration levels, related specifically to passenger ship emissions, has been finally quantified through the comparison between the concentration levels computed by the dispersion models and the Air Quality limits (AQLs) set by European legislation.

European AQLs have been established to minimize the adverse effects on human health due to chronic and acute exposure to air pollution. The exposure evaluation process carried out within the project has taken into account all the AQLs currently in force, except for O_3.

The overlapping between the number of inhabitants living in each simulation domain and the air pollutant concentrations estimated by the dispersion models has allowed to highlight where the major impact on population is expected and to estimate the variation among different scenarios. The relevance of the amount of air pollution coming from the ships has been evaluated taking into account increasing concentration thresholds in respect to AQLs set by each pollutant. The higher is the percentage of concentration related to ship emissions in respect to the AQL, the higher is the strength of its impact on population, considering that, in each urban domain, also other emission sources affect air pollution and, consequently, population exposure.

Thresholds defining the increasing significance of cruise ships emissions to air pollution have been defined as 5, 10, 50 and, obviously, 100% of long and short term AQLs. It means that, according to CAIMANs approach, a contribution of ship plumes more than 5% of at least one of the AQLs is considered significant in respect to other emission sources. For example, a contribution from passenger ship on the NO_2 annual mean concentration greater than 2 μg/m^3 (5% of the long term NO_2 AQL) is highlighted as remarkable.

6.2. PRESENT AND FUTURE TIME POPULATION EXPOSURE IN EACH PORT CITY

The results of population exposure assessment for each city is presented in tables and maps which follow common conventional colors: green areas indicate inhabited cells where air pollutant concentration levels exceed the first threshold; in yellow the ones where concentration levels are between the 10% and the 50% threshold and in red the ones where the concentrations go beyond half of the AQL. Finally, a comparison among these results is discussed.

6.2.1. Barcelona

The total number of people exposed to pollutant concentrations due to the dispersion of ship emissions was calculated. Calculations were performed for the present time, future trend and mitigation scenarios and considering the pollutant statistics exceeding the 5%, 10%, 50% and 100% of the short-term and long-term AQL. In the following, the numbers of people exposed to pollutants are presented but only for those with ambient levels that are mostly affected by the passenger ship traffic (mainly NO_2). In addition, maps are shown to give an overview of the spatial distribution of the exposed population. The population density for the Barcelona metropolitan area (Barcelona and neighboring municipalities) is shown in Figure 6.2.1.1.

Figure 6.2.1.2 depicts the number of people exposed to NO_2 and the spatial distribution of the exposed population in those areas where the 99.8 percentile of the hourly NO_2 concentrations timeseries exceeds the 5%, 10% and 50% of the NO_2 hourly AQL for the present time emission scenario (BC2013), the future trend scenario (SC2020) and the mitigation scenario (LNG2020). For the present and future scenarios, most of the population in the city of Barcelona is exposed to levels exceeding the 5% of the NO_2 hourly AQL criterion. The total number of exposed inhabitants is 2,238,281 in BC2013, whereas 2,492,547 in SC2020, representing respectively about 68% (BC2013) and 76% (SC2020) of the total population within the modeling domain. The respective numbers are substantially reduced for the 10% of the NO_2 hourly AQL criterion (403,925 inhabitants in BC2013 and 485,140 inhabitants in SC2020, approximately 12% and 15% of the population, respectively). 1,761 people are living in areas of the centre of the city where the 99.8 percentile of the hourly NO_2 concentrations timeseries exceeds the 50% of the NO_2 hourly AQL for BC2013 (around 0.05% of the population), while these numbers are increased to 2,081 inhabitants (0.06%) for the SC2020 scenario.

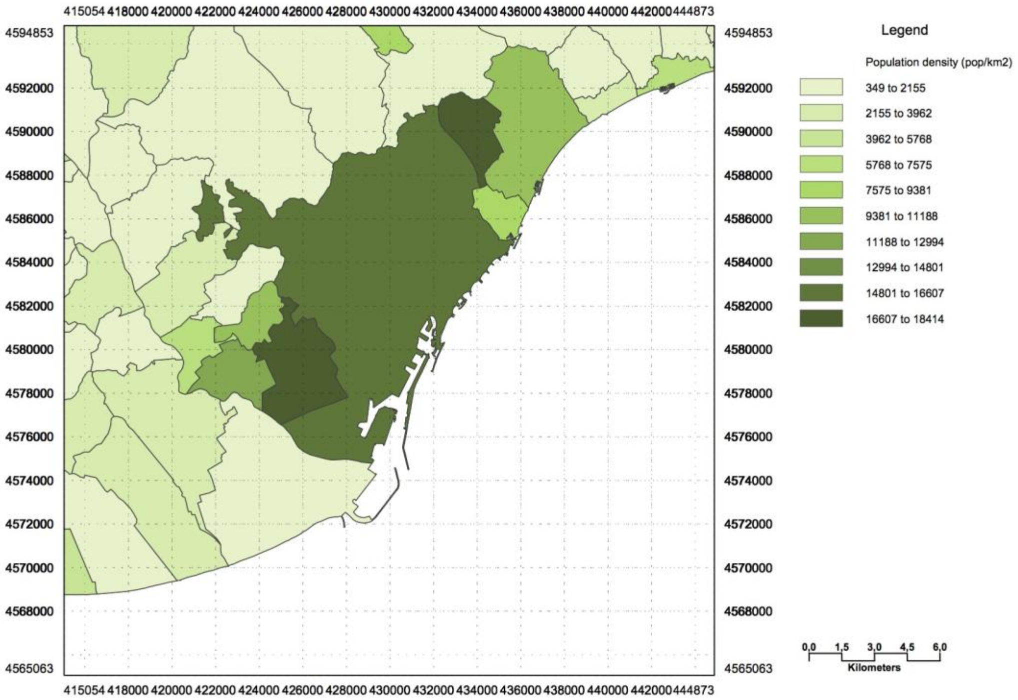


Fig. 6.2.1.1. Population density of the Barcelona metropolitan area.

This same Figure 6.2.1.2 (bottom) illustrates the population exposure maps analogous to those commented above (number of people exposed to NO_2 and the spatial distribution of the exposed population in those areas where the 99.8 percentile of the hourly NO_2 concentrations timeseries exceeds the 5%, 10% and 50% of the NO_2 hourly AQL), but for the LNG mitigation scenario implemented in the year 2020. It is revealed that the population exposure with respect to this AQL is noticeably reduced. No people is living in areas where the 99.8 percentile of the hourly NO_2 concentrations timeseries is exceeding the 50% or the 10% of the NO_2 hourly AQL, while those living in areas where the NO_2 statistic is higher than the 5% of this limit value (very close to the Barcelona port) are reduced from 2,492,547 (76% of the population) in SC2020 to just 9,284 inhabitants in LNG2020 (0.28% of the population).

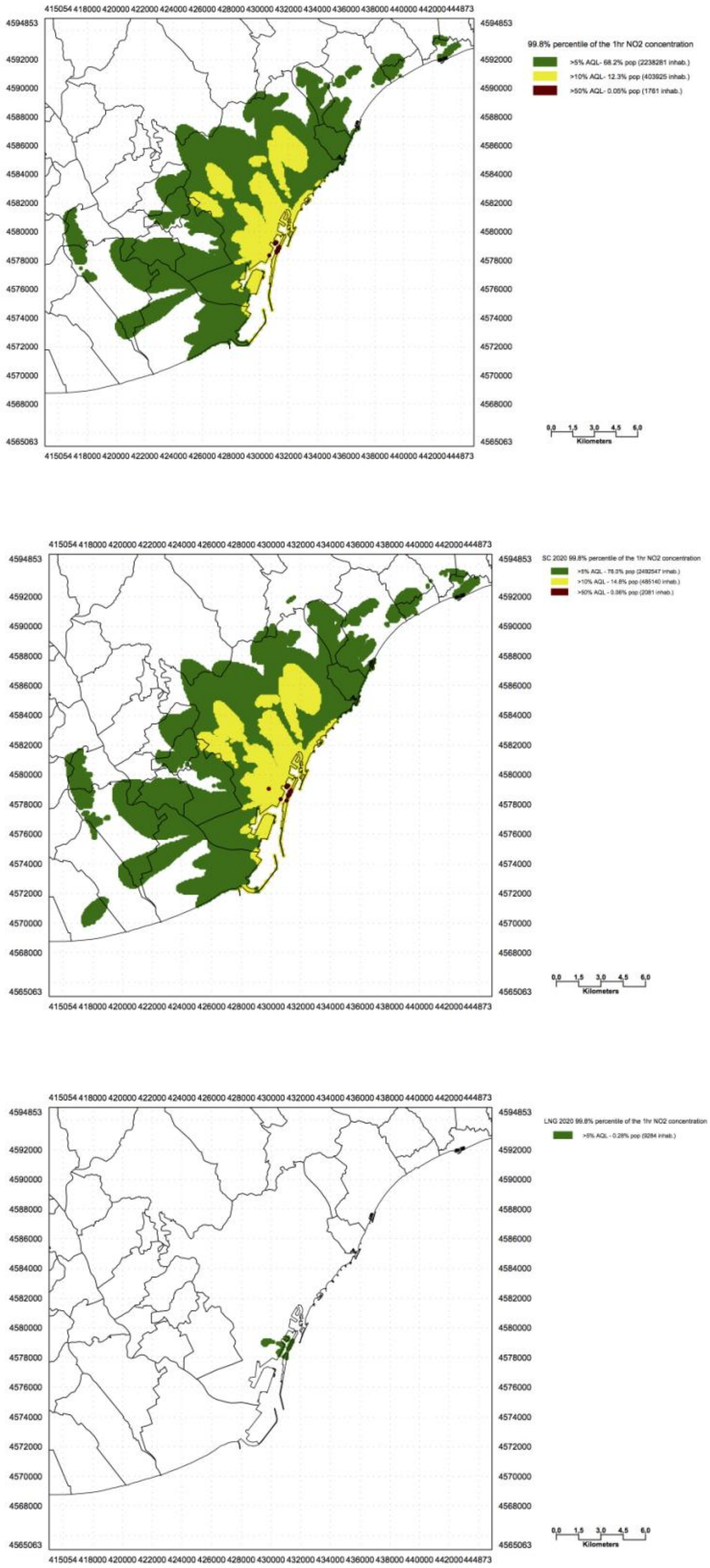
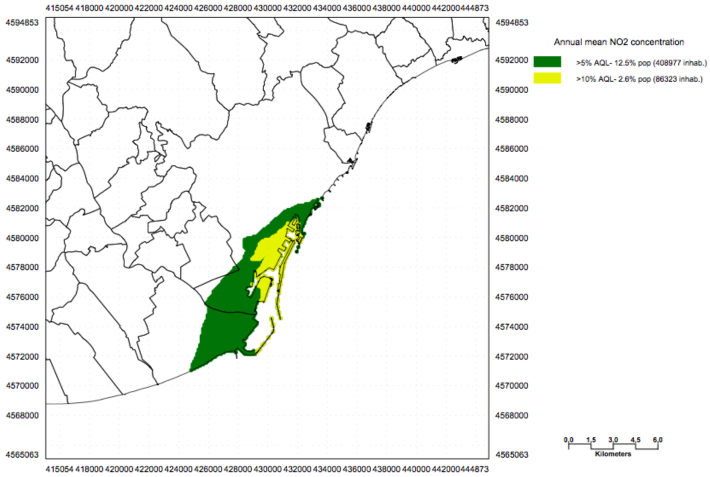


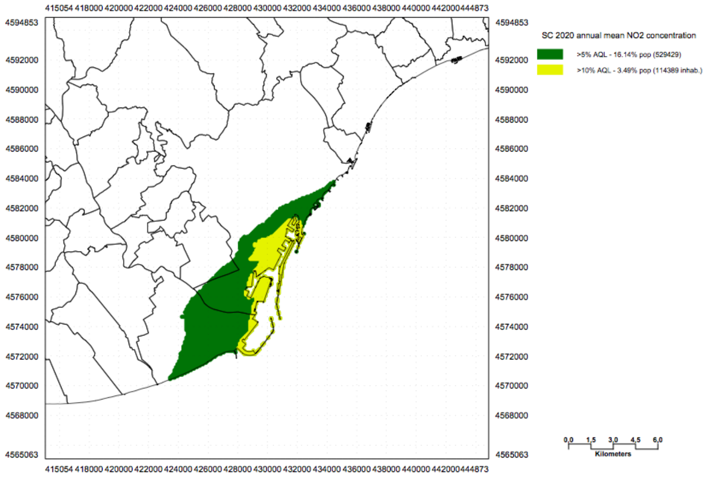
Fig. 6.2.1.2. Population exposure with respect to the NO_2 hourly AQL for the (top) present time (BC2013), (centre) future trend (SC2020) and (bottom) mitigation (LNG2020) scenarios.

Figure 6.2.1.3 depicts the number of people exposed to annual NO_2 AQL exceeding the 5% and 10% of the AQL for BC2013, SC2020 and LNG2020. The total number of exposed inhabitants is 408,977 in BC2013 and 529,429 in SC2020, representing about 12% and 16% of the total population within the modeling domain respectively. The numbers decrease for the 10% of the NO_2 annual AQL criterion (86,323 inhabitants in BC2013 and 114,389 inhabitants in SC2020, approximately 3% and 3.5% of the population, respectively). No population lives in areas exceeding the 5% of the NO_2 annual AQL in the LNG2020 scenario.

Figure 6.2.1.4 depicts the number of people exposed to SO_2 and the spatial distribution of the exposed population in those areas where the annual mean concentration exceeds the 5%, 10% and 50% of the AQL (20 $\mu g/m^3$) for the present time emission scenario (BC2013), the future trend scenario (SC2020) and the mitigation scenario (LNG2020). For BC2013 and SC2020, just 61,040 and 108,758 inhabitants living in areas surround the Barcelona port are exposed to the 5% of the SO2 annual AQL criterion, representing 2% and 3% of the total population, respectively. For the LNG, no population is exposed to concentrations above 5% of the AQL. It should be remarked that the population exposed to SO_2 and PM (including metals and benzo(a)pyrene) for different AQL is zero in the case of the LNG scenario.

Last, Figure 6.2.1.5 illustrates the population exposure maps analogous to those commented above, but for the PM_{10} daily AQL (number of people exposed to PM_{10} and the spatial distribution of the exposed population in those areas where the 90.4 percentile of the daily concentrations exceed the 5%, 10% and 50% of the AQL). For BC2013, SC2020 and LNG2020, the inhabitants living in areas over the 5% of the AQL are 12,165; 22,250 and no inhabitants. These numbers represent 0.4%, 0.7% and 0% of the total population, respectively.





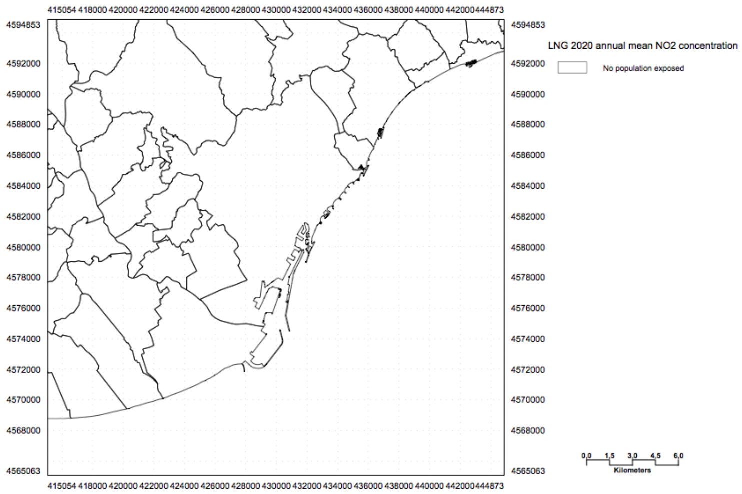
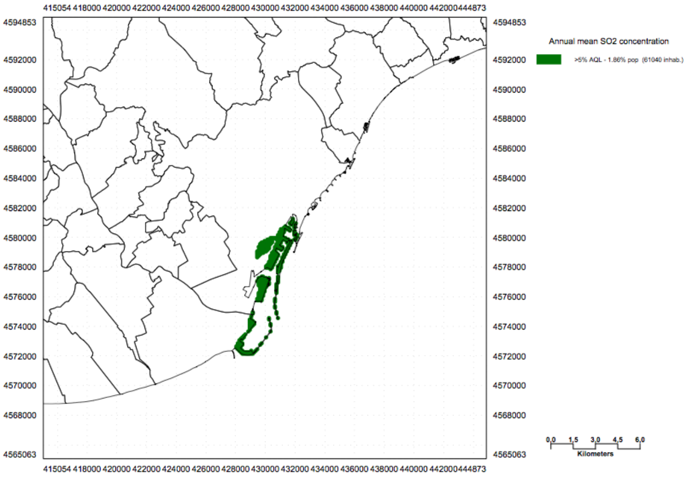
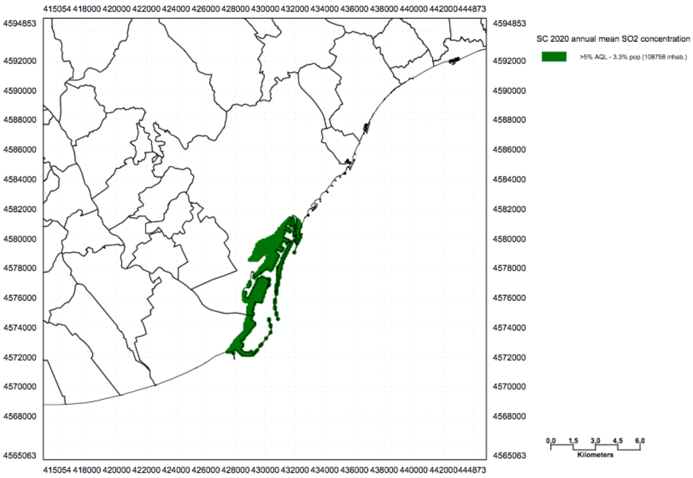


Fig. 6.2.1.3. Population exposure with respect to the NO_2 annual AQL for the (top) present time (BC2013), (centre) future trend (SC2020) and (bottom) mitigation (LNG2020) scenarios.





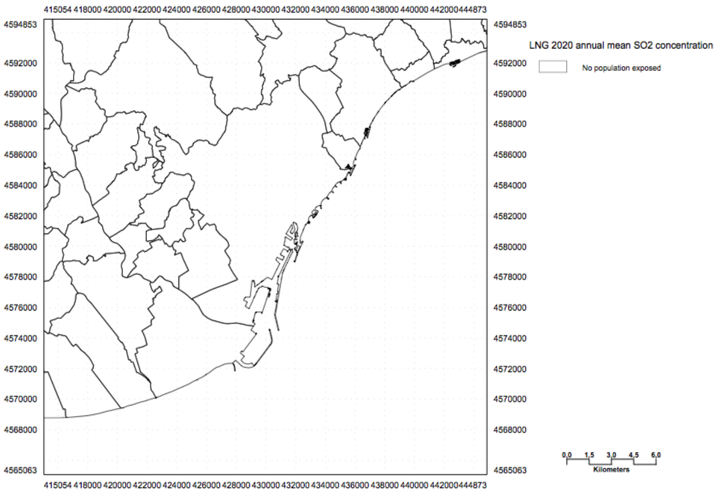


Fig. 6.2.1.4. Population exposure with respect to the SO_2 annual AQL for the (top) present time (BC2013), (centre) future trend (SC2020) and (bottom) mitigation (LNG2020) scenarios.

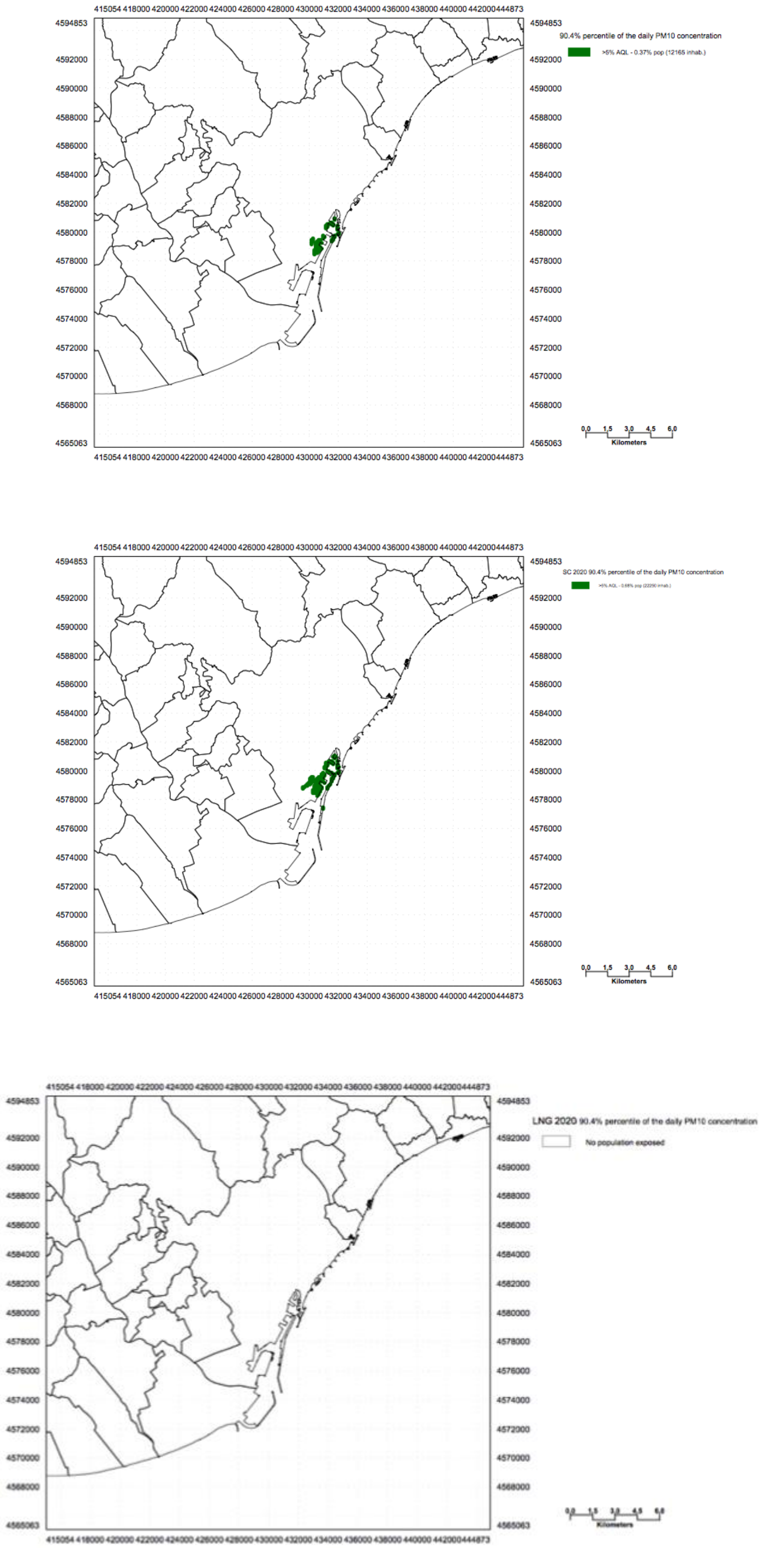


Fig. 6.2.1.5. Population exposure with respect to the PM_{10} daily AQL for the (top) present time (BC2013), (centre) future trend (SC2020) and (bottom) mitigation (LNG2020) scenarios.

6.2.2 Genoa

Comparing concentration output data obtained by ADMS simulations with number of inhabitants per grid cell provided by Genoa Municipality we evaluated the population exposure to the pollutants emitted by passenger ships traffic. Once again, in particular we focused our attention on NO_2, which was identified in the previous analysis to be the most critical pollutant on Genoa area.

In Figure 6.2.2.1 we show the number of inhabitants in the Genoa simulation domain. The Genoa geomorphology is pretty peculiar with most of the populated region on the coast side, between the sea and the hills standing above the narrow inhabited region. Genoa extends for about 32 km along the coast, thus the simulation domain, which includes the area where the passenger ships traffic impact on air quality is relevant, corresponds to less than a third of the total urban area. The total number of inhabitants in the simulation domain is 193,183.

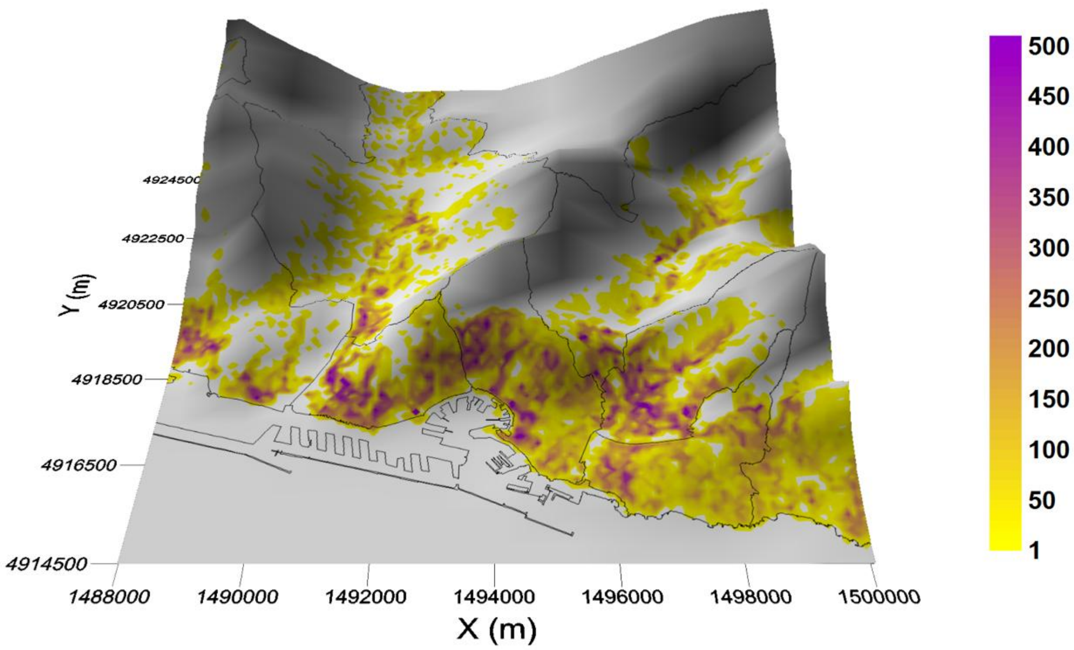
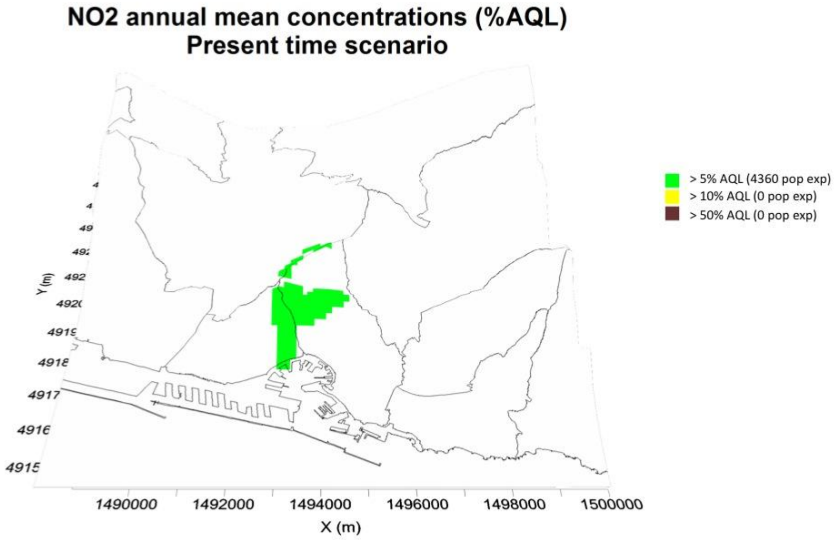


Fig. 6.2.2.1. Number of inhabitants in the Genoa area simulation domain (projection over ADMS receptor grid). Data provided by Genoa Municipality.



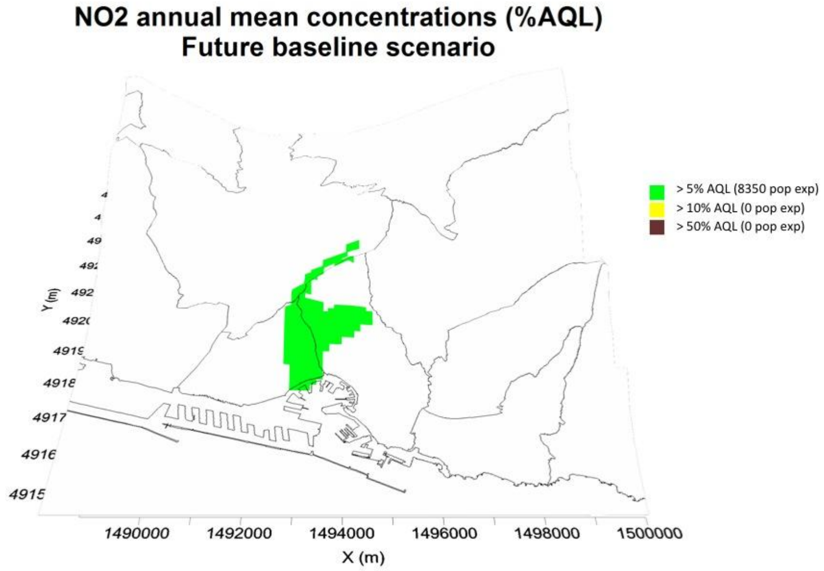


Fig. 6.2.2.2. Population exposed to 5%, 10% and 50% of AQL for NO_2 annual mean concentrations simulated for present (top) and baseline future (bottom) scenarios.

Population data have been compared with simulated NO_2 concentration, and number of people exposed to 5%, 10% and 50% of air quality limits has been calculated for different scenarios, in order to provide a preliminary evaluation of health effects related to passenger ships traffic.

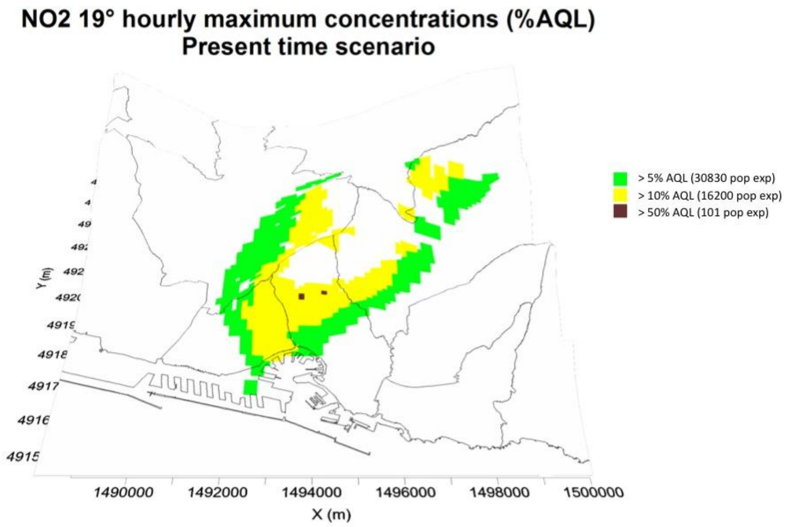
The framework for Genoa case, from the point of view of population exposure, is pretty lucky. In fact the meteorology favors the pollutant transport over a quite narrow area at the North side of Genoa Maritime Station and most of the region affected by passenger ship traffic related pollution is not really populous and often uninhabited.

Concerning the annual mean values we calculated for 4,360 people exposed to 5% AQL for present scenario and 8,350 people exposed to 5% AQL for future baseline scenario, as presented in Figure 6.2.2.2.

Regarding the NO_2 hourly concentration, in Figure 6.2.2.3 we show the inhabited regions with NO_2 concentrations exceeding the percentage of the short term AQL (99.8 percentile of the hourly NO_2 concentrations timeseries) for present scenario and future base scenario. An increase can be observed for future baseline scenario, according to the evaluation exposed in the previous sections. In the following table we report the number of people exposed to different percent of hourly NO_2 concentration limits over the whole simulation domain.

Table 6.2.2.1. Number of inhabitants exposed to the increasing percentage of the NO_2 short term AQL in the Genoa area simulation for the present and future baseline scenarios.

	Number of exposed people – NO_2 Short term concentrations	
	Present time	**Future baseline**
100% AQL	62	62
50% AQL	101	230
10% AQL	16,200	17,635
5% AQL	30,830	35,881



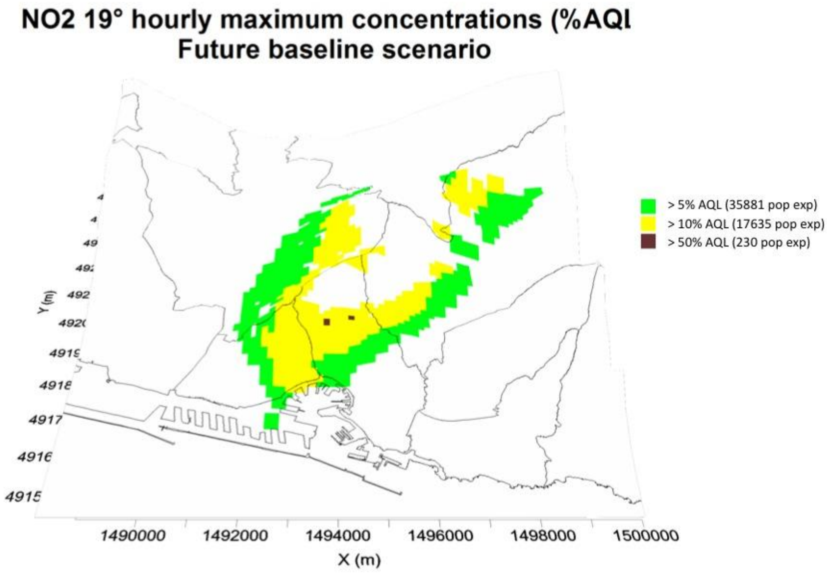


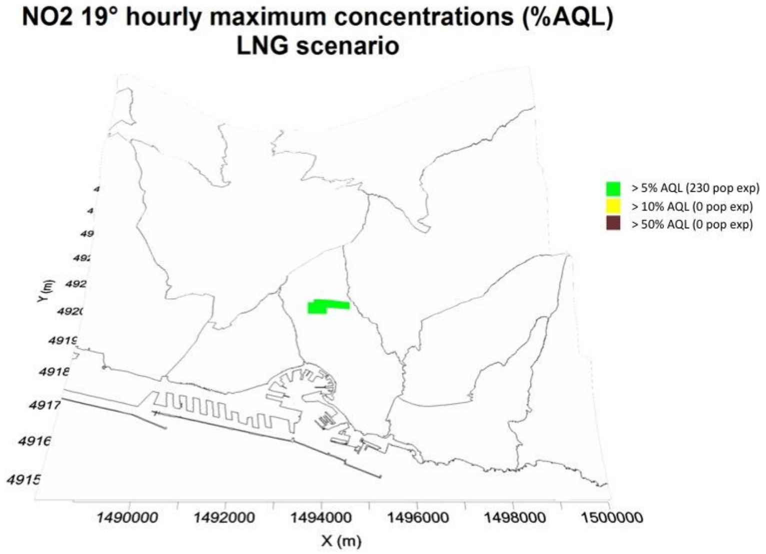
Fig. 6.2.2.3. Population exposed to 5%, 10% and 50% of AQL for 19th hourly maximum concentrations simulated for present (top) and baseline future (bottom) scenarios.

Both the mitigation scenarios confirm the highly positive effect on the reduction of pollution impact related to passenger ships traffic, with only a residual percentage of population exposed to 5% AQL of short term NO_2 concentrations.

Table 6.2.2.2. Number of inhabitants exposed to the increasing percentage of the NO_2 short term AQL in the Genoa area simulation for the future mitigation scenarios.

	Number of exposed people – NO_2 Short term concentrations	
	LNG scenario	**OPS scenario**
50% AQL	0	0
10% AQL	0	0
5% AQL	230	2046

In Figure 6.2.2.4 we show the inhabited regions with NO_2 concentrations exceeding the percent of AQL for LNG scenario and OPS scenario.



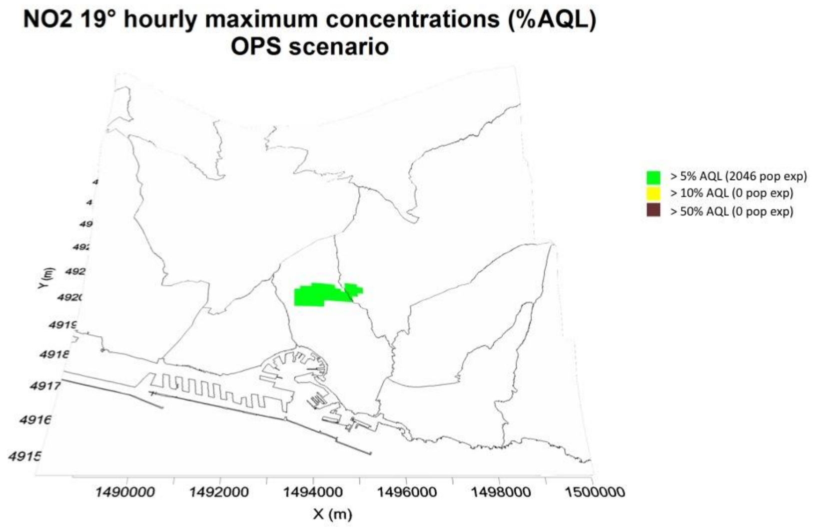


Fig. 6.2.2.4. Population exposed to 5%, 10% and 50% of AQL for 19th hourly maximum of NO_2 concentrations simulated for LNG scenario (top) and OPS scenario (bottom).

6.2.3 Marseille

The figure 6.2.3.1 shows the repartition of the population, by buildings, on the simulated domain area. The total number of inhabitants in this zone is 588,132, with most of the people in southern part of the area. The population exposure has been calculated according to the methodology described in paragraph 6.1.

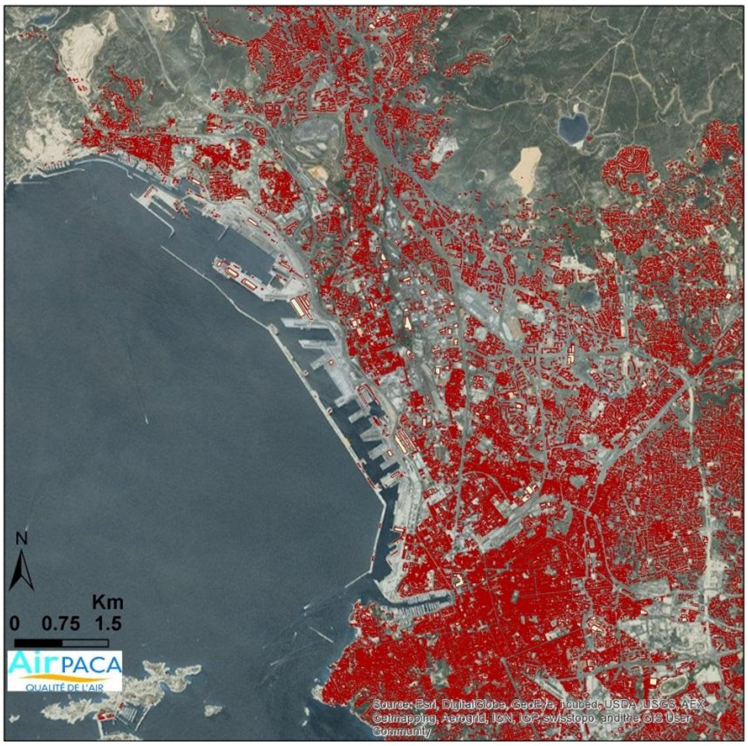


Fig. 6.2.3.1. Population, classified by buildings, in the Marseille area

Figure 6.2.3.2 presents the state-of-the-art of the population exposure in 2013. Figure 6.2.3.2 (a) shows that about 12% of the population is exposed to an annual concentration exceeding 10% of the NO_2 annual AQL. These inhabitants are mainly located close to the port area. In the meantime, 100 % of the population is exposed in the whole area to values exceeding 10% of the hourly NO_2 AQL, as revealed in Figure 6.2.3.2 (b).

Figure 6.2.3.3 shows the population exposure with respect to the NO_2 annual AQL, for (a) the future trend in 2025 and (b) after applying the LNG scenario.

While 17% of the population (about 98,627 inhabitants) was exposed to annual concentrations exceeding 10% of the NO_2 annual AQL in 2025, by applying the mitigation scenario of LNG, a significant decrease of the population exposure can be observed. Indeed, almost no population is exposed anymore.

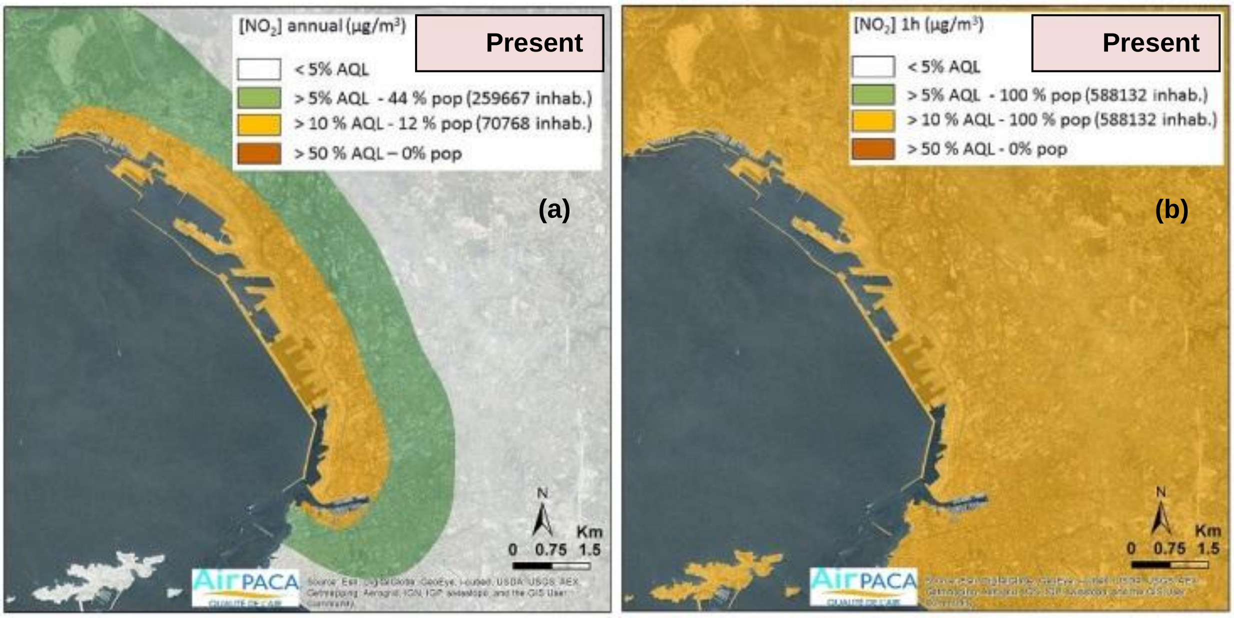


Fig. 6.2.3.2. Population exposure with respect to (a) annual NO_2 concentrations and (b) the NO_2 hourly AQL at present time (2013).

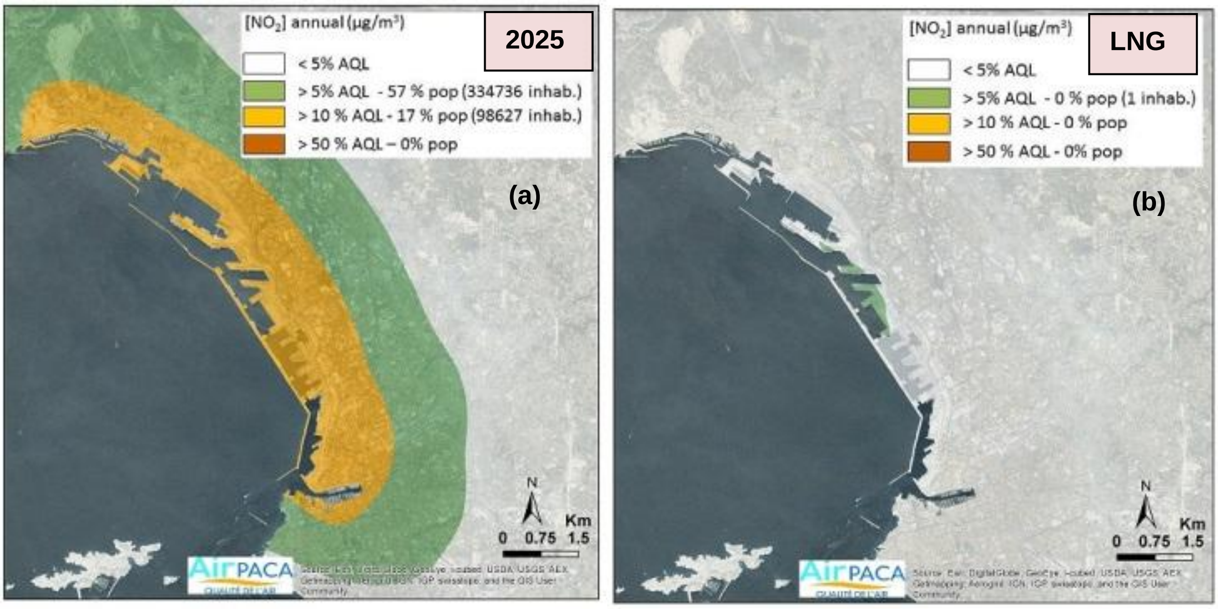


Fig. 6.2.3.3. Population exposure with respect to the NO_2 annual AQL for (a) the future trend (2025) and (b) the LNG scenarios.

Figure 6.2.3.4 indicates the population exposure with respect to the NO_2 hourly AQL, for the future trend in 2025 (a) and after applying the LNG scenario (b). A significant decrease of the area exceeding 10% of the NO_2 hourly AQL is observed by applying the mitigation scenario. Initially, 100% of the population was exposed to such a value, while with the LNG scenario, only 2 % (10,251 inhabitants) and 47 % (273,756 inhabitants) of the population are exposed to 10% and 5% of the hourly AQL, respectively.

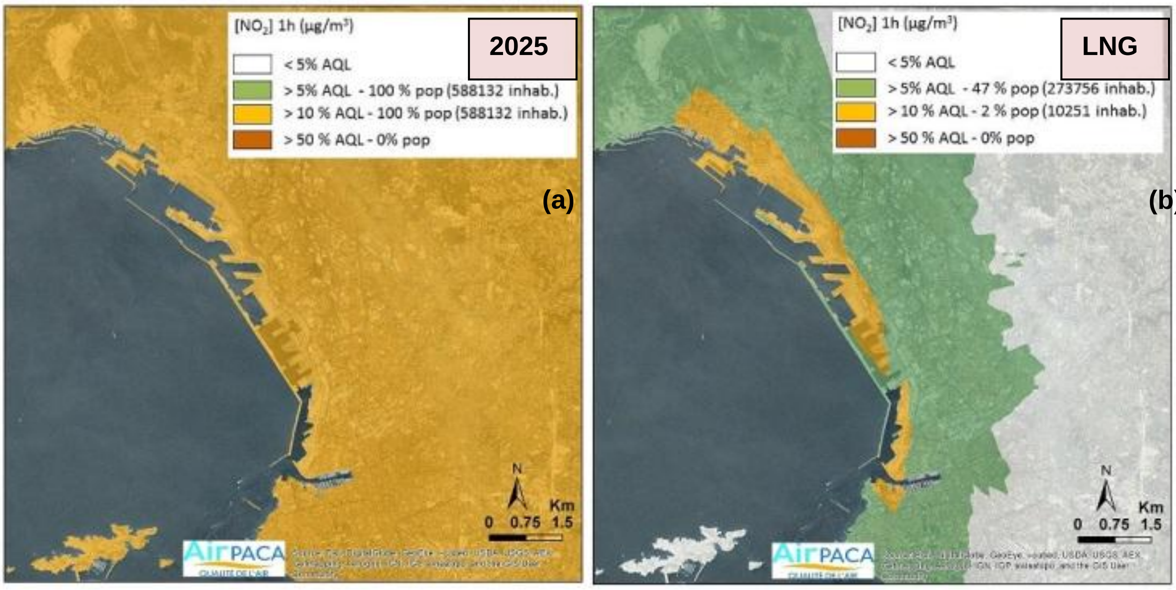


Fig. 6.2.3.4. Population exposure with respect to the NO_2 hourly AQL for (a) the future trend (2025) and (b) the LNG scenarios.

Maps for the other pollutants discussed in the previous chapters (SO_2 and Ni) are not shown here. In 2025 (future trend), about 22% (130,404 inhabitants) of the population were exposed to annual SO_2 concentrations exceeding 5% of the annual AQL, while 5% (27,909 inhabitants) of the population was exposed to annual Ni concentrations exceeding 5% of the annual AQL. These exposed populations were mainly concentrated close to the port area.

By applying the LNG scenario, no more emissions of Ni and SO_2 are dispersed (100% emissions reduction), thus no more population is exposed to these pollutions.

6.2.4 Thessaloniki

The total number of people exposed to pollutant concentrations due to the dispersion of ship emissions was calculated. Calculations were performed for the present time, future trend and mitigation scenarios and considering the pollutant statistics exceeding the 5%, 10%, 50% and 100% of the short-term and long-term AQL. In the following, the numbers of people exposed to pollutants are presented but only for those with ambient levels that are mostly affected by the passenger ship traffic (mostly NO_2). In addition, maps are shown to give an overview of the spatial distribution of the exposed population. Figure 6.2.4.1 illustrates the population density for the greater Thessaloniki area (i.e. municipality of Thessaloniki and neighboring municipalities).

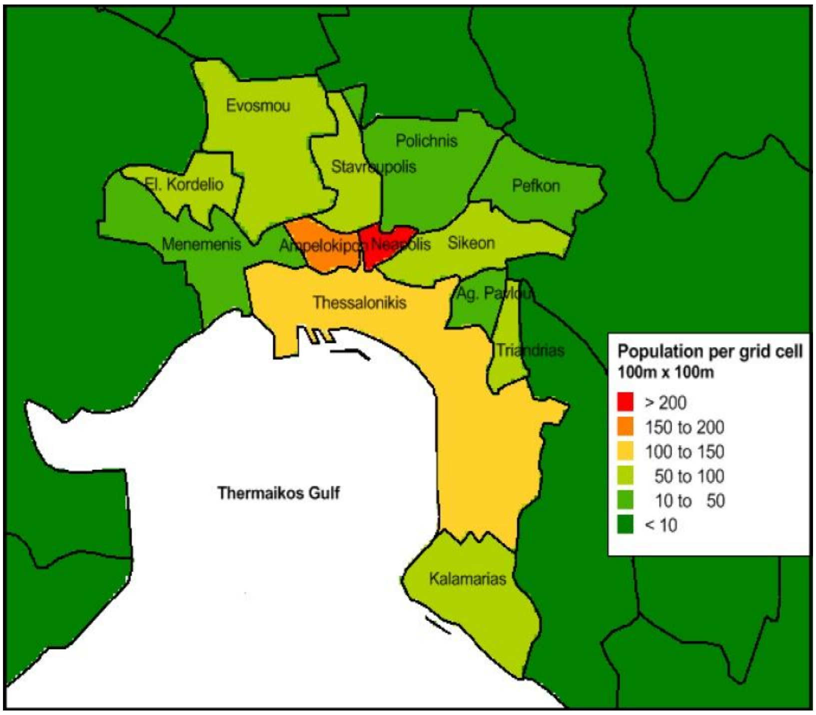


Fig. 6.2.4.1. Population density of the greater Thessaloniki area.

Figure 6.2.4.2a illustrates the number of people exposed to NO_2 and the spatial distribution of this exposed population in the areas where the 99.8 percentile of the hourly NO_2 concentrations timeseries exceeds the 5%, 10% and 50% of the NO_2 hourly AQL for the present time emission scenario (i.e. mainly the central and eastern part of the city). In the case of the 5% of the NO_2 hourly AQL criterion, the total number of exposed people is 314,760 representing about 46% of the total population within the modeling domain. The respective numbers are about the half for the 10% of the NO_2 hourly AQL criterion (167,814 people, approximately 24% of the population). 3,848 people are living in areas of the center of the city where the 99.8 percentile of the hourly NO_2 concentrations time series exceeds the 50% of the NO_2 hourly AQL.

In the year 2025, the population exposure is expected to increase significantly compared to the year 2013 due to the important increase in future passenger ship traffic as targeted by the Port Authority of Thessaloniki. As it is obvious form the Figure 6.2.4.2b, the areas where the 99.8 percentile of the hourly NO_2 concentrations timeseries will be exceeding the 5% and 10% of the NO_2 hourly AQL will be more extended in the future, including also the west and east coasts of the Thermaikos Gulf. Around 65% and 45% respectively of the domain wide population will be living in these areas (about +20% more compared to present time). More people will be living in city center areas where the 99.8 percentile of the hourly NO_2 concentrations timeseries will be exceeding the 50% of the NO_2 hourly AQL (33,910 people, about +4.5% more compared to present time). It is also characteristic that in the future also the annual NO_2 concentrations due to passenger ship traffic are expected to become higher than the 5% and 10 % of the AQL (Figure 6.2.4.3). In the future, 1,013 citizens will be living in areas where the 99.7 percentile of the hourly SO_2 concentrations time series will exceed the 5% of the SO_2 hourly AQL.

Figure 6.2.4.4 illustrates population exposure maps for the LNG and cold ironing mitigation measures to be implemented in year 2025. Comparing the Figure 6.2.4.4a with those of the Figure 6.2.4.2, it is revealed that the population exposure with respect to the NO_2 hourly AQL is significantly reduced. No people is living in areas where the 99.8 percentile of the hourly NO_2 concentrations timeseries is exceeding the 50% of the NO2 hourly AQL while those living in areas where the NO2 statistic is higher than the 5% and 10% of the NO2 hourly AQL (i.e. in a part the city center) are reduced by about -60% and -42% respectively with respect to the future trend scenario. Also the population exposed to SO_2 and PM (including metals and benzo(a)pyrene) is zero in the case of the LNG scenario. Cold ironing results in small decreases (about -8%) in the future population exposure with respect to the 5% and 10% of the NO_2 hourly AQL criteria.

This measure is more effective in reducing the population exposure with respect to the 50% of the NO_2 hourly AQL criteria. Future population exposure to SO_2 is not significantly changed because of the cold ironing measure.

The previous discussion reveals that, for the study area of Thessaloniki, the use of LNG as ship fuel is more efficient in the limitation of health impacts compared to the electrification of ships while at berth.

(a) (b)

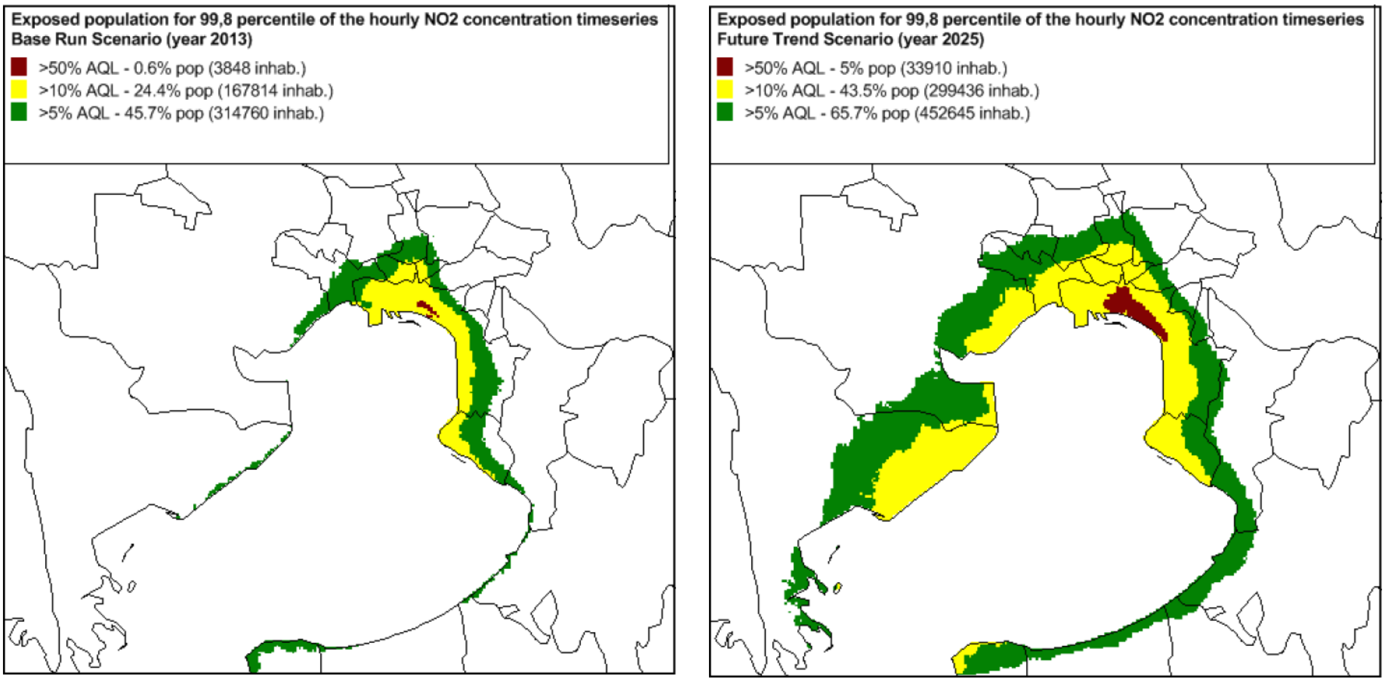


Fig. 6.2.4.2. Population exposure with respect to the NO2 hourly AQL for (a) the) present time (2013) and (b) future trend (2025) scenarios.

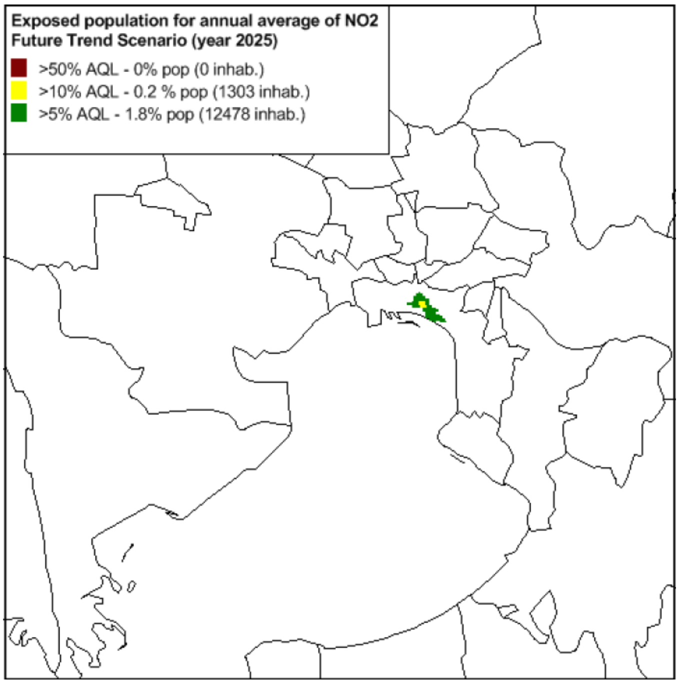
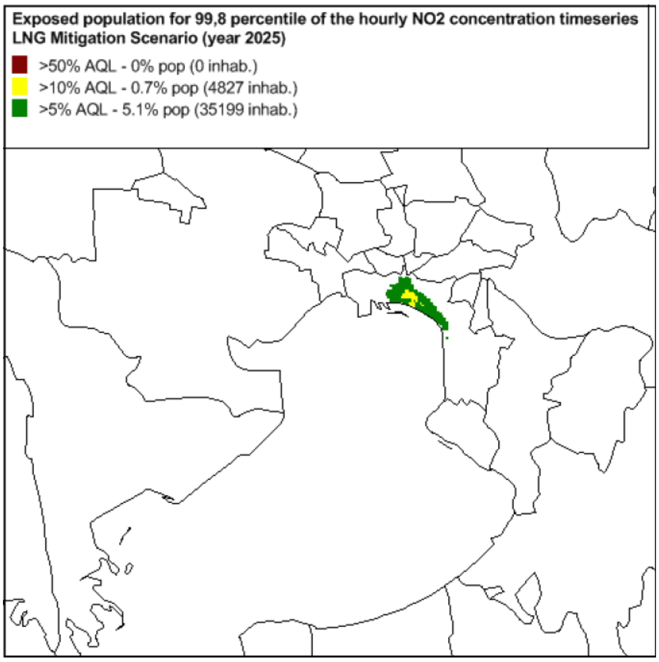


Fig. 6.2.4.3. Population exposure with respect to the NO2 annual AQL for the future trend (2025) scenario.

(a)



(b)

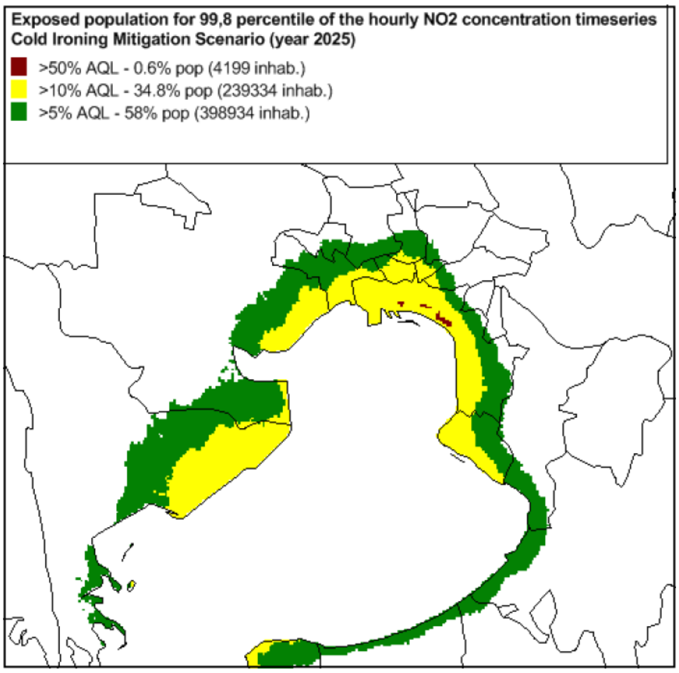


Fig. 6.2.4.4. Population exposure with respect to the NO2 hourly AQL for the (a) LNG and (b) cold ironing scenarios.

6.2.5 Venice

In the simulation domain of Venice, the amount and percentage of population exposed to a significant contribution from passenger ship plumes is presented for those pollutants exceeding at least the 5% of the short or long term AQL thresholds.

Like in the other ports, also in Venice the more significant issue concerning the impact of ship plumes on air quality is related to the NO_2 short term concentrations. Examining the results in respect to the other AQLs, in every scenario actually only a negligible amount of people living in Venice is exposed to concentrations that exceed the 5% of the AQL for NO_2 annual value and SO_2 hourly values.

Focusing on the short term population exposure to NO_2, the maps represent where inhabited cells in the model domain exceed at least the 5% threshold of the short term AQL, which is the 19th maximum of the hourly concentrations of NO_2 estimated by the model, namely 10 $\mu g/m^3$.

Considering the present and the future baseline scenarios, the model estimates that almost all the population in the simulation domain is exposed to a contribution coming from passenger ship that overtakes the 5% of the AQL, whereas about 90% is affected by concentrations greater than the 10% threshold. Only a small amount of inhabitants in Venice historical center (1% in the present scenario), located close to the large cruise ship terminal (Marittima), is exposed to a contribution that exceeds the 50% of this short term limit. This area of major exposure is estimated to decrease in the future baseline scenario, due to the reduction of the NOx Emission Factors related to a partial fleet renewal, and to the transfer of the Ro-pax vessels from the historical center terminal (Marittima) to the new terminal of Fusina, in Porto Marghera (see Chapter 3).

Table 6.2.5.1. Population exposure for the 2013 scenario.

AQ Statistic	Scenario	5% AQL threshold	10% AQL threshold	50% AQL threshold	5% AQL threshold	10% AQL threshold	50% AQL threshold
		n° of inhabitants			% of inhabitants (tot inhab. in the domain: 252500)		
NO_2 19° hourly max	Present	251,000	224,000	2,430	99%	89%	1%
NO_2 annual mean		180	0	0	0%	0%	0%
SO_2 25° hourly max		15	0	0	0%	0%	0%
NO_2 19° hourly max	Future	251,000	217,000	180	99%	86%	0%
NO_2 annual mean		3	0	0	0%	0%	0%
SO_2 25° hourly max		1,530	0	0	1%	0%	0%
NO_2 19° hourly max	OPS for large cruise ships	241,100	147,800	0	95%	59%	0%
NO_2 annual mean		0	0	0	0%	0%	0%
SO_2 25° hourly max		113	0	0	0%	0%	0%
NO_2 19° hourly max	Contorta channel	252,500	221,400	180	100%	88%	0%
NO_2 annual mean		0	0	0	0%	0%	0%
SO_2 25° hourly max		7	0	0	0%	0%	0%
NO_2 19° hourly max	New cruise ship terminal	185,300	85,100	0	73%	34%	0%
NO_2 annual mean		0	0	0	0%	0%	0%
SO_2 25° hourly max		0	0	0	0%	0%	0%
NO_2 19° hourly max	LNG	2,900	0	0	1%	0%	0%
NO_2 annual mean		0	0	0	0%	0%	0%
SO_2 25° hourly max		0	0	0	0%	0%	0%

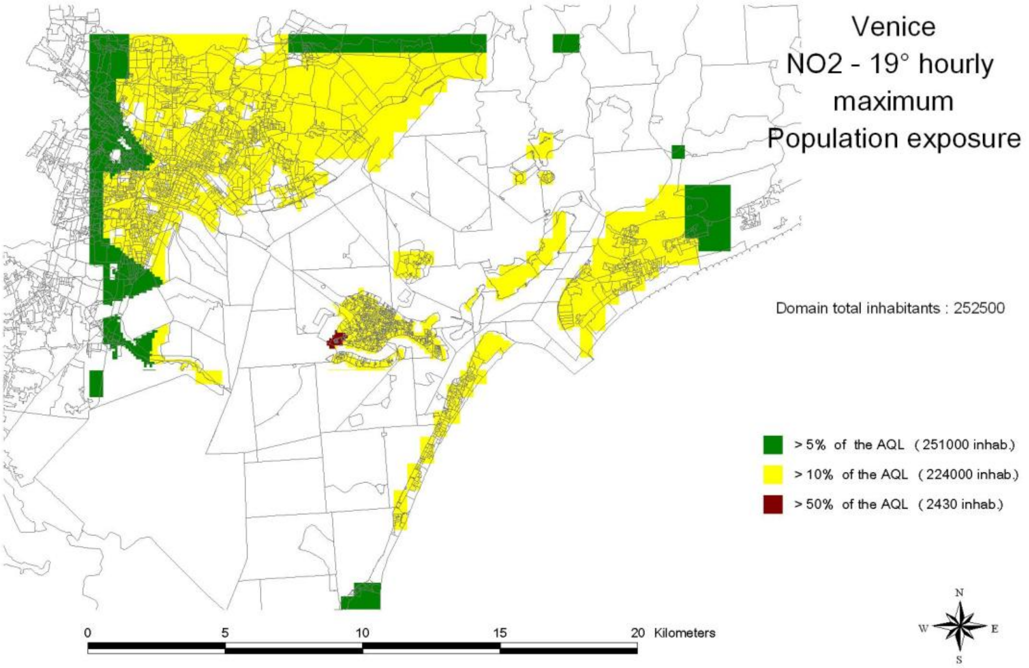


Fig. 6.2.5.1. Population exposure in respect to NO_2 hourly Air Quality limit for the 2013 scenario.

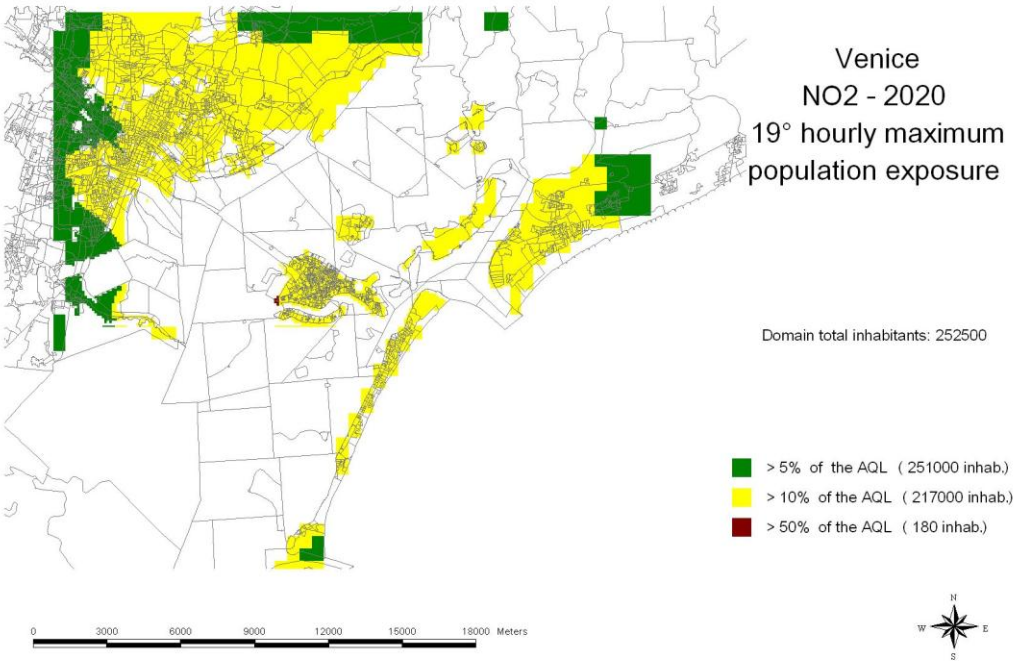


Fig. 6.2.5.2. Population exposure in respect to NO_2 hourly Air Quality limit for the 2020 scenario.

As described in Chapter 5, besides the LNG common scenario, three local scenarios, regarding cruise ships with gross tonnage larger than 40,000 tons, have been analyzed for Venice: the OPS for the cruise ship terminal (OPS Marittima), a new maneuvering route from the lagoon entrance to the mentioned cruise terminal (Contorta Channel), and the establishment of a new cruise terminal outside the lagoon (Punta Sabbioni terminal).

The first local scenario (OPS Marittima) had been analyzed in the context of the APICE project, with the reduction of the 90% of the large cruise ship emissions during the hoteling phase.

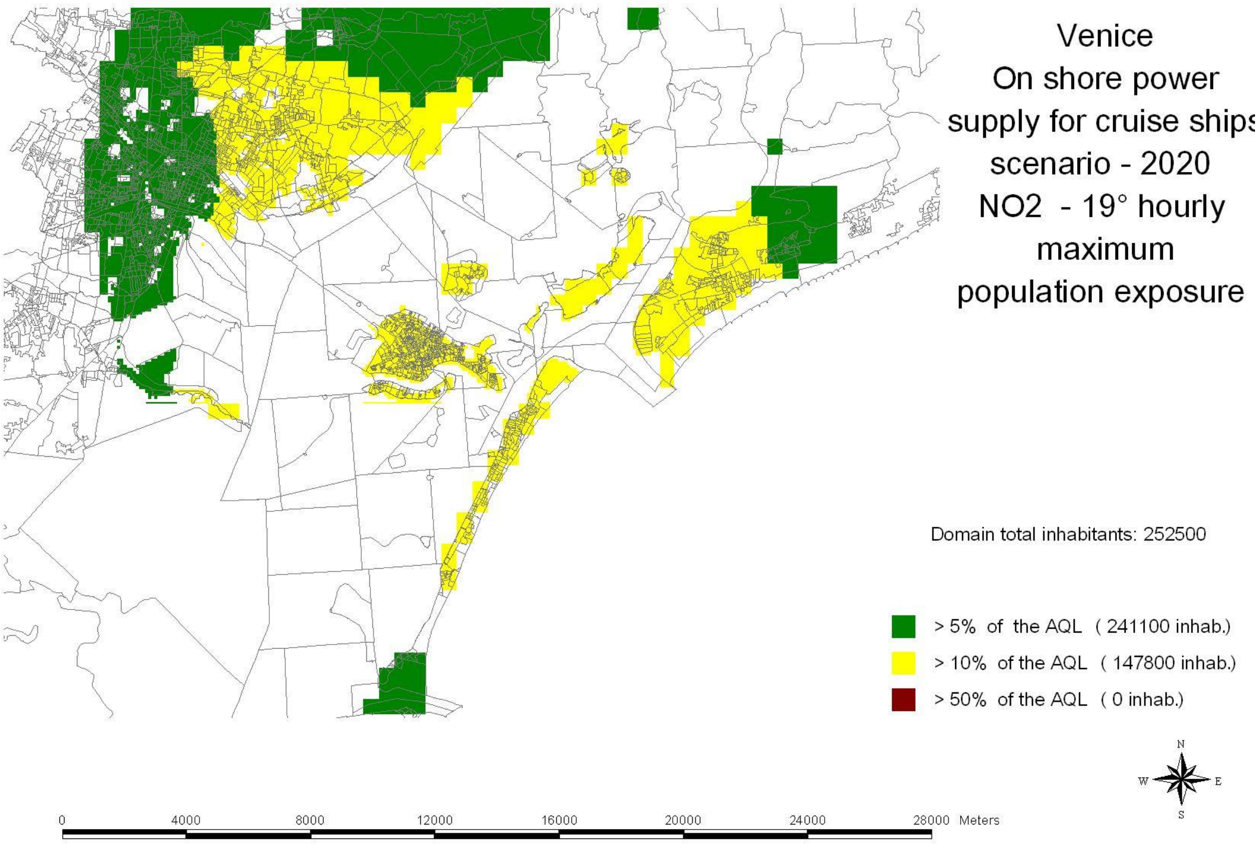


Fig. 6.2.5.3. Population exposure in respect to NO_2 hourly Air Quality limit for the OPS scenario.

In respect to the future baseline scenario, a reduction in the number of inhabitants directly affected by ship plumes is achieved, with no people exposed to concentrations that overtake the 50% threshold and less than the 60% of people in the domain interested by a contribution from passenger ships greater than the 10% of the short term AQL.

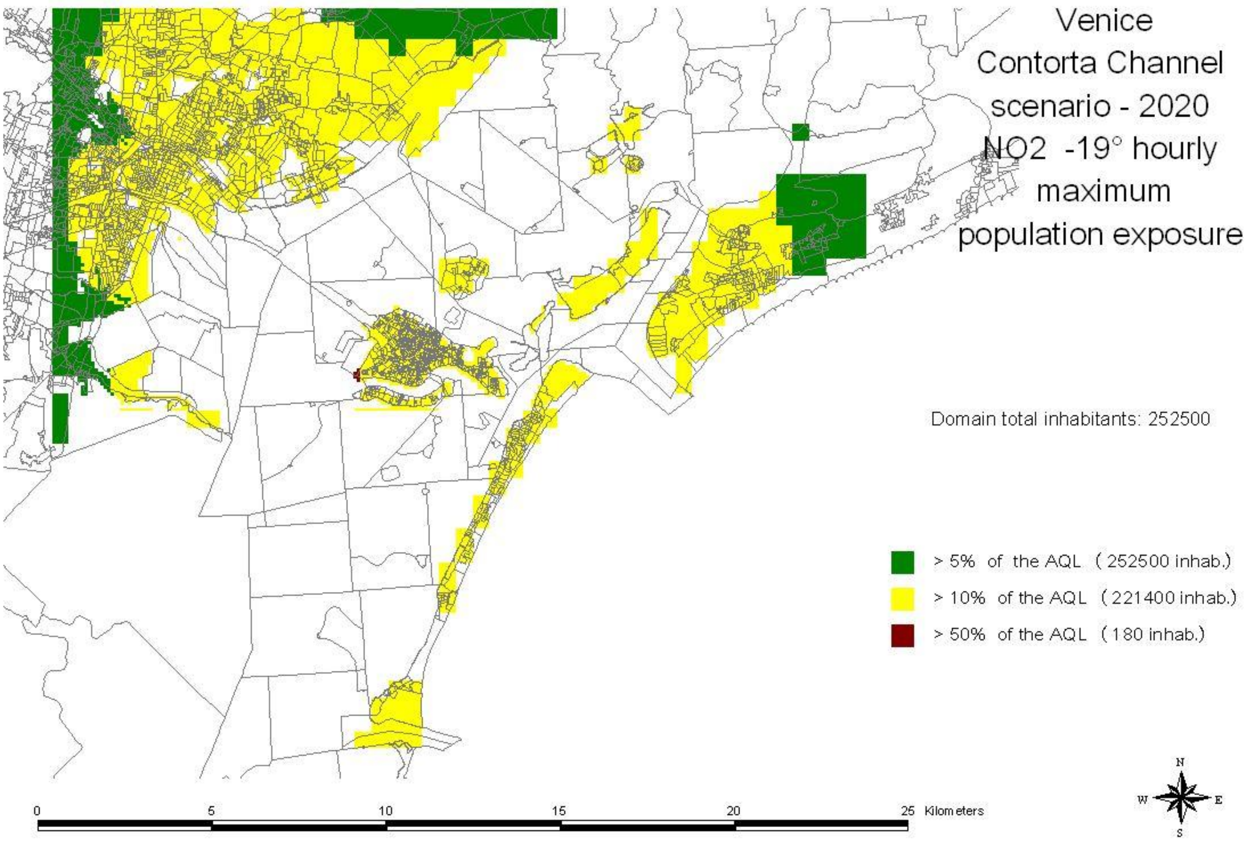


Fig. 6.2.5.4. Population exposure in respect to NO_2 hourly AQ limit for the Contorta Channel scenario.

In the "Contorta channel" scenario although an increment of the time spent by cruise ships in the maneuvering phase has been calculated, the new route would avoid the direct impact of ship plumes along the Giudecca channel in the very heart of the historical city. Nevertheless this scenario doesn't estimate significant changes in population exposure in respect to the baseline future scenario. It entails only a little increase in the number of inhabitants exposed to concentrations greater than 10% of the AQL from passenger in the mainland part of Venice Municipality.

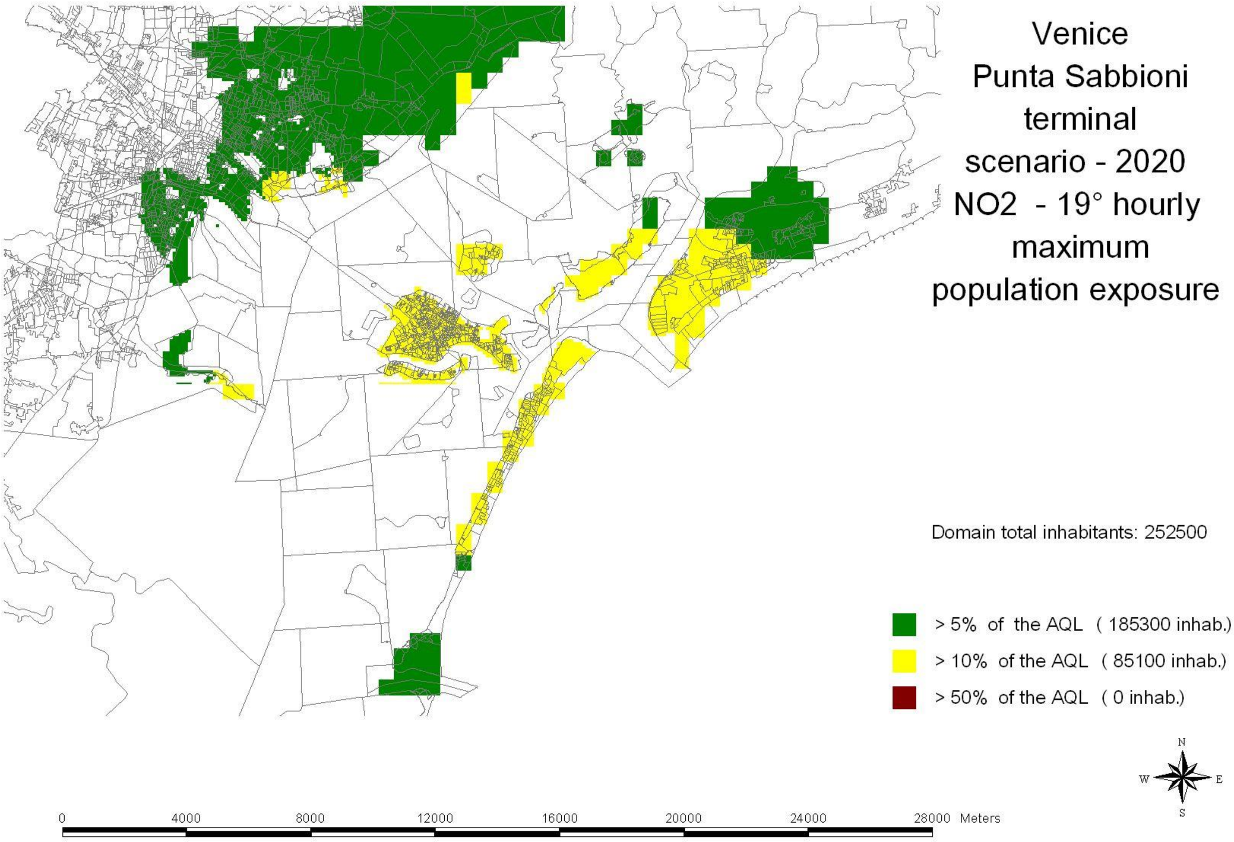


Fig. 6.2.5.5. Population exposure in respect to NO_2 hourly AQ limit for the new cruise terminal scenario.

The new cruise terminal scenario ("Punta Sabbioni" terminal) is only an "exploratory" scenario, as only the emissions coming from the large cruise ships have been taken into account. The impact of the transfer of passengers, related belongings and ship provisions from the Lido lagoon entrance to the Marittima terminal is not analyzed here. Considering only the cruise ship emissions, this scenario shows a relevant decrease in the number of people exposed to concentrations that exceed the 5% and the 10% of the NO_2 short term AQL. The population affected by a contribution greater than the 5% of the limit varies from the 99% in the baseline future scenario to the 73% in this scenario, while the people affected by concentrations over the threshold of 10% decrease from the 86% in the baseline future to the 73% in this new cruise terminal scenario.

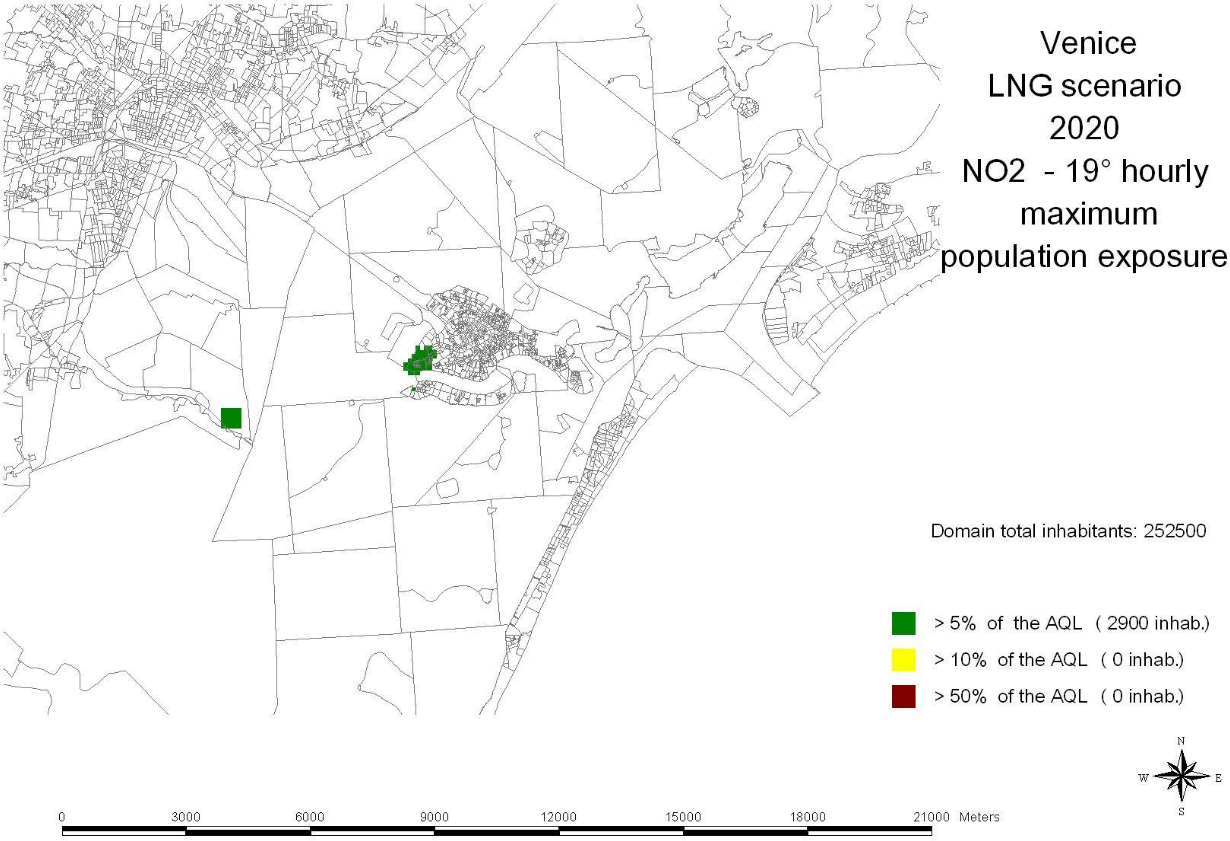


Fig. 6.2.5.6. Population exposure in respect to NO_2 hourly AQ limit for LNG scenario.

Finally, the complete switch of the passenger ship fleet to the LNG fuel could entail a strong decrease of plume ship contribution to urban air pollution; in this scenario in fact only 1% of people in the Venice simulation domain is affected by a remarkable signal of passenger ship emissions on NO_2 hourly concentration.

6.3 COMPARISON OF THE PORT CITIES IN TERMS OF POPULATION EXPOSURE TO PASSENGER SHIPS PLUMES

As for the model results, the tables here in after report the number of people exposed to the various thresholds, both for the long and the short term AQLs.

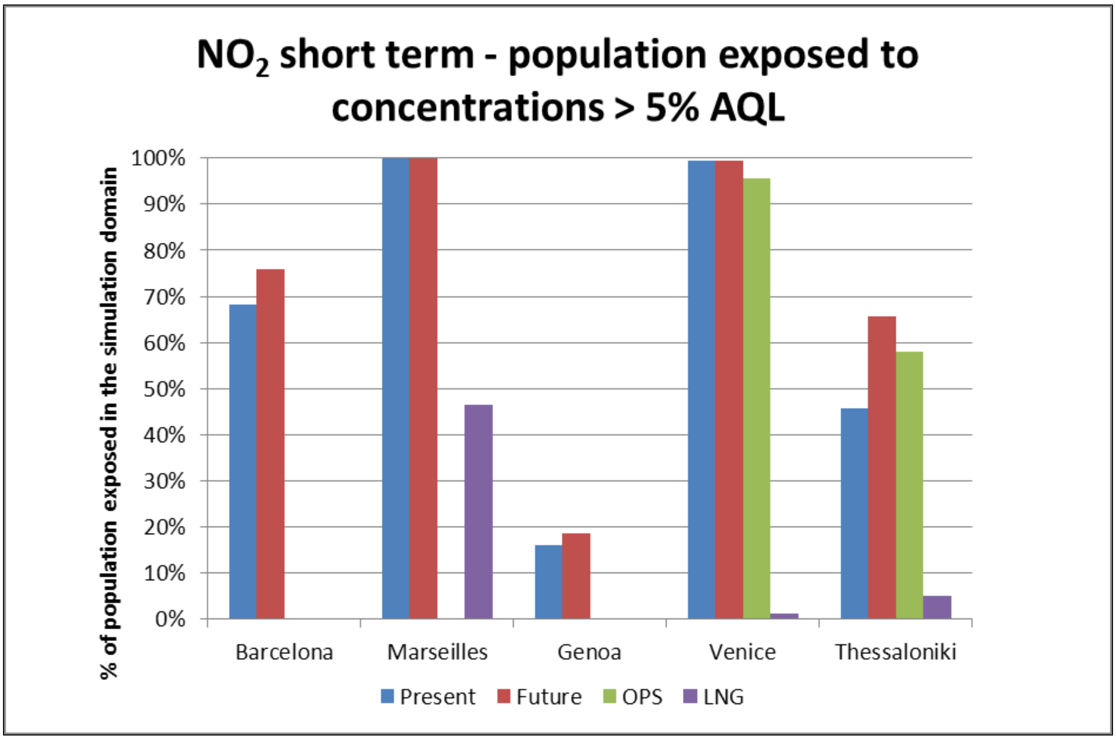
It is evident that, except for a small number of people living in Barcelona and in Thessaloniki for PM_{10} daily values, and in Marseilles for Ni annual mean, only NO_2 and SO_2 estimated values exceed some thresholds.

In particular for NO_2, both the thresholds related to long and short term exposure are exceeded in each pilot area. Specifically in the NO_2 short term case even thresholds higher than 5-10% are frequently exceeded. In Thessaloniki and in Genoa the models estimate, even for a very little number of persons, maximum hourly average concentrations that exceed the short term AQL.

Exceedances of 5% threshold of SO_2 are estimated in more than one pilot area, and in Marseilles, also the 10% threshold (both for long and short term AQL) in the present and future scenarios.

In all the ports examined by the project, the baseline future scenario shows comparable results in respect to the present scenario, except for a slight increase in the number of people exposed to concentrations exceeding the first two thresholds. This is due to the expected increase in the number of passenger ship movements in almost all the harbors.

It is evident that the most populated domains, as Barcelona and Marseille, show the highest number of people exposed to significant concentrations of NO_2 arising from ship emissions. Moreover these are the ports where the highest number of passenger ship movements is recorded and foreseen in the future.



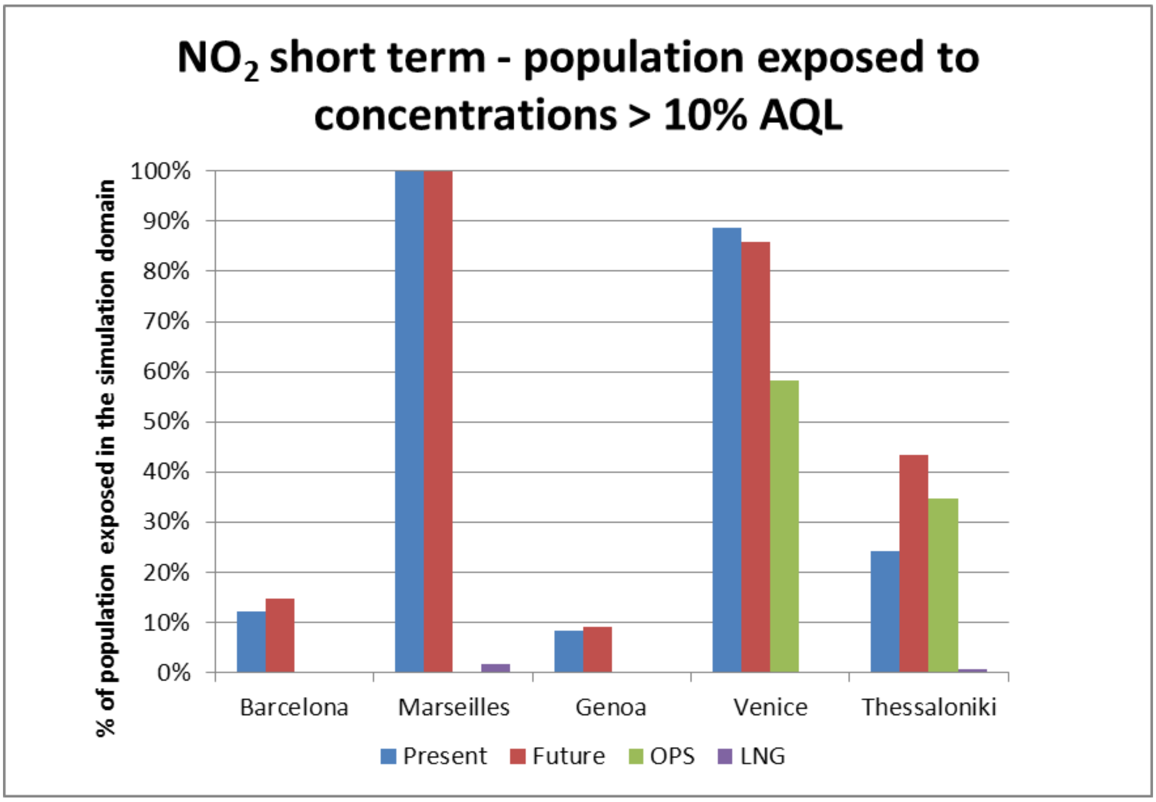


Fig. 6.3.1. Population exposure to NO_2 short term value – comparison among cities and scenarios.

The graphs in Figure 6.3.1 show the comparison among scenarios and cities, in terms of percentage of people exposed over the 5 and the 10% thresholds of the NO_2 hourly AQL. The OPS scenario has been considered for Thessaloniki, Venice and Genoa, whereas the LNG scenario for all the pilot areas.

In Venice and Marseilles, both in the present and future scenarios, almost all the people living in the simulation domains are exposed to concentrations between 5% and 50% of the short term AQL, whereas in Barcelona the people interested by a significant contribution from ship plumes represent around the 70% of the total population in the present scenario and the 76% in the baseline future one. In terms of number of inhabitants, in Barcelona there are around 2.5 million of people affected by plume ships. In Thessaloniki the increase of passenger ship traffic foreseen in the next future brings to a relevant increase in population exposure that could be partly controlled by the implementation of the OPS for cruise ships. In Genoa, instead, the typical meteorological conditions and the wind regime imply a smaller percentage of population exposed to ship emissions that could be further reduced by the OPS implementation.

The extreme scenario of complete conversion to LNG of the passenger fleet, brings in all port to a drastic reduction of population exposure, particularly significant for the higher concentrations estimated by the models.

In conclusion, focusing on the contribution of passenger ship emissions on population exposure, the CAIMANs approach allows to highlight that the air pollutants of major concern are the NO_2 and in lesser extent the SO_2, especially in respect to the short term values. The influence of ship plumes on particulate matter and micropollutants AQL doesn’t result as particularly significant.

Without mitigation actions, the impact on population is estimated to increase in the future scenarios for most of the cities of the project. This increment could be efficiently reduced by the implementation of the on power supply technologies for those passenger ships which dock close to the more populated areas; moreover a complete conversion to LNG fuel, estimated as the “extreme” scenario, could imply a drastic reduction of population exposure.

Table 6.3.1. Population exposure – present scenario.

n° inhab.	NO_2	SO_2	PM10	PM2.5	Ni	Pb	As	Cd	B(a)P
	Barcelona (n° of inhabitant in the modeling domain: 3280290)								
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	86,323	0	0	0	0	0	0	0	0
5% AQL	408,977	61,040	0	0	0	0	0	0	0
	Marseilles (n° of inhabitant in the modeling domain: 588132)								
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	70,768	937	0	0	0	0	0	0	0
5% AQL	259,667	66,786	0	0	6302	0	0	0	0
	Genoa (n° of inhabitant in the modeling domain: 193183)								
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	0	0	0	0	0	0	0	0	0
5% AQL	4,360	0	0	0	0	0	0	0	0
	Venice (n° of inhabitant in the modeling domain: 252500)								
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	0	0	0	0	0	0	0	0	0
5% AQL	180	0	0	0	0	0	0	0	0
	Thessaloniki (n° of inhabitant in the modeling domain: 688617)								
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	0	0	0	0	0	0	0	0	0
5% AQL	579	0	0	0	0	0	0	0	0

n° inhab.	NO_2 hourly c.	SO_2 hourly c.	SO2 daily conc.	PM10 daily conc.
	Barcelona			
AQL	0	0	0	0
50% AQL	1,761	0	0	0
10% AQL	403,925	0	0	0
5% AQL	2,238,281	0	0	12,165
	Marseilles			
AQL	0	0	0	0
50% AQL	0	0	0	0
10% AQL	588,132	82,806	2	0
5% AQL	588,132	488,066	79,557	0
	Genoa			
AQL	62	0	0	0
50% AQL	101	0	0	0
10% AQL	16,200	0	0	0
5% AQL	30,830	0	0	0
	Venice			
AQL	0	0	0	0
50% AQL	2,430	0	0	0
10% AQL	224,000	0	0	0
5% AQL	251,000	15	0	0
	Thessaloniki			
AQL	290	0	0	0
50% AQL	3,848	0	0	0
10% AQL	167,814	0	0	0
5% AQL	314,760	145	0	0

Table 6.3.2. Population exposure – future baseline scenario.

Annual mean concentrations (cruise and other passenger vessels)									
n° inhab.	NO_2	SO_2	PM10	PM2.5	Ni	Pb	As	Cd	B(a)P
Barcelona (n° of inhabitant in the modeling domain: 3280290)									
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	114,389	0	0	0	0	0	0	0	0
5% AQL	529,429	108,758	0	0	0	0	0	0	0
Marseilles (n° of inhabitant in the modeling domain: 588132)									
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	98,627	12,540	0	0	16	0	0	0	0
5% AQL	334,736	130,404	0	3	27,909	0	0	0	0
Genoa (n° of inhabitant in the modeling domain: 193183)									
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	0	0	0	0	0	0	0	0	0
5% AQL	8,350	0	0	0	0	0	0	0	0
Venice (n° of inhabitant in the modeling domain: 252500)									
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	0	0	0	0	0	0	0	0	0
5% AQL	3	0	0	0	0	0	0	0	0
Thessaloniki (n° of inhabitant in the modeling domain: 688617)									
AQL	0	0	0	0	0	0	0	0	0
50% AQL	0	0	0	0	0	0	0	0	0
10% AQL	1,303	0	0	0	0	0	0	0	0
5% AQL	12,478	0	0	0	0	0	0	0	0

Short term concentrations				
n° inhab.	$NO_{2\ hourly\ c.}$	$SO_{2\ hourly\ c.}$	$SO2_{daily\ conc.}$	$PM10_{daily\ conc.}$
Barcelona				
AQL	0	0	0	0
50% AQL	2,081	0	0	0
10% AQL	485,140	0	0	0
5% AQL	2,492,547	0	0	22,250
Marseilles				
AQL	0	0	0	0
50% AQL	0	0	0	0
10% AQL	588,132	215,834	41,253	0
5% AQL	588,132	578,361	194,573	3
Genoa				
AQL	62	0	0	0
50% AQL	230	0	0	0
10% AQL	17,635	0	0	0
5% AQL	35,881	0	0	0
Venice				
AQL	0	0	0	0
50% AQL	180	0	0	0
10% AQL	217,000	0	0	0
5% AQL	251,000	1530	0	0
Thessaloniki				
AQL	2,027	0	0	0
50% AQL	33,910	0	0	0
10% AQL	299,436	145	0	0
5% AQL	452,645	1,013	290	290

Table 6.3.3. Population exposure – future LNG scenario.

	Annual mean concentrations (cruise and other passenger vessels)								
n° inhab.	NO_2	SO_2	PM10	PM2.5	Ni	Pb	As	Cd	B(a)P
	Barcelona (n° of inhabitant in the modeling domain:)								
AQL	0								
50% AQL	0								
10% AQL	0								
5% AQL	0								
	Marseilles (n° of inhabitant in the modeling domain:)								
AQL	0								
50% AQL	0								
10% AQL	0								
5% AQL	1								
	Genoa (n° of inhabitant in the modeling domain:)								
AQL	0								
50% AQL	0								
10% AQL	0								
5% AQL	0								
	Venice (n° of inhabitant in the modeling domain: 252500)								
AQL	0								
50% AQL	0								
10% AQL	0								
5% AQL	0								
	Thessaloniki (n° of inhabitant in the modeling domain:)								
AQL	0								
50% AQL	0								
10% AQL	0								
5% AQL	0								

	Short term concentrations			
n° inhab.	NO_2 hourly c.	SO_2 hourly c.	SO2 daily conc.	PM10 daily conc.
	Barcelona			
AQL	0			
50% AQL	0			
10% AQL	0			
5% AQL	9284			
	Marseilles			
AQL	0			
50% AQL	0			
10% AQL	10251			
5% AQL	273756			
	Genoa			
AQL	0			
50% AQL	0			
10% AQL	0			
5% AQL	230			
	Venice			
AQL	0			
50% AQL	0			
10% AQL	0			
5% AQL	2900			
	Thessaloniki			
AQL	0			
50% AQL	0			
10% AQL	4827			
5% AQL	35199			

CONCLUSIONS

CAIMANs was funded by the MED Programme 2007-2013 inside the "Maritime Integrated Call" specifically aimed at identifying relevant actions at transnational level as the basis for potential future projects and at putting in place new relevant partnerships that could later be involved in implementing the next operational Programme 2014-2020. CAIMANs, which had been running for a one year period only, together with the other 13 projects approved within the call, were asked to actively participate to the joint communication and capitalisation strategy, set up and coordinated by the Marina-Med project. Thus, main messages and key deliverables of the 14 Maritime Integrated Projects are available on the common web site of the Maritime Integrated Projects, http://www.medmaritimeprojects.eu/ CAIMANs focused on air quality impact and greenhouse gases emission assessment for cruise and passenger ships.

The scientific insight on the Air Quality Impact and Greenhouse Gases Assessment of Cruise and Passenger Ships was the first step activity of CAIMANs. The present report is the detailed document that describes the methodology applied and the results achieved. Databases and outcomes of this activity are available for free download on the CAIMANs website subsections: http://www.medmaritimeprojects.eu/section/caimans
On every one of the five MED harbors, Barcelona, Marseilles, Genoa, Venice and Thessaloniki, the Air Quality Impact and Greenhouse Gases Assessment of Cruise and Passenger Ships was applied through the following steps:

1) bottom up macro and micro pollutant emission estimations applying the reference European methodology for ship traffic emissions (EMEP/EEA Emission Inventory Guidebook, 2013)

   - for the current scenario (year 2013), using as input the passenger ship movements recorded;
   - for a mid-term future development scenarios (2020 or 2025 depending on the city) using as input the foreseen passenger ship movements accordingly to the specific development scenarios of each harbour;
   - for future mitigation scenarios (LNG fleet, shore side electrical power for hoteling of the ships, displacement of terminals or routes, change of fuel in maneuvering phase).

Greenhouse gases emissions were calculated, as well as Carbon dioxide was studied to link results with climate change indicators.

The outcomes of this step activity are the pollutant passenger ship emissions databases for every harbor-cities for the different scenarios.

2) Air dispersion modelling at high-resolution of micro- and macro-pollutants emitted by passenger ships, for the current, the future development scenario and the mitigation scenarios.

The outcomes of this step activity are the concentration maps with the various pollutant statistics (yearly averages, daily or hourly percentiles) linked to the Air Quality Limits (AQD 2008/50/EC)

3) population exposure mapping, obtained by overlapping air dispersion maps with the population living in the city.

The outcomes of this step activity are maps of the people exposed to various percentages of the Air Quality Limits.

4) Pointing out the most effective actions for the reduction of medium and long-term passenger ship emissions by the comparison among the population exposure maps of the different mitigation scenarios .

Comparison among the cities and different scenarios was studied to identify the most effective actions for the reduction of medium and long-term emissions

Beside this snapshot of the situation in the five Mediterranean ports, a theoretical scenario of a total shift of all the ships crossing the Mediterranean to engines fuelled with LNG was studied as well, in order to integrate the analysis on a wider scale and considering also effects of secondary pollution. Even if very extreme, this scenario gave interesting hints for the assessment of this mitigation measure.

The specific results and conclusion of the various phases of the analysis are summarized below:

a) Present time pollutant annual emissions by passenger ships

For cruise ships, NOx are the most emitted macropollutants in both hoteling and maneuvering phase in present time (year 2013). More specifically, in all the harbors, the annual NOx emissions in hoteling phase are almost double of those in the maneuvering phase due to the much higher number of hours spent in a year in hoteling than in maneuvering. The ranking among the cities for NOx emissions shows that NOx hoteling emissions are highest in Barcelona and Venice while in Marseille and Venice the highest NOx emissions in the maneuvering phase are emitted. Concerning the metals, the emissions in the hoteling phase are higher for Zn, Ni and Cu and refer to Venice and Barcelona. The most important metal in the maneuvering phase, in terms of amounts emitted in the atmosphere, is Ni; emissions are the highest for Marseille. Among the different organic micropollutant studied within the project, BaP is emitted mostly with its emission being higher for Venice and then Marseille.

NOx are the most emitted macropollutants also for the other passenger ships. Ro-pax NOx emissions are higher than cruise vessel ones in Marseilles and Genoa, lower in Barcelona and Venice, while in Thessaloniki they are almost the same. Ro-pax emissions hoteling NOx emissions are higher than those on the maneuvering phase. The ranking among the cities is: Marseilles, Genoa, Barcelona, Venice and Thessaloniki. Zn, Ni and Cu in the hoteling phase and Ni in the maneuvering phase are the metals most emitted by this type of ships. BaP is the most important, in terms of emissions, among the organic micropollutants studied within the project. Emissions are the highest for Marseille.

Because of the implication of greenhouse gases on the climate, CO_2 emissions have been estimated within CAIMANs. The hoteling component is the prevailing one in all the five harbors studied both for ro-pax and cruise ships. In Marseilles and Genoa, ro-pax emissions are higher than the cruise ship ones, whereas in Barcelona and Venice the proportion is the opposite; in Thessaloniki, the emissions from both types of ships are almost the same.

b) Present time pollutant concentrations due to passenger ships

In the year 2013, the pollutants emitted by ships which have been identified as more important for the air quality in the study areas are NO_2 and SO_2.

Both the long-term and short-term NO_2 concentrations due to ship plumes are air quality issues; the impact of ship emissions is more evident on the short-term NO_2 levels. The domain-wide maximum value of the short-term NO_2 concentration statistics seriously exceeds the AQL in Barcelona and Thessaloniki; it represents an important share of the AQL in Venice and Marseille while in Genoa the comparison to the AQL results in a moderate ratio.

As for SO_2, both the long-term and short-term concentrations due to passenger ship emissions are of concern in Barcelona and Marseille. The latter are more important in Venice and Thessaloniki. The ratios of the domain wide long-term and short-term SO_2 concentration statistics with the corresponding AQL have been estimated moderate to small. Only in Genoa, SO_2 from ship plumes is not an issue.

c) Future time pollutant annual emissions by passenger ships

According to the future trend emission scenario, increases in the cruise ship hoteling emissions are expected in the future in the study areas except for Venice where no change in the hoteling emissions has been estimated. The percentage increase of the future cruise ship hoteling emissions with respect to the present time emissions is very high in Thessaloniki. The current ship traffic in the port of Thessaloniki is low and a very high increase in the cruise ship traffic is expected in the future compared to the other ports. Regarding the other study areas, the percentage increase of pollutant emissions in the hoteling phase is small to moderate for most of the pollutants considered. Similar are the results, assessed within the project, for the maneuvering and cruising phases emissions, except for Venice where: a) very high percentage increases have been estimated for some of the pollutants in the maneuvering phase since in the future trend scenario the ban for BFO due to the Blue Flag 2 Agreement, as implemented for the estimation of the present time emissions, is supposed to not be in force and b) in the cruising mode all pollutants are expected to record no change in emissions with the exception of SO_2 and NOx for which a decrease is foreseen. This is the result of the unchanged number of calls for cruise ships supposed in the future for Venice port along with the regulated future decrease of sulfur content in the fuels used by passenger ships and the penetration of new vessels with IMO Tier II standard into the fleet.

When considering all passenger ships, the results are similar with those for cruise ships except for the hoteling emissions in Venice high are expected to have a small percentage increase for all pollutants.

d) Future time pollutant concentrations due to passenger ships

In the mid-term future, in accordance with the present time results, the pollutants emitted by ships which are expected to be critical for the future air quality of the study areas are NO_2 and SO_2. The domain wide maximum values of the long-term and short-term NO_2 concentration statistics are estimated to increase in all study areas except for Venice. For the short term NO_2 statistics, the increases will represent a high share of the AQL in Thessaloniki, a moderate share in Genoa and will be low in Barcelona and Marseille when compared to the AQL; the decrease has been assessed as moderate for Venice when compared to the AQL.

Increases have been estimated in the future for the domain wide maximum values of the long-term and short-term SO_2 concentration statistics in all study areas representing though small percentage values when compared with the corresponding AQL.

The previous discussion suggests that the existing legislation is expected to result in a more effective control of future SO_2 concentrations due to passenger ship traffic compared to that for NO_2.

e) Effectiveness of passenger ship emission mitigation actions

The investigation of the effectiveness of the local mitigation actions studied within the project, i.e. the replacement of the passenger fleet with ships fuelled by LNG and the “On Shore Power Supply” of cruise and passenger ships during the hoteling phase, revealed that both measures have beneficial impact on both short and long term NO_2 concentration statistics in all pilot cities.

For both kinds of scenarios, an adaptation is necessary to use LNG or electric quays by ships. These adaptations will have an economic impact for ship companies which will be profitable on condition that these solutions would be shared between a large number of ports around the Mediterranean Sea.

In addition, as a transnational mitigation action, the use of LNG as fuel for ships in the Mediterranean Sea during summertime will allow a reduction of NO_2 concentrations and an emission reduction of primary particles and gaseous species involved in secondary particles formation. Moreover, this mitigation action will provide a benefit for the climate, as ozone (O_3) that contributes to the Green House Effect will be reduced.

f) Population exposure to passenger ship plumes

Focusing on the contribution of passenger ship emissions on population exposure, the CAIMANs approach allows to highlight that the air pollutants of major concern are NO_2 and in lesser extent SO_2, especially with respect to the short term values. Without mitigation actions, the impact on population is estimated to increase in the future for most of the cities studied within the project. This increase could be efficiently reduced by the implementation of the “On Shore Power Supply” technologies for those passenger ships which dock close to the more populated areas; moreover a complete conversion to LNG fuel, estimated as the “extreme” scenario, could imply a drastic reduction of population exposure.

Beside the mentioned detailed results, CAIMANs project, collaborating with the other 12 projects of the Maritime Integrated approach and under the direction of the 14th project MarInA-Med in charge of the communication and capitalization activities, cooperating in delivering a synthetic message for the joint policy paper (http://www.medmaritimeprojects.eu/article/com-cap-marina-med-final-policy-paper-1).
The contribution by CAIMANs as technical hints is here below recall:

- Air pollution mitigation of passenger ships needs complementary and integrated policies and planning, from international to national and local levels, to find the most effective solutions that minimize the impact on population, the environment and the cultural heritage of Mediterranean port cities.
- European and international policies on fuels, engine technologies and ship emission abatement, by acting on a wider domain, could be very effective in the mitigation of negative impacts on public health and the environment; on the contrary, local regulations on these issues could penalize single harbors that try to reduce ship impacts on a local scale. Nonetheless, planning strategies on the local scale could be more effective in implementing specific mitigation actions, such as displacement of ship terminals or maneuvering routes, which could significantly reduce the population exposure.
- Considering air quality limits set by the current European legislation in order to protect human health, the hourly nitrogen dioxide (NO_2) concentrations are those of major concern among all air pollutants emitted by passenger ships.
- The shift to a passenger ship fleet with engines fuelled by Liquefied Natural Gas (LNG) is a very effective air quality mitigation scenario for the foreseen growing emissions in maritime touristic traffic.

As governance hints, the message delivered is that: “future cooperation projects on governance level, aiming at mitigating air pollution due to maritime transport, should promote, strengthen, and enhance networking between Ports, Local Environmental Authorities and Scientific Institutions”.

Indeed, a network of competent Authorities and Institutions involved in air quality management in harbor cities throughout the Mediterranean basin (including also Southern Countries) has become to be established within CAIMANs experience.

In the perspective of future projects of transnational cooperation, the adaptive tool developed as common instrument of the Air Quality Impact Assessment for harbor emissions in CAIMANs could be further improved and developed for future analysis and could be also transferred, with the expert support from CAIMANs partnership, to other harbor areas.

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Annex A: Transnational scenario

A.1 Introduction

In the framework of the CAIMANs approach, a common scenario is shared and studied over each port area, using the same methodology. This approach allows a comparison of the forecasted impact after application of a mitigation action according different port configurations and traffic. Results provide a guideline for decision makers in order to improve air quality inside port areas. However, no information is available outside the high resolution domain to evaluate the impact at a larger scale. On the other hand, dispersion models used at high resolution, as ADMS and CALPUFF, only consider some basic chemical reactions, with very simple chemical schemes. They are not able to compute large photochemical pollution events which occur over the Mediterranean border during summer.

The common mitigation action studied by each partner in the CAIMANs project is the Liquefied Natural Gas (LNG) scenario. As described in the main part of this report, LNG is considered as a clean fuel because it allows reducing emissions of several pollutants as NOx emissions which are involved in ozone (O_3) production. To evaluate this scenario at the scale of the Mediterranean basin and to study the impact over secondary species as ozone, a Chemical Transport Model (CTM) is required.

The aim of this specific annex is to adapt the common LNG scenario as a transnational scenario, to provide an evaluation of this action at the scale of the Mediterranean basin and to study its impact for secondary species.

A.2 Methodology

A.2.1 - Description of the modeling system

A modeling system consists of several models and tools to compute air pollutant concentrations. This part introduces the main models and parameterization used for this study.

A.2.1.1 - Simulation area

The modeling system used for this study includes two nested simulation domains (Figure A.2.1). The first domain includes the overall Mediterranean Sea, a large part of Europe and the northern part of Africa. It is composed by 56 cells in the south-north direction and 100 cells in the east-west direction with a spatial resolution of 45km. The second domain includes the western and central part of the Mediterranean Sea with 93 cells in the south-north direction and 189 cells in the east-west direction for a spatial resolution of 15km. Both domains are used to compute meteorological fields, gridded emissions, boundary and initial conditions and other specific inputs required by CTMs and computation of final concentration fields.

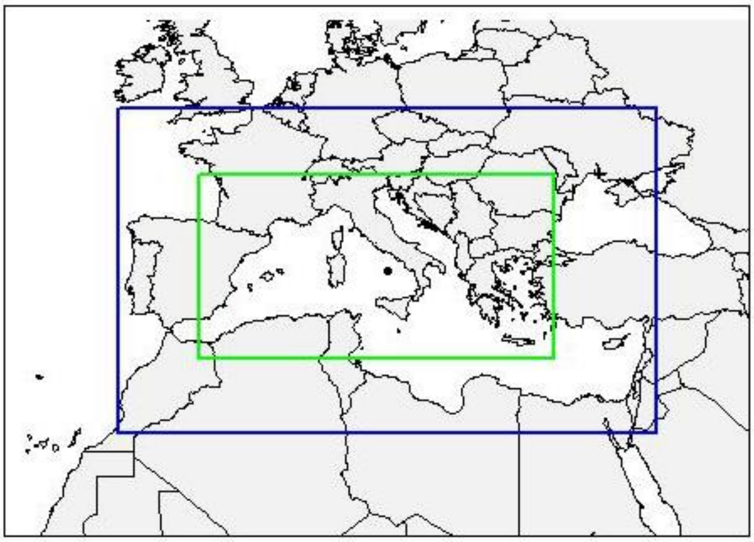

Fig. A.2.1.1_1: Extent of simulation domains.

A.2.1.2 - Meteorological fields

CTMs require several meteorological fields to compute transport and chemistry inside each grid cell. They are provided by the Weather Research and Forecasting[1] (WRF) model v3.5 for the two nested domains with a 1 hour temporal resolution. Initial and boundary conditions required for the first domain are provided by the National Centers for Environmental Prediction (NCEP) issue from the Global Data Assimilation System (GDAS).

A.2.1.3 - Concentrations fields

The CHIMERE[2] model v2008 is used to compute concentration fields over the two nested domains. Boundary and initial conditions required for the largest domain are supplied by the LMDz-INCA2[3] model.

A.2.1.4 - Emission data

Anthropogenic emissions are supplied by the European Monitoring and Evaluation Programme (EMEP) for the reference year of 2012 with a spatial resolution of 50 km. Emissions are downscaled according to the land cover with the spatial resolution of the related domain. Natural emissions are calculated by the Model of Emissions of Gases and Aerosols from Nature[4] v2.04 (MEGAN). An additional module of CHIMERE, named “diagbio”, calculates dust and sea salts emissions. Both models use meteorological fields issue from WRF to force natural emissions.

A.2.2 - Scenario description

The first scenario, named “Base scenario”, use the total emission database, without any modification. This scenario is defined to compute a reference simulation.

The second scenario, named “LNG - Passenger scenario” uses the hypothesis defined in by the common scenario, described in the main part of this report. Ship emissions are

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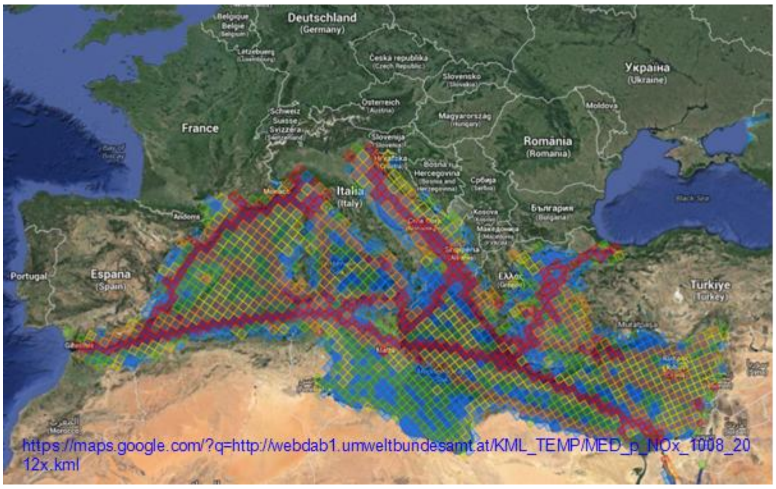
split from total emissions by selecting the eighth sector of the Standardized Nomenclature for Air Pollutants (SNAP 08), which provides emissions for other mobile sources and machinery (non-road sector), and by computing a spatial join over the Mediterranean area. An illustration of NOx emissions from this sector is provided in the Figure A.2.2_1. Within total Mediterranean traffic, passenger ships (cruise) and passenger Ro-Ro (ferries) count for around 4.2% of total Mediterranean port calls and transits[5]. Standard reduction emission factors (Table A.2.2_1) are applied on this base. As no spatial information are available to split maritime emissions into passenger emissions and other traffic, an assumption of a homogeneous repartition of passenger ships over the EMEP grid is done.

***Table A.2.2_1**: Standard reduction emissions factors for ship using LNG as fuel*

Pollutants	NOx	SOx	Particulate Matter
Reduction factors	- 90 %	- 100 %	- 100 %

The third scenario, named "LNG - All ships scenario", is a theoretical scenario to provide a range of evolution respect to LNG scenario. In this scenario, all ships crossing the Mediterranean Sea use LNG as fuel and reduction factors are applied to all maritime emissions over the Mediterranean area.



[5] Study of Maritime Traffic Flows in the Mediterranean Sea - Final Report - Unrestricted Version - July 2008. Lloyd's Marine Intelligence Unit for the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC).

Fig. A2.2_1: *NOx emissions from SNAP 08 in 2012 over the Mediterranean Sea. Color scale is provided on a indicative basis.*

A.2.3 - Simulation period

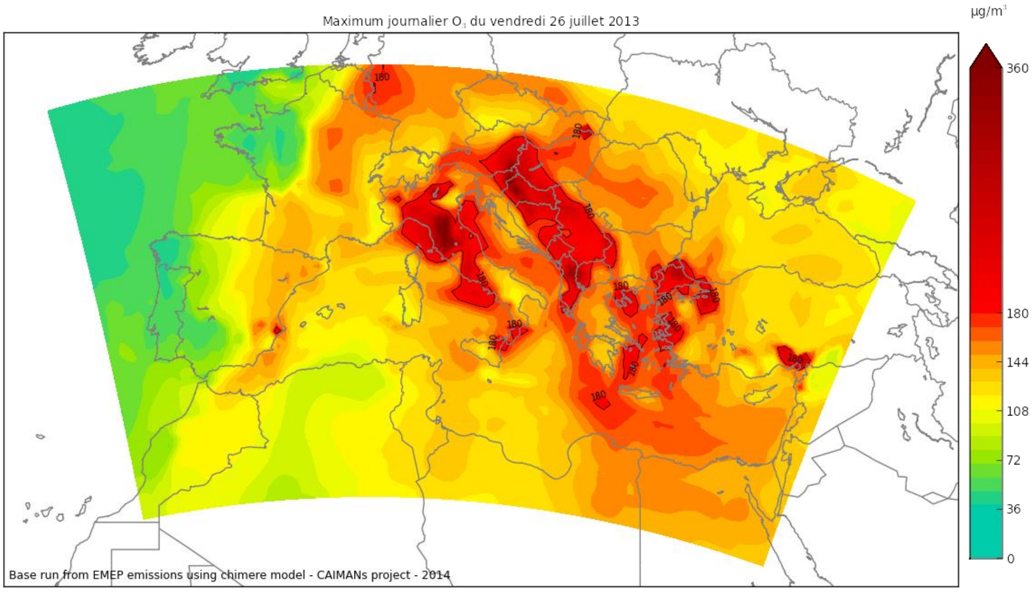
The modeling system runs from July 1st to August 31st in 2013, with an initial computation time of 1 week before. This period considers specific conditions in terms of emissions and meteorological data which lead to photochemical pollution events at large scale. The modeling system provides a 1-hour output.

A.3 Results

In this study, a specific focus is done on ozone (O_3) as it is one of the main problematic pollutants over the Mediterranean area. O_3 is a secondary specie, issue from complex chemical reactions into the troposphere, between NOx and organic compounds as volatile organic compounds (VOCs). Ozone events mainly occur during summer with high heat waves as its formation is catalyzed by sunlight. The Air Quality Limit (AQL) reported in this part for O_3 is the hourly limit which has not to exceed 180µg/m^3 during the day.

A.3.1 - Base scenario

Results for a typical day during the summer period over the two nested domains are reported in Figure A.3_1. This map illustrates than O_3 concentrations are high over a large part of the Mediterranean area and lead to local exceedences of the AQL. Outputs from this “Base scenario” are used in the following parts to evaluate the different scenario in terms of increases or decreases of concentration fields.



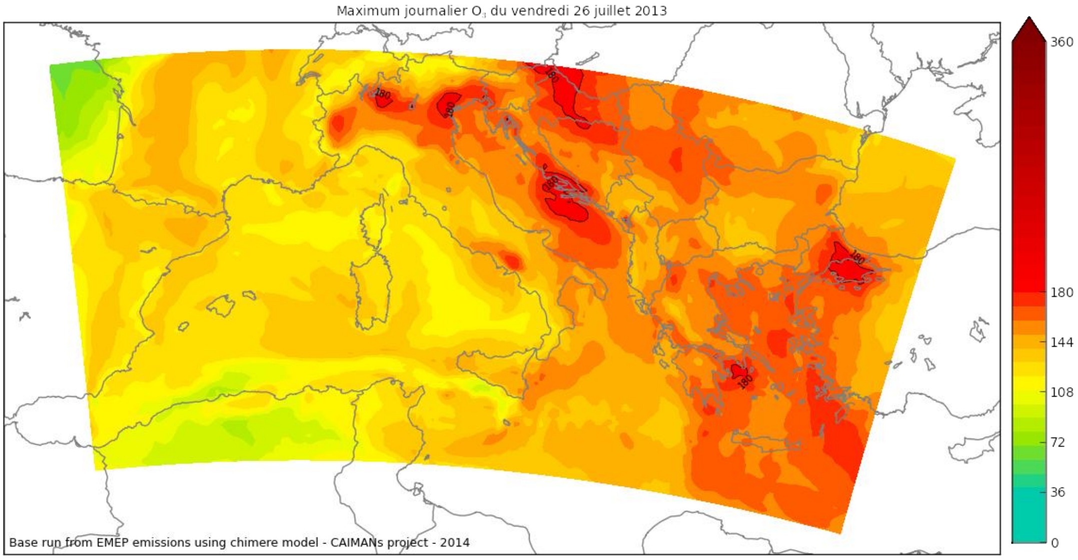


Fig. A.3_1: *Hourly maximum O_3 during July 26th 2013 over the large domain with a spatial resolution of 45km (top) and the CAIMANs domain with a spatial resolution of 15km (down).*

A.3.2 - LNG - Passenger scenario

Application of LNG standard reduction emissions factors for passenger ships leads to a global reduction of NOx emissions over the domain. This reduction mainly impacts the “maritime highway” between Gibraltar and Suez with a heavy traffic. Concentration fields associated to this scenario are reported in the Figure A.3.2_1 for a typical day during summer period. To estimate the impact of this scenario, maps of difference between the “Base scenario” and the “LNG - Passenger scenario” are computed in relation to AQL. An example of the forecasted results is shown in the Figure A.3.2_2 for both NO_2 and O_3 concentration fields.

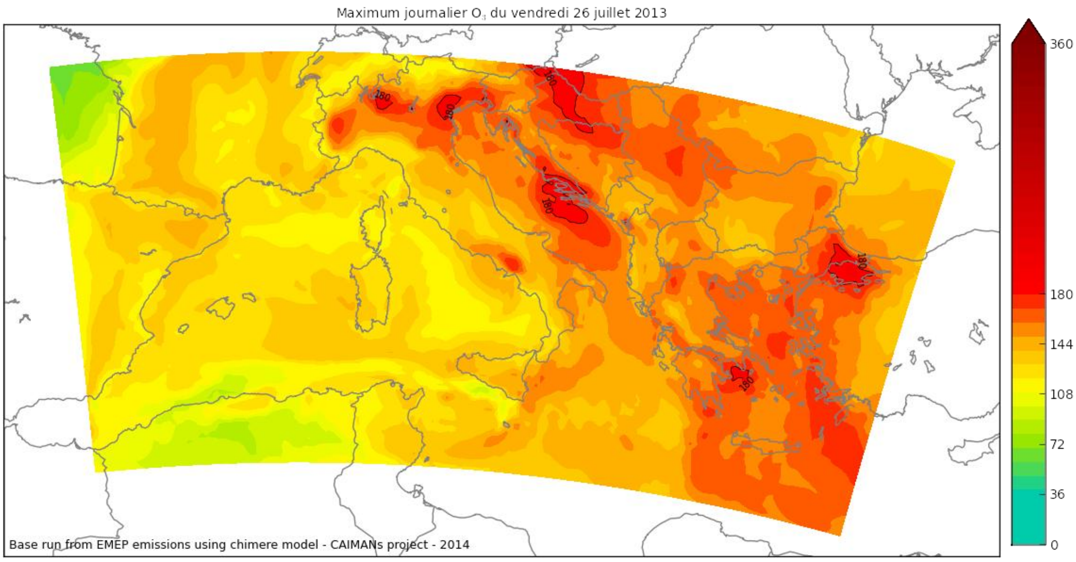


Fig. A.3.2_1: *Hourly maximum O_3 during July 26th 2013 over the CAIMANs domain with passenger ships using LNG as fuel*

Results for O_3 concentration fields show a global decrease over a large part of the domain but also some specific increases. Maximal variations during this typical day are in range of -1.5% and +2%. The comparison with variations of NO_2 concentration fields shows that O_3 increases spatially match with NO_2 decreases. This expected result is due to titration process where O_3 is removed by NO_2 over large emissions area. For this typical day, the forecasted maximal reduction of NO_2 is -2%.

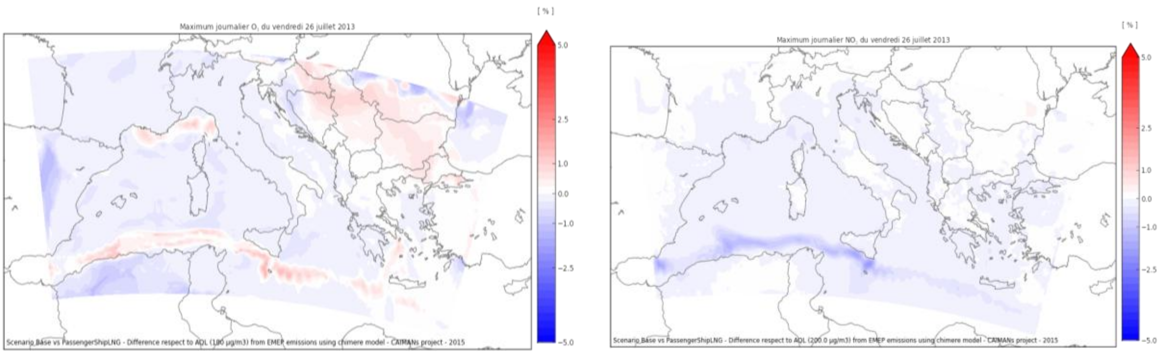


Fig. A.3.2_2: *Difference between "Base scenario" and "LNG - Passenger scenario" in relation to AQL for O_3 (left) and NO_2 (right) during July 26th 2013 over the CAIMANs domain.*

By computing a global average during the summer period, the maximal forecasted reduction for O_3 and NO_2 is very low with -0.1% and -0.4% in relation to AQL respectively.

A.3.3 - LNG - All ships scenario

Application of LNG standard reduction emissions factor for all ships crossing Mediterranean Sea leads to a significant reduction of NOx emissions over the domain. Ozone concentration fields associated to this scenario for a typical day during summer are reported in the Figure A.3.3_1. For this date, a large part of areas displaying an exceedence of AQL in the reference simulation is removed as over the Adriatic Sea or the Aegean Sea.

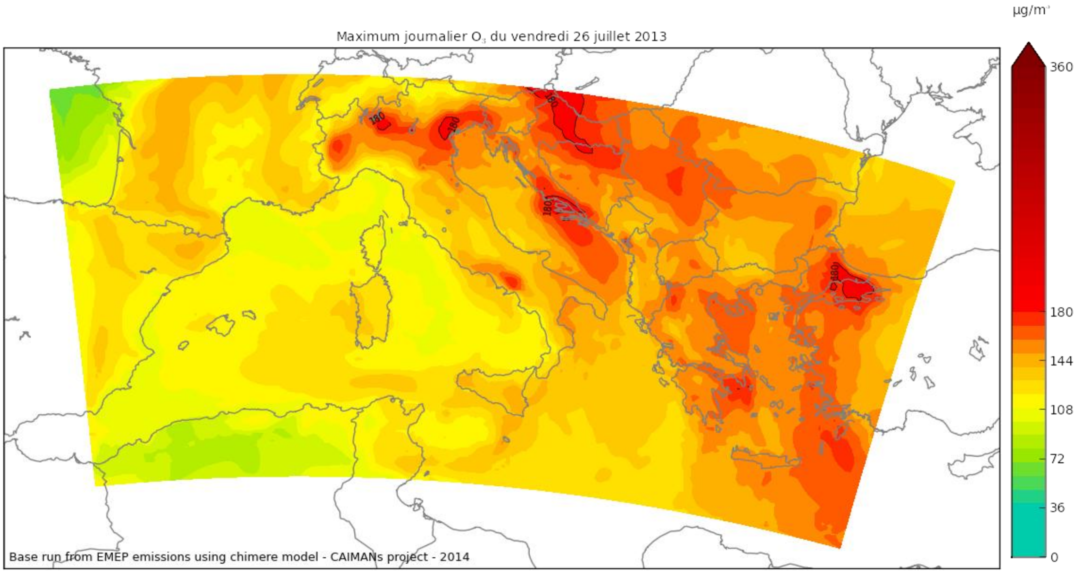


Fig. A.3.3_1: *Hourly maximum O_3 during July 26th 2013 over the CAIMANs domain with all ships using LNG as fuel*

As for the previous scenario, O_3 concentration fields show a global decrease over a large part of the domain and some specific increases during this typical day (Figure A.3.3_2). For this scenario, increases of O_3 concentrations are exactly located over the "maritime highway" where NO_2 concentrations decrease with a maximal reduction of -33% in respect to the AQL. The maximal variations of O_3 concentrations are in range of -15% and +23%. The spatial repartition of these variations shows that increases of O_3 concentrations are located over the sea whereas reductions of concentrations are mainly forecasted close to the land borders.

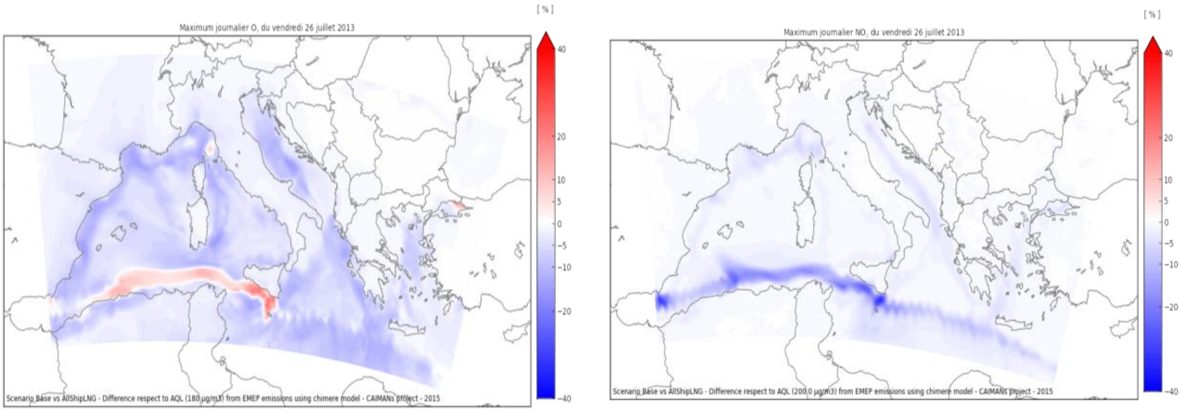


Fig. A.3.3_2: *Difference between “Base scenario” and “LNG - All ships scenario” in relation to AQL for O_3 (left) and NO_2 (right) during July 26th 2013 over the CAIMANs domain.*

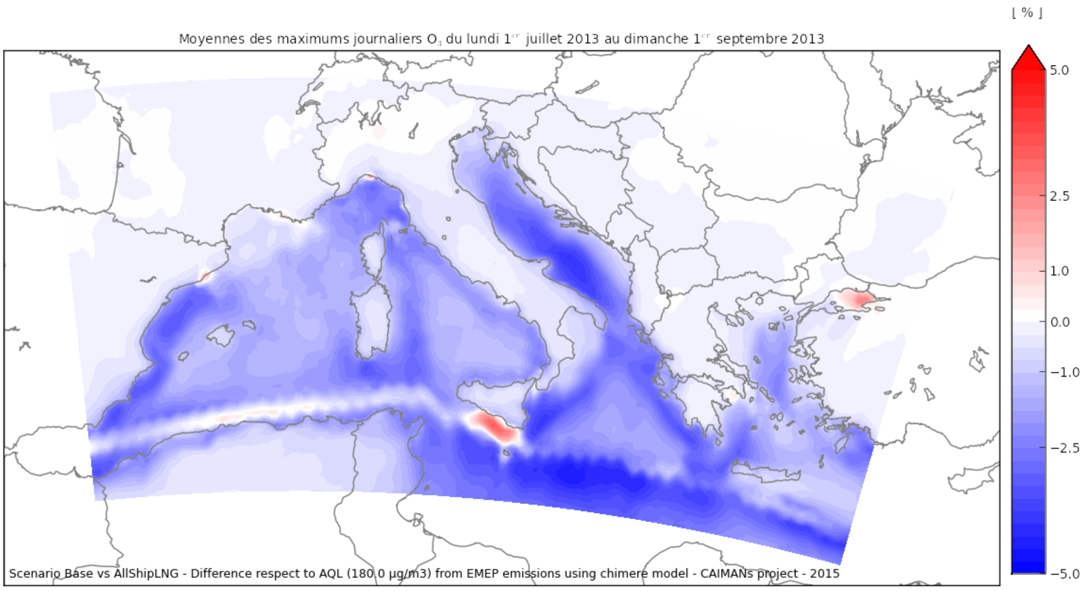


Fig. A.3.3_3: *Difference between “Base scenario” and “LNG - All ships scenario” in relation to AQL for O_3 in average during summer 2013 over the CAIMANs domain.*

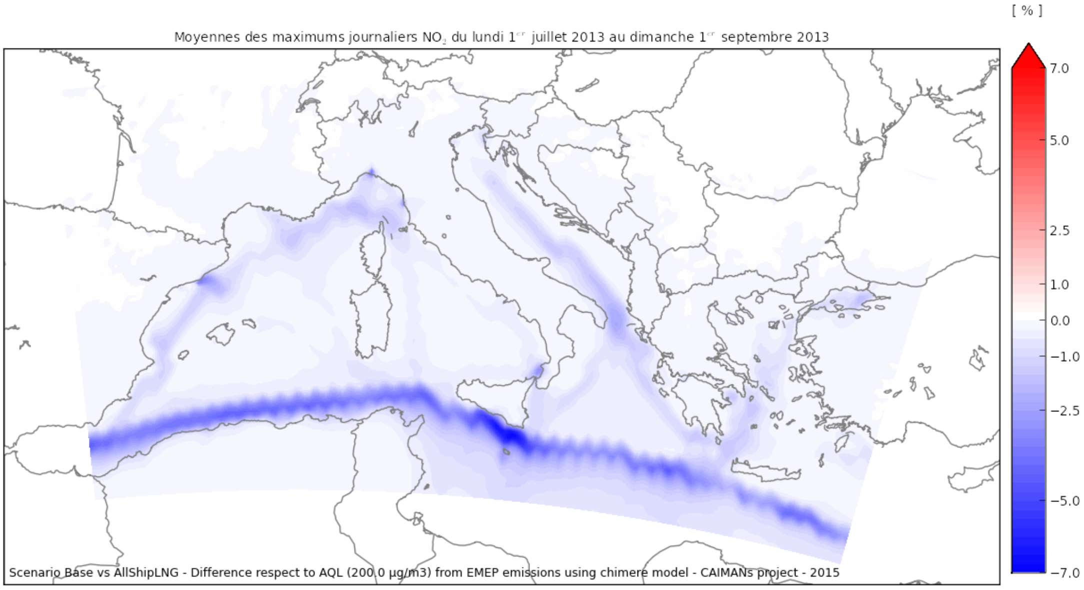


Fig. A.3.3_4: *Difference between "Base scenario" and "LNG - All ships scenario" in relation to AQL for NO_2 in average during summer 2013 over the CAIMANs domain.*

By computing the global average during the summer period and comparing to the "Base scenario", the maximal reductions for O_3 and NO_2 are more significant than for the previous scenario with -4.5% and -7% respectively in relation to AQL.

The forecasted reductions inside each port area, computed as the average at the nine-point grid cell, are given in the Table A.3.3_1. During summer, a global reduction of -3% of O_3 concentrations in relation to AQL is forecasted for Barcelona, which is the area with the maximal reduction. The reductions for Thessaloniki are insignificant, with variations lower than -1%.

Table A.3.3_1: Difference between "Base scenario" and "All ships scenario" in relation to AQL at the nine-point grid cell for each port area during the summer period of 2013.

Pollutants	**O_3**	**NO_2**
Barcelona	- 3 %	- 4 %
Marseille	- 1 %	- 1 %
Genoa	- 2 %	- 3 %
Venice	- 1 %	- 1 %
Thessaloniki	- 0.4 %	- 0.2 %

A.4 Conclusions

The study of the common LNG scenario at the Mediterranean scale using a CTM has provided an evaluation of this mitigation action at the global scale for secondary species as ozone. Using LNG as “clean fuel” leads to a reduction of NOx emissions involved in O_3 production. Due to titration process, O_3 concentrations might increase where NOx emissions decrease as over the “maritime highway” between Gibraltar and Suez or inside the port areas.

At the global scale, significant decreases of NO_2 are forecasted with this mitigation action, mainly over the emissions areas. O_3 concentration reductions are forecasted outside these emissions areas, in relation with chemical and transport processes.
With the common scenario, where only passenger ships will use LNG as fuel, the maximal reduction in O_3 during the summer period will be -4.5% of the maximal hourly concentrations in relation to the limit value, whereas the average reduction during summer is not significant. These results highlight an impact of this mitigation action for the short-term concentrations.

In the second theoretical scenario, where all ships over the Mediterranean Sea will use LNG as fuel, the maximal reduction in O_3 during the summer period will be -19% of the maximal hourly concentrations in relation to the limit value. Also, this action will have an impact over the long-term concentrations as a maximal reduction of -4.5% is expected in average during summer.

Using LNG as fuel for ships over the Mediterranean Sea will allow a reduction of NO_2 concentrations, as shown in the different maps of this study, and an additional emission reduction of primary particles and of gaseous species involved in secondary particles formation too. Finally, this mitigation action will provide an additional benefit for the climate, as O_3 contributes to the Green House Effect.