ECAMED: a Technical Feasibility Study for the Implementation of an Emission Control Area (ECA) in the Mediterranean Sea

synthesis report – January 11th, 2019

Ineris,
French national institute for industrial environment and risks,
with contributions from Cerema, Citepa and Plan Bleu

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

MINISTÈRE
DE LA TRANSITION
ÉCOLOGIQUE
ET SOLIDAIRE

Cerema

CITEPA

Plan Bleu
Construisons ensemble l'avenir de la Méditerranée

INERIS
controlling risks
for sustainable development

Authors:

- Laurence Rouïl (Ineris)
- Catherine Ratsivalaka (Cerema)
- Jean-Marc André (Citepa)
- Nadine Allemand (Citepa)

With the contribution from:

- Florian Couvidat (Ineris)
- Alicia Gressent (Ineris)
- Elsa Réal (Ineris)
- Simone Schucht (Ineris)
- Irving Tapia-Villarreal (Citepa)
- Thamara Vieira-da-Rocha (Citepa)
- Renaud Martin (Cerema)
- Antoine Lafitte (Plan Bleu)

Table of content

Table of Tables

Table of Figures

Acronyms and abbreviations

AIS	Automatic Identification System
BC	Black Carbon
CLRTAP	Convention on Long Range Transboundary Air Pollution
CO_2	Carbon Dioxide
ECA	Emission Control Area
EEA	European Environment Agency
EU-EEZ	European Union Exclusive Economic Zone
HIA	Health Impact Assessment
HFO	Heavy Fuel Oil
IMO	International Maritime Organisation
LNG	Liquefied Natural Gas
MARPOL VI	IMO International Convention for the Prevention of Pollution from Ships, Annex VI (Global fuel-sulphur limit of 0.5% S)
MDO	Marine Distillate Oil
MGO	Marine Gas Oil
MTES	French Ministry for the Ecological and Inclusive Transition
NECA	NO_x Emission Control Area (in this report referred to generally as NECA)
NO_x	Nitrogen Oxides
PM ($PM_{2.5}$)	Particulate Matter (Particulate Matter 2.5µm or smaller)
POPs	Persistent Organic Pollutants
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
SECA	SO_x Emission Control Area (in this report referred to generally as SECA)
SO_x	Sulphur oxides
UNECE	United Nations Economic Commission for Europe
VOLY	Value Of Life Year
VSL	Value of a Statistical Life (or monetary value to reduce risk of a statistical premature death)
WHO	World Health Organisation

1 Executive Summary

To this day, despite the regulations to combat air pollution that have been implemented for several years in many countries, air pollution remains one of the most sensitive and harmful environmental concerns. According to a recent report[1] published by the World health Organisation (WHO) and the Organisation for Economic Co-operation and Development (OECD), in 2010, ambient air pollution was still responsible for about 500 000 premature deaths in Europe. This number represents a decrease by 11 % compared to 2005 and gives an indication of the efficiency of air pollution control policies that have been implemented in Europe for several decades, but it is still too high.

In Europe, one of the most important text that bears air pollution management is the so-called National Emission Ceilings Directive revised in December 2016 (2016/2284/EU). This Directive sets country specific emission reduction commitments to be respected by the European countries in 2020 and 2030. To meet these objectives, emission control strategies must be implemented in various activity sectors: industry, road and off-road transport, residential heating, agriculture … It is worth noting that despite international maritime shipping being an important source of emissions of air pollutants, this sector is not targeted by this legislation. However, it obviously causes important impacts on air quality in port cities, and because of the long-range transport and complex chemistry, emissions from shipping can also degrade inland air quality.

In 2007, an epidemiological study published by (Corbett et al)[2] pointed out that about 60 000 premature deaths occurring near coastlines in Europe, East Asia, and South Asia could be attributable to increase exposure to PM resulting from shipping air pollutants emissions. Despite this, several studies show that shipping emissions in European seas may remain stable from 2000 to 2030 and might be as large as in-land European emissions in 2030.

The French National Reduction Plan of Atmospheric Pollutants Emissions (also called PREPA) adopted in 2017 in the French law[3], envisages the implementation of new low emission zones in the Mediterranean Sea. In that perspective, The French Ministry for the Ecological and Inclusive Transition (MTES) was interested in assessing the feasibility and the potential benefits of the implementation of a NECA (NO_x emissions control area) or/and SECA (SO_x emissions control Area) in the Mediterranean Sea.

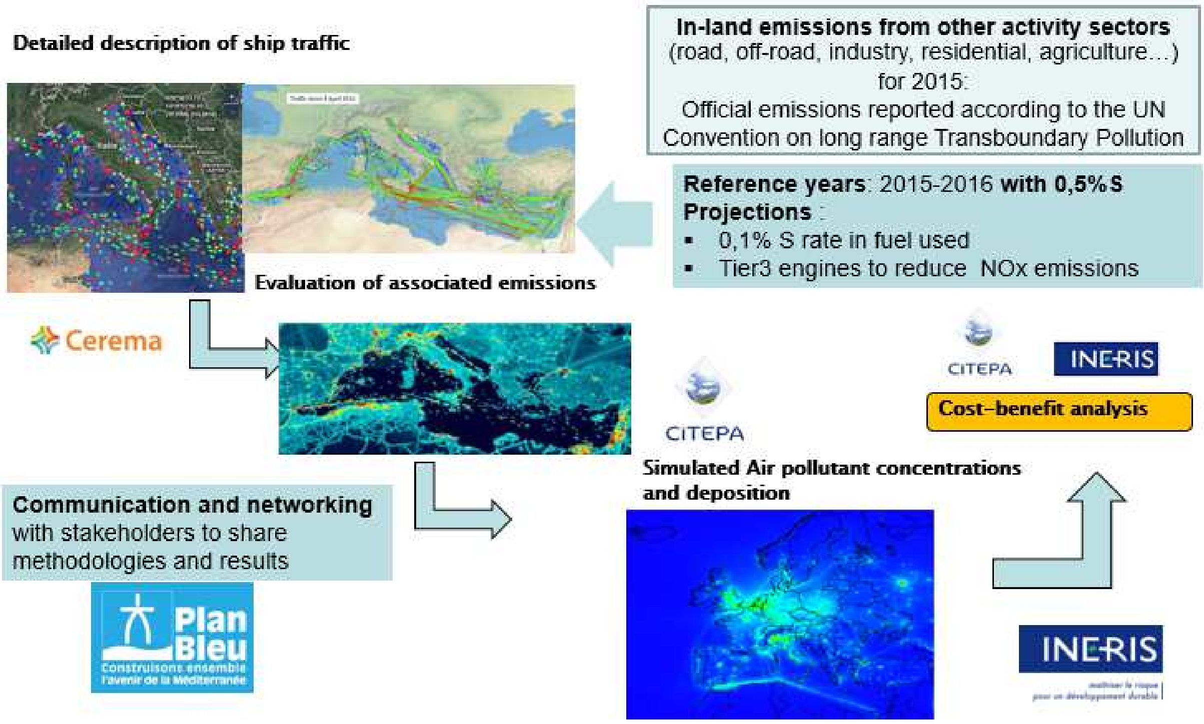
In this context, INERIS, CITEPA, CEREMA and Plan Bleu set-up a partnership project, coordinated by INERIS, to carry out this feasibility study based on scientific information. Its objectives were to assess the cost and the benefits for air quality of the implementation of an Emissions Control Area (ECA) in the Mediterranean Sea. This is the ECAMED project. Emissions and air quality modelling tools have been used to elaborate such a diagnostic, with respect with the project set-up synthesised by the scheme below.

---

[1] WHO Regional Office for Europe, OECD (2015). Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth. Copenhagen: WHO Regional Office for Europe

[2] J J . Corbett , J . J . Winebrake , E. Green , P. Kasibhatla, V . Eyring , and A. Lauer, Mortality from shipping emissions: a global assessment, *Environ. Sci. Technol.* **2007,** *41,* 8512–8518

[3] Arrêté du 10 mai 2017 établissant le Plan national de réduction des polluants atmosphériques



The purpose of the study is to document and quantify benefits on air quality in the Mediterranean countries associated with emission reduction scenarios. These scenarios are characterized by the following reductions in emission factors associated to maritime shipping that could be achieved in the future:

- Reduction of the Sulphur content in fuels used from 0.5% (this rate will be mandatory according to the MARPOL regulation in 2020) to 0.1%. This will reduce SO_x and PM emissions from ships, and this is the definition of the SECA scenario;
- Reduction of NO_x emissions by equipping a certain amount (50% or 100%) of engines with SCR or other techniques (to comply with TIER III cleaner technologies). This is the NECA scenario.

These assumptions were applied to the shipping activity data established for the current years (2015-2016). **No projection about future traffic activity, content of the fleet, or engine renewal rates has been established.**

Therefore, **the net impact of emission reduction strategies on air pollution** and its harmful effects is assessed in this cost-benefits analysis, without the influence of the future evolution of shipping activity and the influence of meteorology.

The first step was to elaborate a detailed description maritime traffic in the Mediterranean Sea, with the inventory of shipping routes, and for each vessel spotted, its location with a high temporal frequency (15 min), and its characteristics (ship type and age, engine type and age, motor power, fuel used, engine load factor, navigation phase). Databases gathering the information retrieved from the Automatic Identification System (AIS) crossed with the Lloyd's register FAirplay allowed us to re-build with a very high resolution about 85% of the trajectories of high tonnage vessels cruising in the Mediterranean Sea for the years 2015 and 2016. Note that those years where targeted in the project because most updated and recent data about maritime traffic was available at the time of the project.

Air pollutant emission factors are associated with each vessel/engines/fuel used/loading factors/navigation phase and the second step was consisting in coupling shipping activity data with emission factors to estimate air pollutant emissions associated with shipping traffic built-up for the years 2015 and 2016. By this way a reference shipping emission inventory was elaborated for 2015 and 2016 (called REF_1516), which is representative of the current situation. Applying emission factors representative of the emission control scenarios targeted in the project allowed to create emission inventories for each of those scenarios. Five scenarios were quantified:

1- The IMO Global Sulphur Cap 2020 named REF_MGO will reduce the emissions (compared to REF_1516) as described below:
    - SO_x by 80%
    - Paticulate Matter by 72%
    - Black Carbon by 30%
    - NO_x by 5%
2- The implementation of a SECA will reduce the emissions (compared to REF_1516) as follows:
    - SO_x by 95%
    - Paticulate Matter by 80%
    - Black Carbon by 51%
    - NO_x by 5%
3- The implementation of a NECA will reduce the emissions (compared to REF_1516) of NO_x:
    - by 38% when 50% of ships will be TIER III
    - by 77% when 100% of ships will be TIER III
4- The combination of SECA and NECA reduction assuming:
    - 100% of vessels were equipped with TIER III engines (SN100)
    - 50% of vessels were equipped with TIER III engines (SN50)

To simulate the impact of emission reduction scenarios on air quality (which means on ambient air pollutant concentrations) a chemistry-transport model (CTM) must be run. CTMs are complex three-dimensional numerical models which resolve dynamics, chemistry and loss processes (deposition) that drive air pollutant dispersion and transformation in ambient air. INERIS develops in collaboration with the National Research Centre (CNRS) the CHIMERE air quality model for more than 15 years.

CHIMERE was run by INERIS to simulate all scenarios envisaged in ECAMED and assess their impact compared to the current situation (2015) or to the Global sulphur Cap 2020. Legislation in 2020 (use of fuel with 0.5% sulphur content) will reduce significantly sulphur dioxide and in some areas PM ambient concentrations in the Mediterranean countries. But the simulation shows that implementation of a SECA/NECA (with 100% of vessels equipped with clean engines) will bring further significant improvements with a reduction by up to $1 \mu g/m^3$ (11%) of annual average of fine particulate matter concentrations ($PM_{2.5}$) compared to the 2020 legislation, and reduction of annual average of nitrogen dioxide (NO_2) by up to $15 \mu g/m^3$ (70%) compared to 2020 legislation.

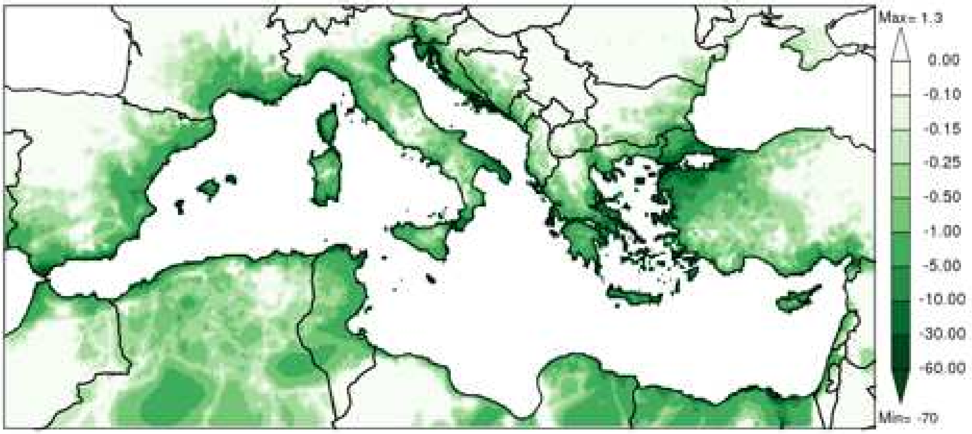


Figure 1 Relative NO_2 annual mean concentration **differences** between SN100 and REF_MGO scenarios (in %). Focus on land territories

Nitrogen and sulphur deposition in response to emission reduction scenarios has been simulated by CHIMERE as well. Sulfur and nitrogen deposition has harmful effects on vegetation and ecosystems such as acidification and eutrophication, which can result in loss of biodiversity. Eutrophying deposition fluxes are directly correlated to nitrogen oxides emissions, and the simulations show that on the environmental point of view, implementation of an ECA leads to benefits, with nitrogen deposition on coastal ecosystems reduced by up to 40% compared to 2020 legislation. Differences of deposition between both situations is displayed on the map below.

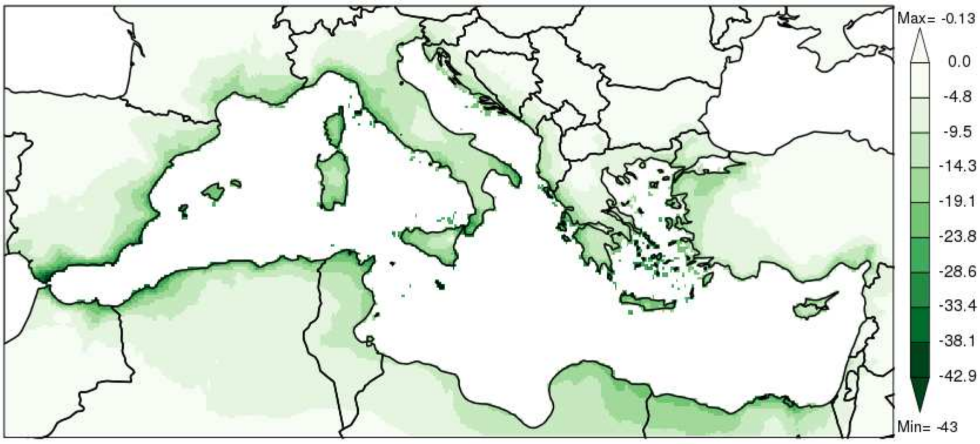


Figure 2 Relative nitrogen annual **differences** between SN100 and REF_MGO scenarios (in %). Focus on land territories

Reduction of air pollutant concentrations are translated in terms of health impact using concentrations-response functions linking levels of pollutant exposure to specific health impacts (also called "end-points" in terms of mortality and morbidity), as well as monetary indicators and values associated with those end-points. The methodology implemented to perform the health impact assessment of the scenario studied was the one adopted by the Europeans Commission for the setting air quality regulations. The impacts of the scenarios on each mortality and morbidity end-point were assessed by the methodology leading to the kind of result presented below: implementation of a SECA/NECA brings additional benefits with about 40% additional avoided premature deaths compared to the impact of the 2020 legislation. Algeria, Egypt, Italy, Greece, Turkey are the main beneficiaries.

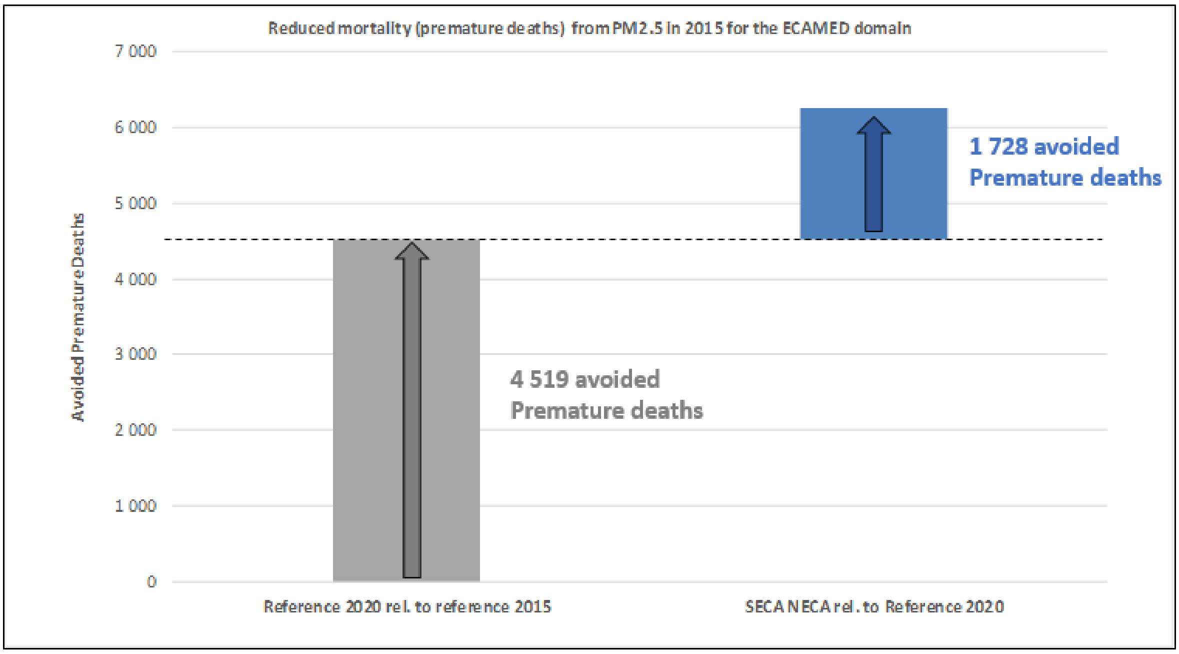


Figure 3 Reduction in $PM_{2.5}$ mortality (premature deaths) – overall ECAMED domain

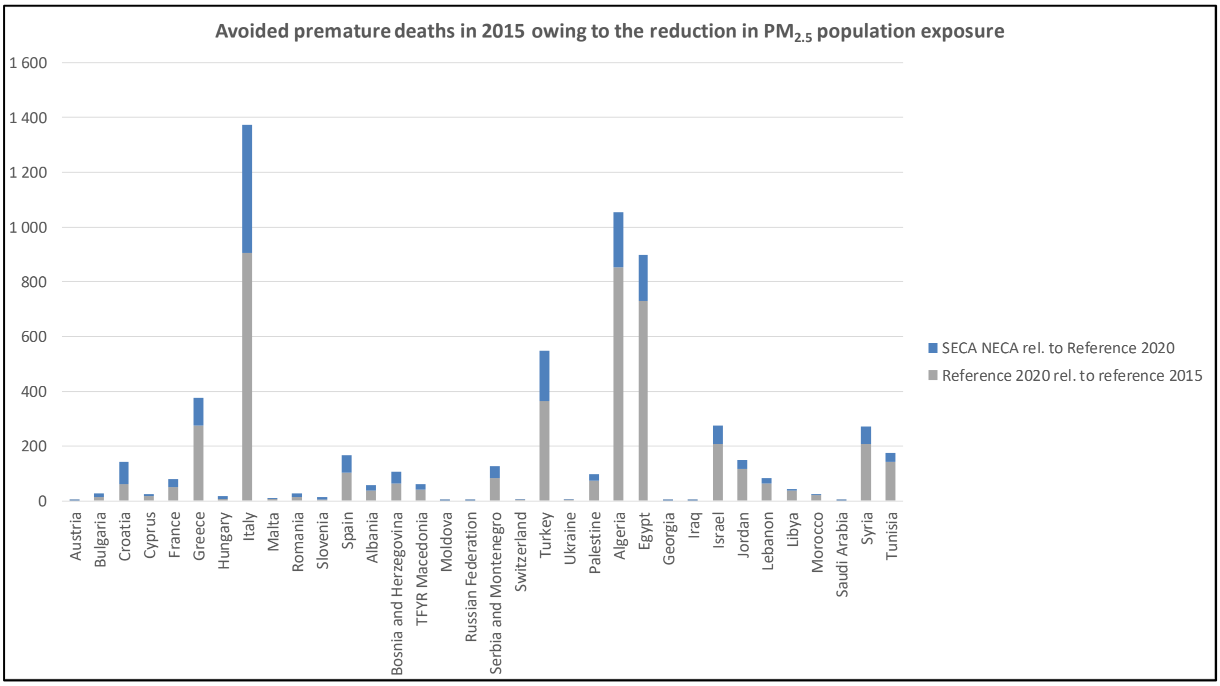


Figure 4 Reduction in $PM_{2.5}$ mortality (premature deaths) – ECAMED domain per country

Figure 5 illustrates the monetized benefits (health impact associate with monetary value) results aggregated over all health end-points and the entire ECAMED domain. High and low estimates are proposed: low estimate uses the reduction of life expectancy as mortality end-point, while high estimate uses the number of premature death as mortality indicator. The conclusions are robust for both indicators:

- Additional benefits attributed to the implementation of a SECA/NECA are very significant,
- In monetary terms, they are of the same order as the benefits expected from the implementation of the Global Sulphur Cap in 2020.
-

Such encouraging results can be explained by several reasons:

- Additional reduction of $PM_{2.5}$ exposure due not only to SO_x emissions reductions but also NO_X emissions reductions, since NO_X are precursors of PM formation as well,
- Additional benefits due to a reduction in exposure to NO_2 and to ozone.

These results highlight the essential need to develop combined SECA and NECA strategies to maximise achievable health benefits.

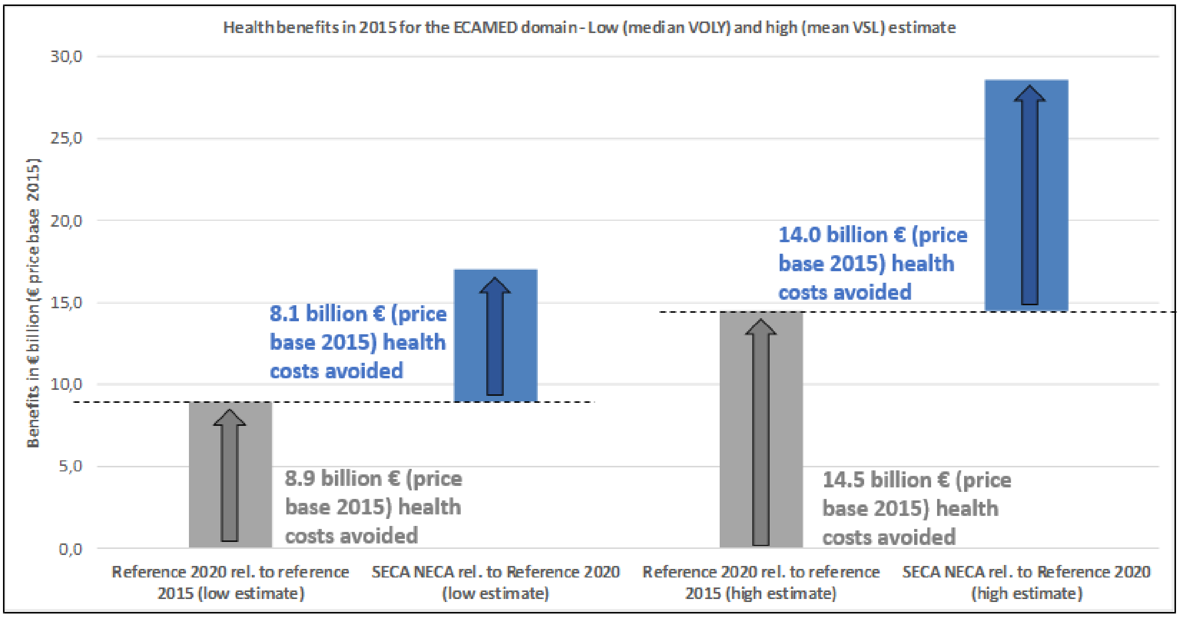


Figure 5 Aggregated Monetised benefits associated with the implementation of a SECA/NECA in the Mediterranean Sea (Low and High values estimates)

Those figures must be put in perspective with the cost of the scenarios (implementation of a SECA/NECA) to estimate objectively net benefices of the emission reduction measures. This work has been performed thanks to an in-depth analysis of the costs associated to changes in fuel used by the shipping sector (towards 0.1% sulphur content fuel) on one hand, and transition to cleaner engines which limit NO_x emissions with Selective Catalytic Reduction technologies on the other hand. For each scenario, a sensitivity study was necessary to account for the uncertainties in this evaluation.

The conclusions of this cost study are illustrated by the histogram graph below, which also includes the monetarized health benefits (on the right) for comparison. For costs (three first couple of bars) as for benefits, low and high estimates are given.

We conclude that in the worst-case health benefits of implementing a SECA/NECA in the Mediterranean Sea are 3 times higher than the costs, demonstrating the relevance of this strategy for protecting health of citizens in the Mediterranean countries.

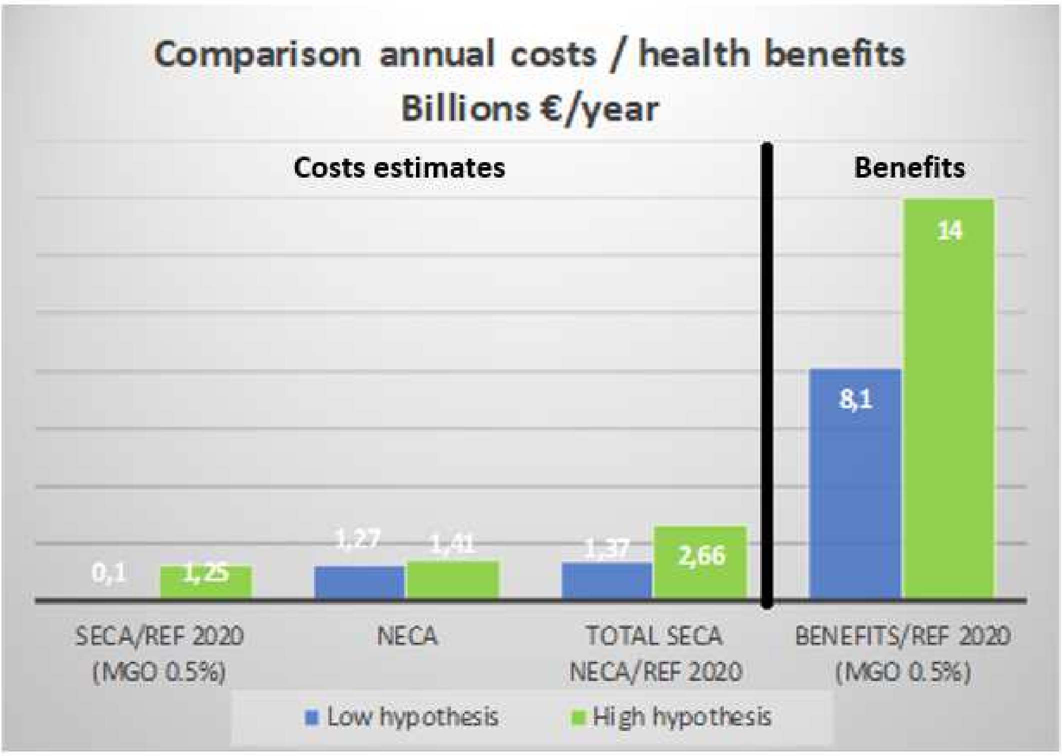


Figure 6 Final results of the cost-benefits analysis

2 Introduction and context

2.1 Background

To this day, despite the regulations to combat air pollution that have been implemented for several years in many countries, air pollution remains one of the most sensitive and harmful environmental concerns. According to a recent report[4] published by the World health Organisation (WHO) and the Organisation for Economic Co-operation and Development (OECD), in 2010, ambient air pollution was still responsible for about 500 000 premature deaths in Europe. This number represents a decrease by 11 % compared to 2005 and gives an indication of the efficiency of air pollution control policies that have been implemented in Europe for several decades, but it is still too high.

Harmful, air pollution effects on health are driven by a number of targeted pollutants: Particulate matter (PM_{10} and $PM_{2.5}$ for particles with diameter lower than 10 and 2.5 microns, respectively), Ozone (O_3), nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2). Ecosystems are impacted by air pollution as well, and in particular, by acidifying and eutrofying effects of Sulphur and nitrogen compounds deposition, and by ground level ozone which puts a constraint on vegetation growth.

In Europe, air quality is monitored and regulated by the air quality Directives (2004/107/EC and 2008/50/EC) and controlled by the so-called National Emission Ceilings Directive revised in December 2016 (2016/2284/EU). This Directive sets country specific emission reduction commitments to be respected by the European countries in 2020 and 2030. To meet these objectives, emission control strategies must be implemented in various activity sectors: industry, road and off-road transport, residential heating, agriculture … It is worth noting that despite international maritime shipping being an important source of emissions of air pollutants, this sector is not targeted by the above cited legislation. This obviously causes important impacts on air quality in port cities, but because of the long-range transport and complex chemistry, emissions from shipping can also degrade inland air quality.

Moving approximately 80% of world's goods, international shipping is an active and growing economic sector. In 2007, an epidemiological study published by (Corbett, 2007) pointed out that about 60 000 premature deaths occurring near coastlines in Europe, East Asia, and South Asia could be attributable to to increase exposure to PM resulting from shipping air pollutants emissions. Despite this, several studies show that shipping emissions in European seas may remain stable from 2000 to 2030 and might be as large as in-land EU emissions in 2030[5] (Figure 7).

In 1997, the IMO Marine Pollution Convention (MARPOL 73/78) adopted the Annex VI which sets out various emission limit values for atmospheric pollutants emitted by shipping activities and forbids releases of substances likely to weaken the ozone layer. Appendix 3 of Annex VI of the MARPOL Convention gives the possibility to define Emission Control Areas (ECA) where Sulphur oxides (SO_x) and nitrogen oxides (NO_x) emitted by maritime traffic should be reduced.

---

[4] WHO Regional Office for Europe, OECD (2015). Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth. Copenhagen: WHO Regional Office for Europe

[5] EEA technical report n°4/2013 : The impact of international shipping on European air quality and climate forcing (https://www.eea.europa.eu/publications/the-impact-of-international-shipping/file)

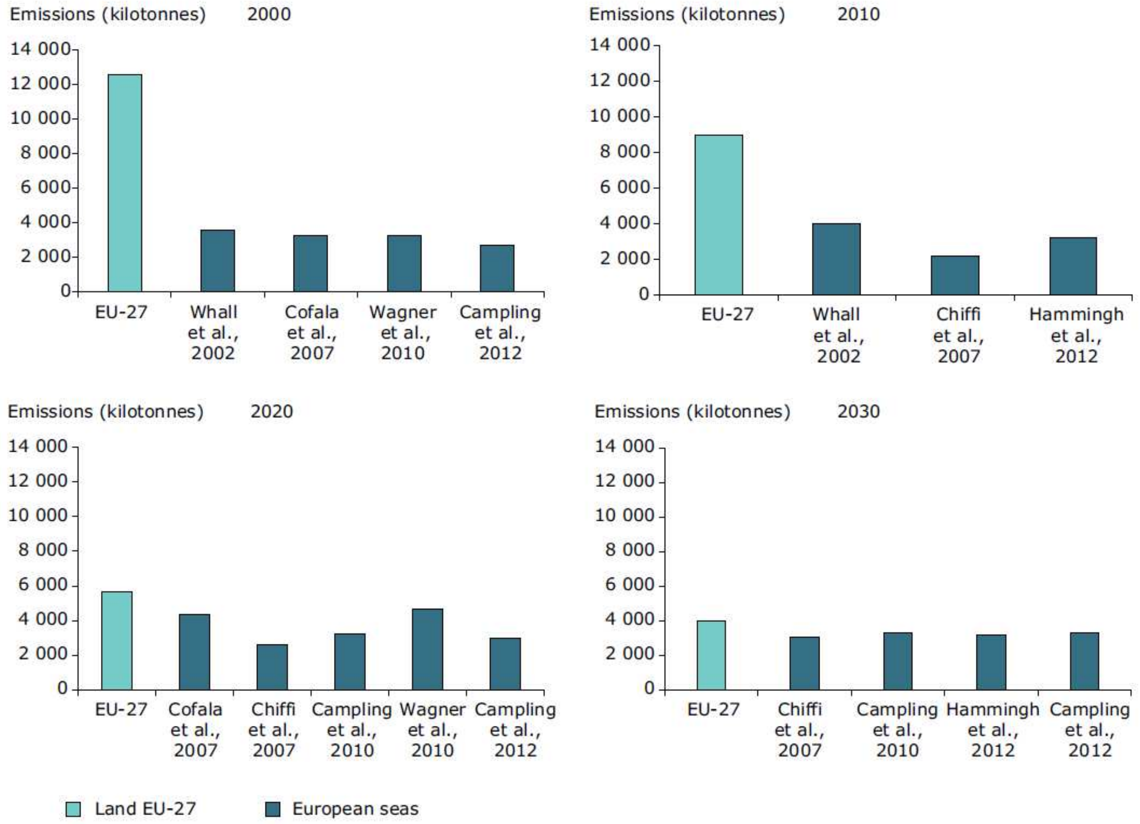


Figure 7 Comparison of estimations and projections in 2000, 2010, 2020 and 2030 between EU in-land and shipping NO_x emissions in European areas (Source: EEA 2013)

According to this text, SO_x Emissions Control Areas (SOx-ECAs or SECA) were established in the Baltic Sea, the North Sea and the English Channel, setting a limit on the sulphur content in marine fuels of no more than 0.10 percent as of 1/1/2015.

In October 2016, the IMO decided to lower the global sulphur limit in marine fuels to 0.50 percent by 2020 for ships sailing outside the ECAs, and to designate the Baltic Sea, the North Sea and the English Channel as NO_x –Emission Control Areas (NOx-ECAs or NECA) as of 2021, introducing strict (Tier III) NO_x emission standards for new ships.

The French National Reduction Plan of Atmospheric Pollutants Emissions (also called PREPA) adopted in 2017 in the French law[6], envisages the implementation of new low emission zones in the Mediterranean Sea. In that perspective, The French Ministry for the Ecological and Inclusive Transition (MTES) was interested in assessing the feasibility and the potential benefits of the implementation of a NECA or/and SECA in the Mediterranean Sea.

In this context, INERIS, CITEPA, CEREMA and Plan Bleu set-up a partnership project, coordinated by INERIS, to carry out this feasibility study based on scientific information. Its objectives were to assess the cost and the benefits for air quality of the implementation of an Emissions Control Area in the Mediterranean Sea. Emissions and air quality modelling tools have been used to elaborate such a diagnostic. They are presented in this report, together with the results and conclusions from the feasibility study.

---

[6] Arrêté du 10 mai 2017 établissant le Plan national de réduction des polluants atmosphériques

2.2 ECAMED Project Set-up

The project assembled the skills and competences from 4 organisations with long-standing experience in the field of air pollution and/or maritime issues:

- INERIS (Institut national de l'Environnement Industriel et des Risques) is the project coordinator. INERIS has a long experience in the field of air quality monitoring, modelling and management. It has supported the Ministry in charge of the Environment in the definition and implementation of related regulations for more than 20 years. Within this project, INERIS performed all the modelling runs and the benefits analysis.
- CITEPA (Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique) is mandated by the Ministry in charge of the Environment for building-up official and regulatory national emission inventories for greenhouse gases and atmospheric pollutants. In the project, CITEPA was responsible for the emissions and projections estimations and for the cost analysis.
- CEREMA (Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement) is a public Institute focused on infrastrutures and mobility, sustainable territories and cities. In the project, CEREMA was responsible for the analysis of activity data in the shipping sector throughout the Mediterranean Sea and provided necessary and consolidated datasets to describe emissions.
- Plan Bleu is one of the Regional Activity Centres of the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP), put in place by France since 1977. Its program of work is approved by the Contracting parties to the Barcelona Convention. In the project, Plan Bleu was responsible for the communication part.

The various steps of the project can be simply illustrated by the Figure 8. Five steps are identified:

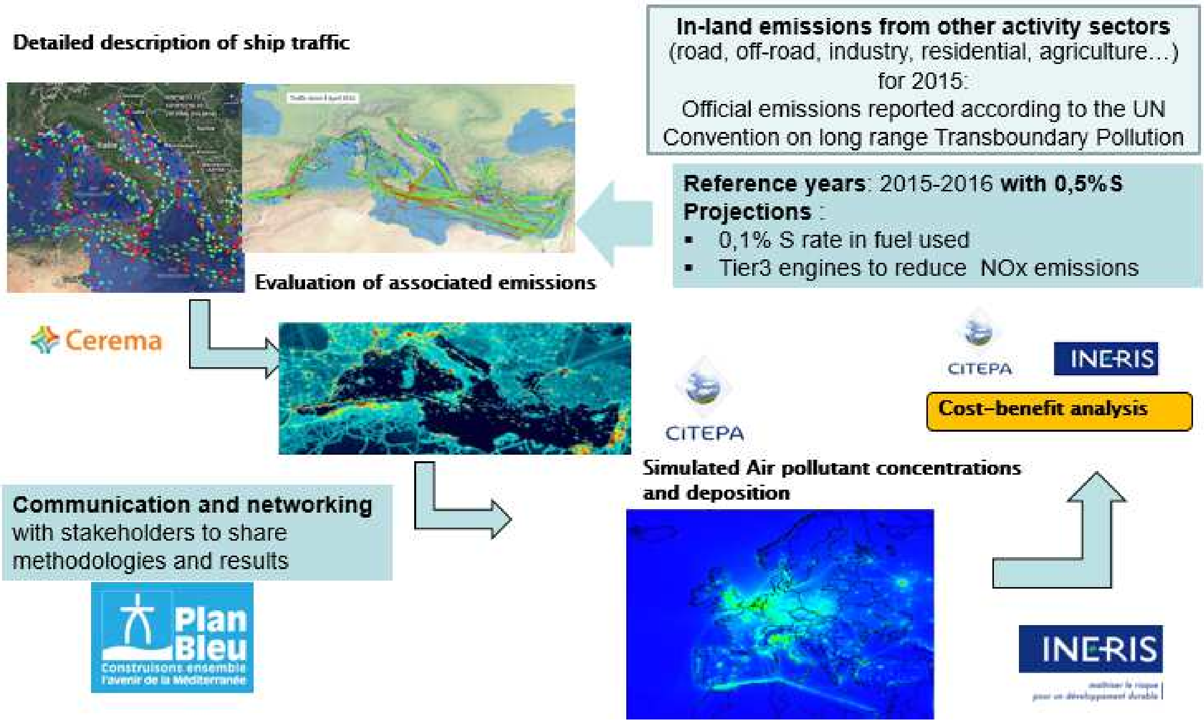
1. Detailed description of maritime shipping traffic in the Mediterranean Sea (CEREMA)
2. Calculation of current emissions and scenarios (CITEPA)
3. Simulation of air pollutant concentrations and deposition (INERIS)
4. Cost-benefits analysis (CITEPA and INERIS)
5. Communication and networking with stakeholders (Plan Bleu)

The methodology applied for each technical step will be described in detail in the following sections. The purpose of the study is to document and quantify benefits on air quality in the Mediterranean countries associated with emission reduction scenarios. These scenarios are characterized by the following reductions in emission factors associated to maritime shipping that could be achieved in the future:

- Reduction of the Sulphur content in fuels used from 0.5% (this rate will be mandatory according to the MARPOL regulation in 2020) to 0.1%. This will reduce SO_x and PM emissions from ships;
- Reduction of NO_x emissions by equipping a certain amount (50% or 100%) of engines with SCR or other techniques (to comply with TIER III cleaner technologies).

These assumptions are applied to the shipping activity data established for the current years (2015-2016) by the CEREMA. **No projection about future traffic activity, content of the fleet, or engine renewal rates has been established**. Therefore, **the net impact of**

emission reduction strategies on air pollution and its harmful effects is assessed in this cost-benefits analysis, taking out the influence of the future evolution of shipping activity and the influence of meteorology.



In-land emissions from other activity sectors
(road, off-road, industry, residential, agriculture…)
for 2015:
Official emissions reported according to the UN Convention on long range Transboundary Pollution

Reference years: 2015-2016 **with 0,5% S**
Projections :
- 0,1% S rate in fuel used
- Tier3 engines to reduce NOx emissions

Communication and networking with stakeholders to share methodologies and results

Figure 8 ECAMED project set-up

The targeted domain is illustrated by Figure 9 below. It has been defined to encompass the entire Mediterranean Sea which is the target of the study. For modelling purposes, the domain should be a bit larger, to account for the influence of in-land sources that could impact the simulation and boundary numerical effects.

Figure 9 ECAMED geographical scope

Terrestrial emissions (for the years 2015-2016) are taken into account in the simulations. They are issued from official emission inventories reported by the neighbouring countries in the framework of the Protocols of the Convention on Long Range Transboundary Air Pollution from the United Nations Economic Commission for Europe.

2.3 Structure of the report

The next 4 sections describe in detail the steps 1 to 4 previously mentioned. Methodologies and assumptions are described and a selection of results presented for each part. Complementary information is available in the annexes.

The final section is the conclusion of the ECAMED study and provides some recommendations for next steps.

3 Detailed description of maritime shipping traffic in the Mediterranean Sea

3.1 Input data

For the calculation of sulphur oxide, PM (including PM_{10} and $PM_{2.5}$)[7] and nitrogen oxide exhaust emissions from ships due to traffic in the Mediterranean Sea, the following data for each vessel is requested:

1. Age of the ship / engine
2. Ship type (Liquid Bulk Ship, Dry Bulk Carrier, Container, General Cargo, Ro Ro Cargo, Passenger, Fishing, Other, Tugs)
3. Engine type (slow-, medium-, high-speed diesel, gas turbine, steam turbine)
4. Rated motor power (kW)
5. Fuel used (bunker fuel oil, marine diesel oil / marine gas oil, gasoline)
6. Use of main engine or auxiliary engine
7. Engine load factor (%)
8. Vessel navigation phase: cruising, manoeuvring, at berth or anchorage
9. Vessel position (latitude and longitude) as a function of time (date and time)
10. Instantaneous speed (km/h) as a function of time (date and time)

The first five data categories are extracted from the Fairplay database, the last two from AIS data and the others calculated (use of engine, load factor, navigation phase).

The Fairplay database of IHS Markit contains the database of all ships sailing around the world with an IMO number (for International Maritime Organization). This is a unique number that identifies a vessel. Associated with the hull, it is invariant no matter the changes of owner, flag or name of the ship. Commercial vessels of more than 100 gross registered tons do have an IMO number by construction.

The Automatic Identification System (AIS) provides automatic updates of the vessel locations and its instantaneous speeds at regular intervals. The ships are identified by their MMSI number in the AIS database along with the ship's name and the IMO number if it exists.

We used the AIS messages received by the terrestrial AIS network and provided by the European Maritime Safety Agency (EMSA) for the years 2015 and 2016. To complete the EMSA dataset, we bought to Orbcomm AIS data collected by satellite to get the coverage of the south-east Mediterranean Sea.

3.2 Methodology

Describing dynamically shipping emissions requires to know for each ship in 15-minute steps:

- its position and its instantaneous speed,
- its navigation phase,
- the load factor of the main engine and auxiliary engines.

Compilation of these sets of information requires data management of more than 1 billion archived AIS messages. To process this large amount of data (around 500MB and 1GB per day), the work has been divided in 8 zones covering the Mediterranean Sea (Figure 10).

---

[7] Particles with diameter lower than 10 and 2.5 µm respectively

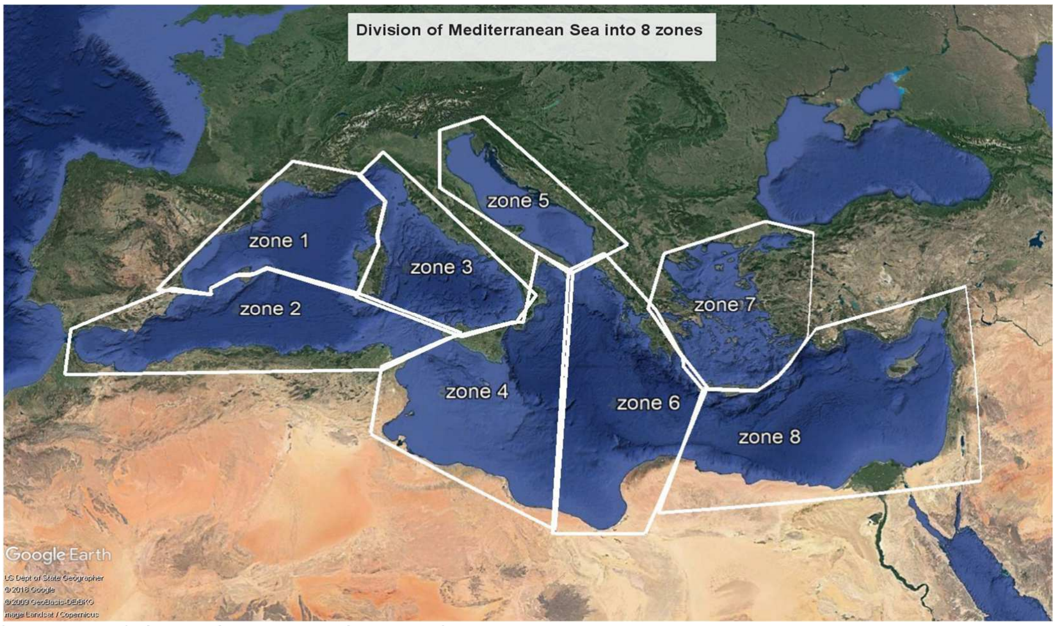


Figure 10 Division of the Mediterranean Sea into 8 zones

The navigation phase is defined by the instantaneous speed, as:

- Either a cruising phase if the speed is more than 4 nm per hour (knots)
- Or a manoeuvring phase if the speed is between 1 et 4 nm per hour (knots)
- Or a berth/anchor phase if the speed is less than 1 nm per hour (knot)

If there is a gap larger than 2 hours between two positions of the same vessel, it is assumed that:

- the vessel may have stopped at the port (or anchorage) or may leave the port (or anchorage) if the two points are located within less than 1NM and recorded speeds are lower than 0.5 knot;
- it can be due to a poor geographical coverage of the data: in this case, we interpolate between the two points if they keep the same heading at + - 45;
- the vessel may go out of the study area and then come back: this assumption has not been implemented (concerns less than 20 cases in 2015, negligible impact).

The load factor of the engines (ratio between the power needed and the maximum or nominal power) depends mainly on the conditions of navigation (speed of the ship, weather conditions, etc.), the loading (draft and attitude), the condition of the hull (state of cleanliness, in particular) and the type of operation of the ship, especially the part of the power not used for propulsion (electricity, hydraulic...).

This power can be provided by the main engine (in case of auxiliaries coupled to propulsion) or by auxiliary engines (generators, hydraulic units...).

The formula used to determine the load factor for propulsion is the same one as in the third IMO study on greenhouse gases (2014) presented to MEPC 67 / INF.3:

$$P_t = \frac{P_{ref}\left(\frac{t_t}{t_{ref}}\right)^{\left(\frac{2}{3}\right)}\left(\frac{V_t}{V_{ref}}\right)^{n}}{\eta_w \eta_f} \tag{1}$$

- Pt, Vt and tt are respectively the instantaneous power, the speed and the draft at time t, Pref is the reference power at the reference speed Vref and the reference's draft, tref (all three provided by Fairplay). If the draft at time t is not given, we propose to take a load corresponding to 70% of the reference draft (or maximum draft if not given) given by the Fairplay base.
- n is an index that represents the relationship between power and speed. As for the IMO study, we took n = 3. This value is generally used for displacement hulls.
- ŋw represents the influence of the weather conditions (wave and wind) on the speed and ŋf represents the forward resistance due to the state of the hull. We assume them equal to 1.

To calculate the load factor, AIS data and ships characteristics from the Fairplay database should be crossed. This is quite easy when the IMO number is known. When it is not the case, we used the Maritime Mobile Service Identity (MMSI), with ship's name and call sign instead.

Approximately 88.06% of the vessels recorded in the AIS database are registered in the Fairplay database. The remaining 11.98% are small vessels under 24 m.

Using the Fairplay database we have been able to retrieve relevant information for:

- 99 % of main engines
- 55 % of auxiliary engines
- 95 % of reference's speeds
- no indication for boilers

The vessels, for which no information on main engines and/or reference's speed is documented have not been taken into account.

To estimate the power used by auxiliary engine, we assumed that:

- for cruise, ROPax and Ferries, the load factor is about 55 % of maximum power of auxiliary engines whatever the navigation phase;
- for other vessels, load factor is about 60 % when manoevring, 40 % at berth or anchored and 30 % in cruising phase;
- If the auxiliary engines value does not exist, the methodology applied in the third IMO study on greenhouse gases (2014) has been used. The estimation of the power used by the auxiliary engines and boilers depends on ship's type (bulk, chemical tanker, cruise, oil tanker, general cargo, container, refrigerated cargo), ship's length, ship's weight and navigation phase.

For the boilers, the same methodology as the one developed in the Third IMO study on greenhouse gases (2014)[8] has been used.

3.3 Results

The Table 1 below summarises the results achieved in terms of percentage of data we managed to consolidate with the methodology described above. They are given for each geographical zone of the domain and as a total throughout the domain.

Table 1 Compilation of information gathered and built-up to describe the maritime traffic in the Mediterranean Sea

	Zone 1	Zone 2	Zone3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Total
Percentage of IMO tracked / all ships	57,85	74,16	64,73	70,34	50,73	87,76	85,10	93,75	**73,05**
Percentage of trajectories consolidated/IMO ships	83,16	87,16	84,75	85,97	87,02	83,13	85,30	87,14	**85,46**
Percentage of No IMO ships/all ships	42,15	25,84	35,27	29,66	49,27	12,24	14,90	6,25	**26,94**

The first row gives the percentages of ships that have been correctly characterized for calculation of emissions. Globally, all ships referred by the IMO have been documented: the last row gives the percentage of Non-IMO ships in data reported which corresponds to the difference. As an average over the domain, 73% of ships have been documented. This percentage is the lowest in zone 1 (along the French and Spanish coast) and in zone 5 (Adriatic Sea) where more pleasure yachts and small vessels (with tonnage lower than 100 GT) cruise compared to the other zones. It is expected that air emissions from those categories are rather limited (they do not use heavy fuel oil) and that they can be negligible in the feasibility study.

We also learn from these figures that almost ¾ of daily traffic in the Mediterranean Sea come from cargos, tankers and passenger vessels with tonnage above 100UMS.

For these large ships, the second row gives the percentage of trajectories we have managed to describe or to rebuild (Figure 11 and Figure 12).

---

[8] http://www.iadc.org/wp-content/uploads/2014/02/MEPC-67-6-INF3-2014-Final-Report-complete.pdf

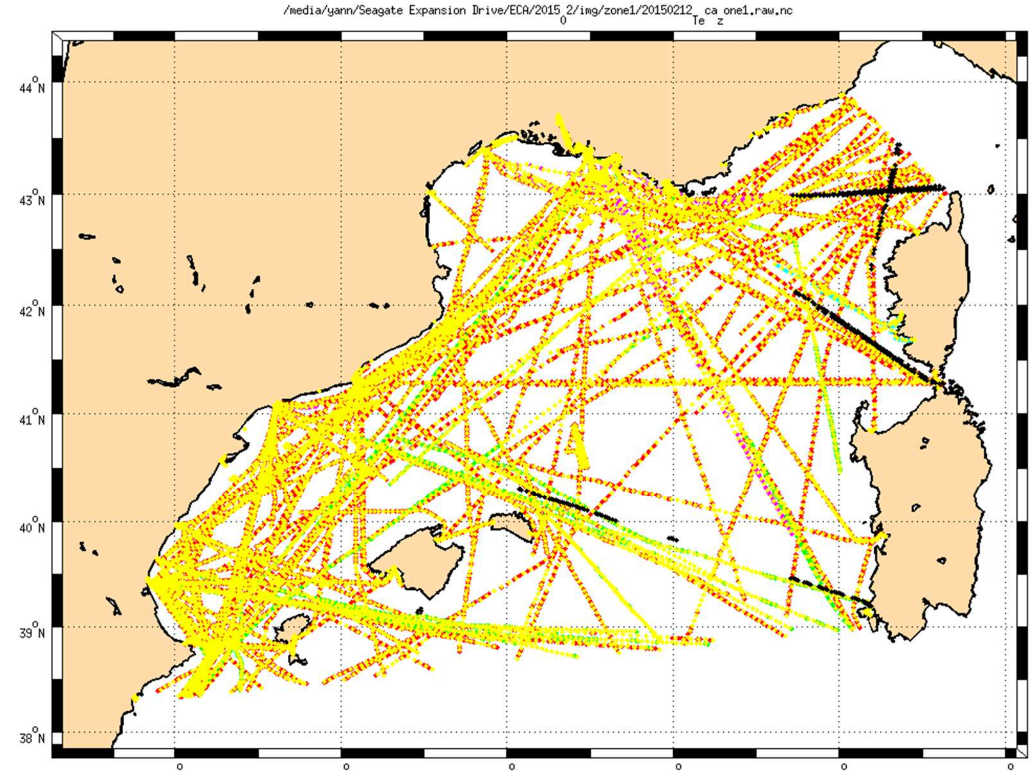


Figure 11 Example on zone 1 for one day: trajectories rebuilt in yellow, in green and red, initial trajectories and in black, trajectories that couldn't have been interpolated

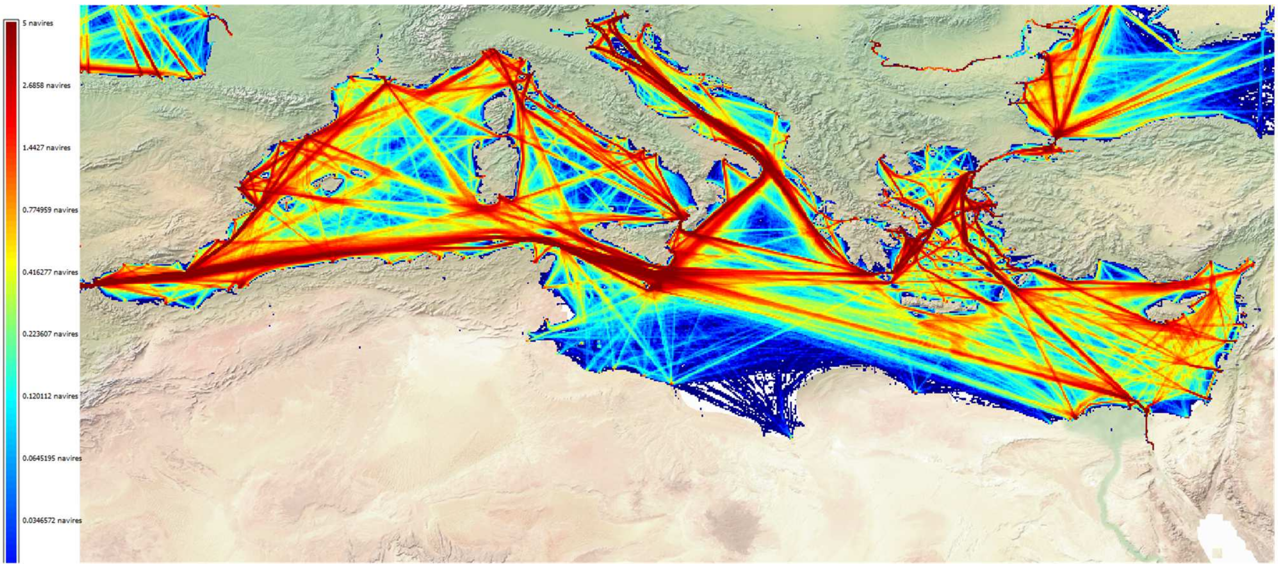


Figure 12 Traffic density map with all AIS data used for the ECAMED study

4 Emission calculations

4.1 Methodology

4.1.1 Mathematical generic functions to determine emissions

The methodology to estimate shipping emissions in the framework of the ECAMED project is the one recommended by European expert groups handled by official reporting frameworks for the implementation of the EU national emission ceilings directive and protocols of the UNECE Convention on Long Range Transboundary Air Pollution. Those groups publish guidelines and reference documents that were used for ECAMED[9].

According to these guidelines, the equation used to calculate emissions based on AIS data from ships is:

$$E(i, lon, lat, t) = \sum_{j} \sum_{m} \sum_{p} \left[\Delta t \sum_{e} \left(P_e . LF_e(lon, lat, t) . EF_{e,i,j,m,p} \right) \right]$$

in which:

- E = emission (tonnes),
- i = pollutant (NOx, NMVOC, PM, etc.)
- lon = *ship's* longitude
- lat = ship's latitude
- t= date and time of the ship on each lat/lon location data.
- j = engine type (slow-, medium-, and high-speed diesel, gas turbine and steam turbine).
- m = fuel type (bunker fuel oil, marine diesel oil/marine gas oil),
- p = the different phase of trip (cruise, hoteling, manoeuvring).
- Δt = duration since the last geographical position
- e = engine category (main, auxiliary)
- LF = engine load factor (%) at each geographical position
- P = engine nominal power (kW)
- EF = emission factor (kg/kWh) depending on type of vessel.

The input files provided by the CEREMA (see previous section and annex 1) allow to apply this equation.

4.1.2 Application to the Mediterranean Sea

In the Mediterranean Sea, according to the MARPOL Convention, ships must use fuels with different sulphur contents with respect to the ship types and the phases of the trip. The following assumption were made to simulate emissions.

---

[9] EMEP/EEA air pollutant emission inventory guidebook 2016. 1.A.3.d Navigation (shipping). https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-d-navigation/at_download/file

4.1.2.1 *Ships at berth more than 2 hours in EU-EEZ*

If the ship (independently of its category) stays more than 2 hours in the EU-EEZ[10], it must use a fuel with a sulphur content of 0.1% maximum.

From the dataset, ships located at berth more than 2 hours in UE-EEZ, are selected if the number of geographical location points for the trip at berth in UE-EEZ recorded is higher than 8 per day (1 location every 15 minutes).

4.1.2.2 *Cruise of passenger ships in EU-EEZ*

Up to the beginning of 2020, the passenger type ships must use a fuel with a sulphur content of 1.5% maximum for the cruise navigation phase and the berth phase less than 2 hours in EU-EEZ.

From 2020, the fuel sulphur content must be at maximum 0.5%.

If a sulphur ECA (SECA) is adopted, the fuel sulphur content must not exceed 0.1% max.

To identify the passenger ships in cruise in UE-EEZ (except those staying more than 2 hours at berth in UE-EEZ), the ships with the flag “ShiptypeLevel5” containing “passenger” have been selected.

4.1.2.3 *Other cases*

Before 2020, in other cases, the ships (whatever their category) use fuels with sulphur content limited to 3.5% (according to the emissions factors and activity data used for the calculations performed in the study it is rather 2.7%).

After 2020, the fuel sulphur content must be at maximum 0.5%.

If a sulphur ECA (SECA) is adopted, the fuel sulphur content must not exceed 0.1% max.

The ships considered in this category are all other cases non-selected in the 2 previous cases.

4.1.3 Scenarios proposed

Different scenarios have been proposed.

4.1.3.1 *Reference situation (2015/2016) (1516)*

The reference scenario corresponds to the pollutant emissions estimated with the current maritime traffic recorded in 2015 and 2016 and the current characteristics of engines and fuels.

For information, in 2015/2016, data provided by CEREMA shows that ~ 50% of vessels are categorised as Tier 0 and Tier I for NO_x emissions and therefore ~ 50% of vessels are in the Tier II category.

The fuels used for the scenario ref_1516 are therefore:

- Distilled fuel oil (MGO / MDO type) at 0.1% sulphur for ships staying more than 2 hours at berth in the EU-EEZ;
- Heavy fuel oil (HFO) at 1.5% sulphur for passenger ships (excluding stops longer than 2 hours at berth) in EU-EEZ;

---

[10] European Union – Exclusive Economic Zone

- Heavy fuel oil (HFO) at 2.7% sulphur for other cases.

4.1.3.2 2020 reference scenario (according to with Marpol VI, MGO)

MGO is a scenario for the years post-2020, where the maximum sulphur content in marine fuels decreases from 3.5% to 0.5% max according to IMO regulation 14.

Not yet knowing how the ships will comply with 0.5% sulphur content, a scenario based on the use of a distilled fuel with a maximum sulphur content of 0.5% (MGO / MDO) was developed.

The fuels used for the MGO scenario are therefore:

- Distilled fuel oils (MGO / MDO type) at 0.1% sulphur maximum for ships staying more than 2 hours at berth in the EU-EEZ;
- Distilled oil (MGO / MDO) at 0.5% sulphur maximum for other cases.

2015/2016 traffic numbers and vessels characteristics were used.

4.1.3.3 SECA scenario

In the SECA scenario sulphur emissions are limited throughout the entire Mediterranean Sea for all ships. The fuel has a maximum sulphur content of 0.1%. This 0.1% sulphur fuel is obtained with distilled fuels (MDO / MGO).

The fuels used for the SECA scenario are:

- Distilled oils (MGO / MDO) at 0.1% sulphur maximum for all ships, in all situations and throughout the entire Mediterranean Sea.

2015/2016 traffic numbers and vessels characteristics were used.

4.1.3.4 SECA/NECA scenarios

4.1.3.4.1 Scenario SECA/NECA 50% (SN50)

This is a "mid-term" NECA scenario coupled with a SECA scenario: we assume 50% of the ships comply with the NO_x Tier III limit values. Therefore, it is assumed that all ships built before 2005 are replaced by ships with the same characteristics but Tier III engines. These ships represent approximately 50% of all vessels in the Mediterranean Sea. To achieve the IMO NO_x Tier III emission standard, these ships are equipped with SCR (Selective Catalytic Reduction) technology to reduce their NO_x emissions.

The fuels are based on the use of MGO / MDO at 0.1% S instead of the MGO / MDO at 0.5% S for all ships, in all situations, throughout the entire Mediterranean Sea.

The fuels used for the SECA_NECA_50 scenario is:

- Distilled oil (MGO / MDO) at 0.1% sulphur content maximum for all ships, in all situations and the entire Mediterranean Sea.

4.1.3.4.2 Scenario SECA/NECA 100% (SN100)

This is a full NECA scenario coupled with a SECA scenario in which 100% of the ships respect the Tier III limit values. It is assumed that all ships built before 2016 are replaced by the same Tier III ones. To achieve the IMO NOx Tier III emission standard, these ships are equipped with SCR (Selective Catalytic Reduction) technology to reduce their NOx emissions.

The fuels are based on the use of MGO / MDO at 0.1% S instead of the MGO / MDO at 0.5% S for all ships, in all situations, throughout the Mediterranean Sea.

The fuels used for the SECA_NECA_100 scenario is:

- Distilled oils (MGO / MDO) at 0.1% sulphur content maximum for all ships, in all situations and the entire Mediterranean Sea.

4.2 Emissions results

Emissions of the different pollutants have been calculated for 5 scenarios (Table 2 & Figure 13):

Table 2 Fuel consumption and pollutants and GHG emissions for the different scenarios.

Scenario	CONSO Mt	NOx kt	SOx kt	TSP kt	PM10 kt	PM 2,5 kt	BC kt	PCB kg	PCDDF g	HCB g
REF_1516	18.4	1 332	759	87.8	87.8	79.0	9.95	8.94	7.66	2399
REF_MGO	17.7	1 264	153	24.9	24.9	22.4	6.97	0.669	2.29	1409
SECA	17.7	1 264	35.2	17.5	17.5	15.8	4.89	0.669	2.29	1409
SN50	17.7	823	35.2	17.5	17.5	15.8	4.89	0.669	2.29	1409
SN100	17.7	303	35.2	17.5	17.5	15.8	4.89	0.669	2.29	1409

Scenario	CO2 Mt	CH4 kt	N2O kt	CO kt	NMVOC kt	NH3 t	BaP kg
REF_1516	57.6	4.40	2.94	51.2	43.5	263	728
REF_MGO	56.7	4.40	2.79	50.9	43.5	263	728
SECA	56.7	4.40	2.79	50.9	43.5	263	728
SN50	56.7	4.40	2.79	50.9	43.5	263	728
SN100	56.7	4.40	2.79	50.9	43.5	263	728

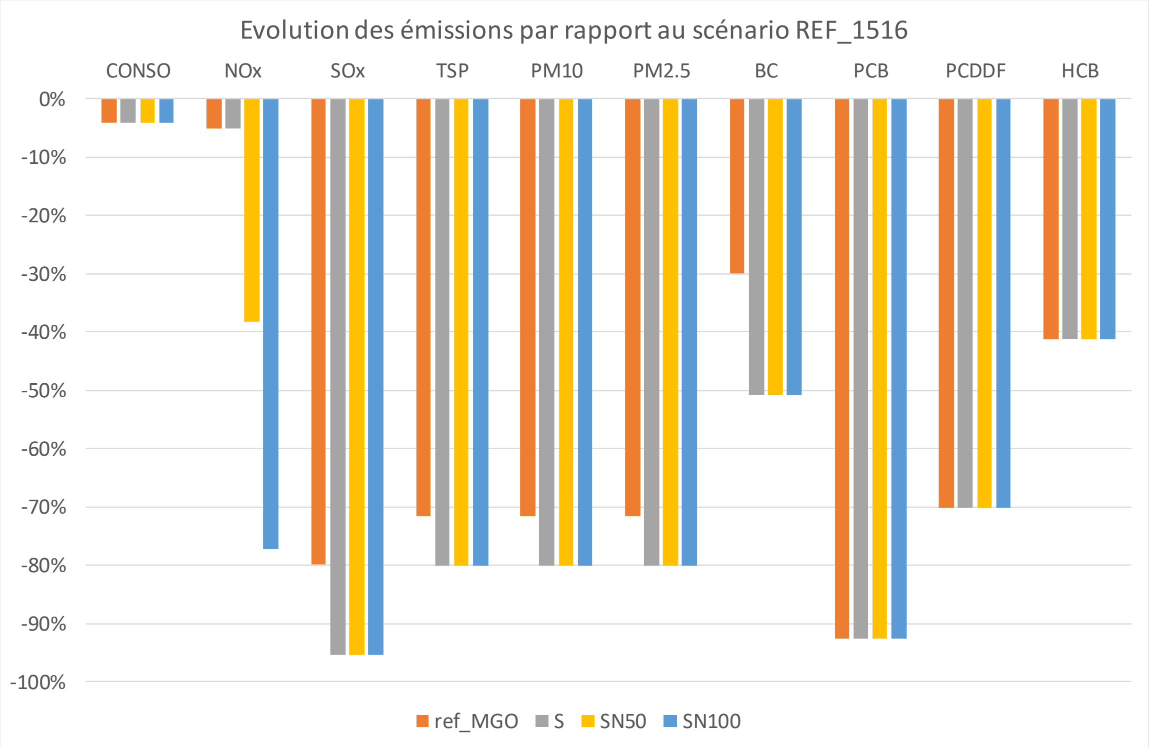


Figure 13 Pollutants emissions evolutions compared to 2015/2016 emissions

The Global Sulphur Cap 2020 will reduce the emissions (compared to 2015-2016 current emissions) as follows:

- SO_x by 80%
- PM by 72%
- BC by 30%
- NO_x by 5%
- POPs by 40% to 93%

The implementation of a SECA will reduce the emissions (compared to 2015-2016 current emissions) as follows:

- SO_x by 95%
- PM by 80%
- BC by 51%
- NO_x by 5%
- POPs by 40% to 93%

The implementation of a NECA will reduce the emissions (compared to 2015-2016 current emissions) of NO_x:

- by 38% when 50% of ships will be TIER III
- by 77% when 100% of ships will be TIER III

5 Impact on air pollutant concentrations

5.1 Input data

To simulate the impact of emission reduction scenarios on air quality (which means on ambient air pollutant concentrations) a chemistry-transport model (CTM) must be run. CTMs are complex three-dimensional numerical models which resolve dynamics, chemistry and loss processes (deposition) that drive air pollutant dispersion and transformation in ambient air. As illustrated in Figure 14, running such models requires availability of several well-documented datasets which describe emissions, meteorology and boundary conditions.

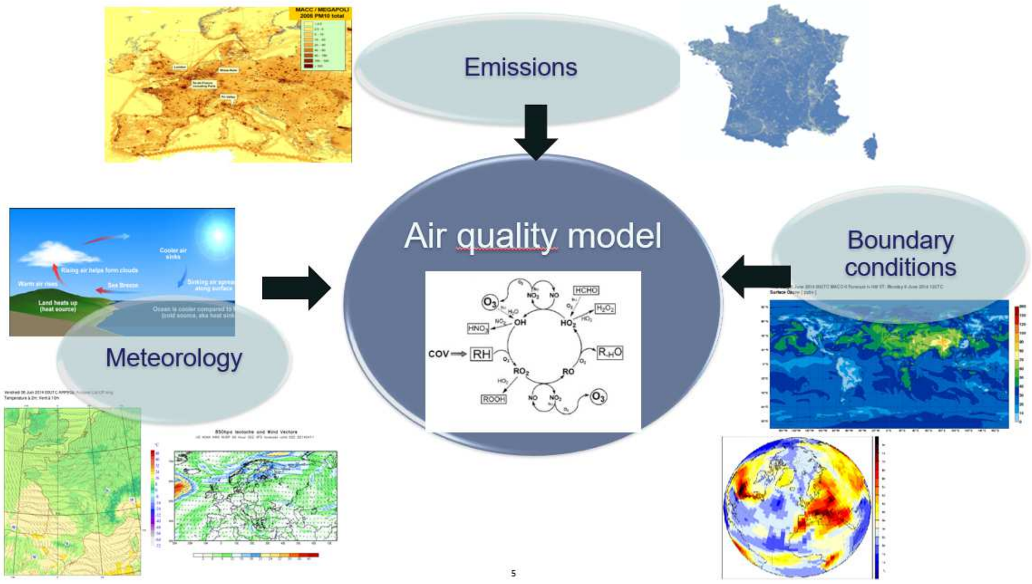


Figure 14 Synthetic representation of input datasets required to feed air quality model

5.1.1 Emissions

Emission datasets have been described in the previous section. They relate to the 5 scenarios studied in ECAMED:

- REF_1516 (current situation),
- REF_MGO (0.5% of sulphur content in fuel used),
- SECA (0.1% of sulphur content in fuel used),
- SN50 (SECA + NECA with 50% of Tier III engines),
- SN100 (SECA + NECA with 100% of Tier III engines).

The datasets provided by CITEPA describe shipping emissions along each trajectory for each vessel calculated with a 15min temporal resolution. To feed the model, gridded datasets are required. They describe with an hourly resolution (which is the model's resolution) the emission level emitted in each grid cell (defined with a km^2 resolution for instance). Therefore, CITEPA's datasets have been processed to build up an hourly gridded emission inventory according to the model's format requirements.

In addition, terrestrial (or in-land) emissions datasets must be taken into account in the simulations. Countries' air pollutant emission inventories reported with respect to European and international agreements have been used. In-land emission datasets for the year 2015 are available on the "webdab" emission web site (http://www.ceip.at/ms/ceip_home1/ceip_home/webdab_emepdatabase/) maintained by the Centre On Emission Inventories and Projections of the UN CLRTAP. These emission datasets have been processed and merged them with the shipping emission datasets to build up gridded emission inventories for each scenario. Note that in-land emission data do not change from one scenario to another. **We assume that only shipping emissions are reduced**.

Figure 15 illustrates the result of the emission integration step performed for each pollutant (NO_x, SO_x and PM).

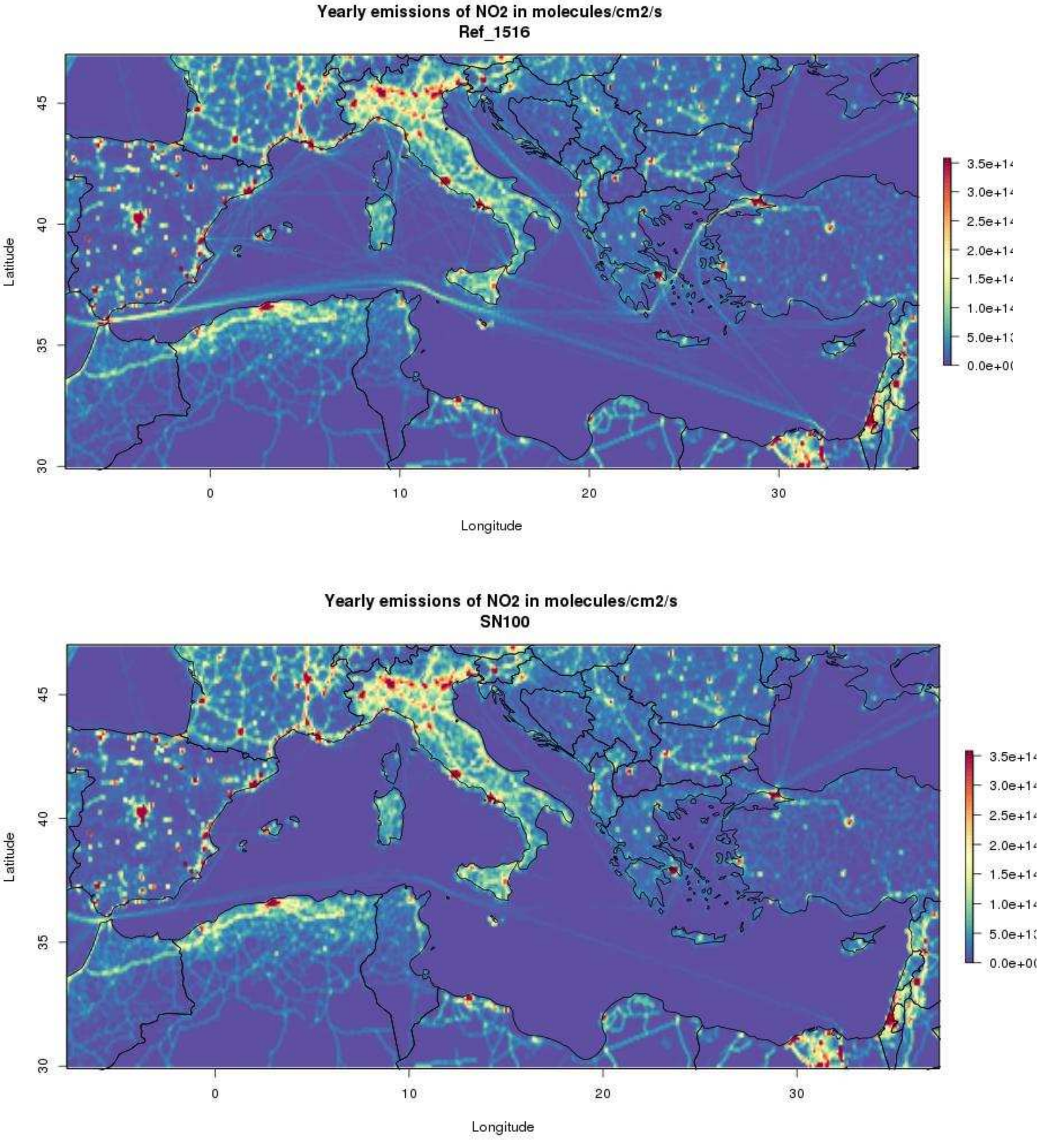


Figure 15 Gridded NOx emissions for REF1516 (top) and SN100 (bottom) scenarios

5.1.3 Meteorology

Meteorological fields relate to the year 2015 for all scenarios. Meteorology (wind, temperature, precipitation, relative humidity, sunshine...) influence dispersion and chemistry of atmospheric pollutants. Therefore, it is important to run the model with the same meteorological conditions for all scenarios to avoid changes or biases in air pollutant concentrations directly attributable to changes in meteorology.

INERIS used IFS meteorological fields for the year 2015 delivered by ECMWF (European Centre for medium-range Weather Forecast). They are available with a spatial resolution of about 10 km, which is satisfactory to run the model.

The year 2015 was chosen for consistency with emission datasets reference year.

5.1.4 Boundary conditions

Boundary conditions characterise the import of air pollutant concentrations at the boundaries of the modelling domain (which covers the Mediterranean Sea, see Figure 9). Usually boundary conditions are taken from air pollution climatologies (statistical evaluation of imported air pollution) or ideally from chemistry-transport model runs that are performed over a larger domain (which includes the targeted domain) with a lower resolution. We have chosen this last option which is more accurate than the other one and run CHIMERE over the whole of Europe for the reference situation (2015) with a 25-km resolution. The resulting air pollutant concentrations were used as boundary conditions of the smaller targeted domain for all scenarios.

5.2 Methodology

The modelling approach is based on the CHIMERE chemistry-transport model that INERIS has been developing in collaboration with the national research Centre (CNRS) since 2001.

CHIMERE has a long history and is fully compliant with the state of the art regarding the simulation of gaseous and particulate air pollutants. It is the angle stone of the PREv'air system (www.prevair.org) which is the national air quality forecasting and mapping system in France. CHIMERE is also one of the 7 models used in the Copernicus atmosphere services run by the European Commission to monitor and forecast air pollution in Europe. Finally, CHIMERE is used for a long time by INERIS to support the Ministry in charge of the Environment in assessing the efficiency and the impact of emission control strategies. CHIMERE was implemented to assess a set of alternatives and/or complementary emission control measures when the National air pollutant emissions reduction plan was defined.

INERIS run CHIMERE in numerous model inter-comparison studies organised at the European level that aim at assessing with common criteria the performances, quality, reliability and robustness of European air pollution models. CHIMERE's performances were always very satisfactory which underlines the model's high relevance in the framework of the ECAMED.

In terms of outputs CHIMERE provides air pollutant concentrations computed with an hourly resolution. The grid resolution chosen to perform the runs is 10 km.

5.3 Modelling results

The 5 scenarios described above have been simulated with the CHIMERE model. All datasets have been archived and are available for further analysis. A limited number of results are presented in this report, but more are available in annex 3 and on demand.

Differences in concentrations between the scenarios can be plotted in maps or shown in tables and time series aggregated over a limited domain (for example over cells that cover an agglomeration). The results commented below have been selected to illustrate important points regarding the conclusions of the feasibility study but they are not exhaustive. The interested reader is invited to contact us for specific information requirements.

5.3.1 Maps of differences of concentrations

5.3.1.1 Sulphur dioxide

Figure 16 and Figure 17 below illustrate in absolute and relative values, respectively, the impact of a SECA/NECA on sulphur dioxide annual mean concentrations compared to the 2020 reference situation (0.5 % of sulphur content in fuels).

Reductions can reach about 80% in some coastal areas (especially the eastern part of Europe) but absolute concentration levels are very low (since the reference scenario already considers low sulphur content in fuels). Nevertheless, additional improvements in air quality due to the implementation of SN100 are demonstrated.

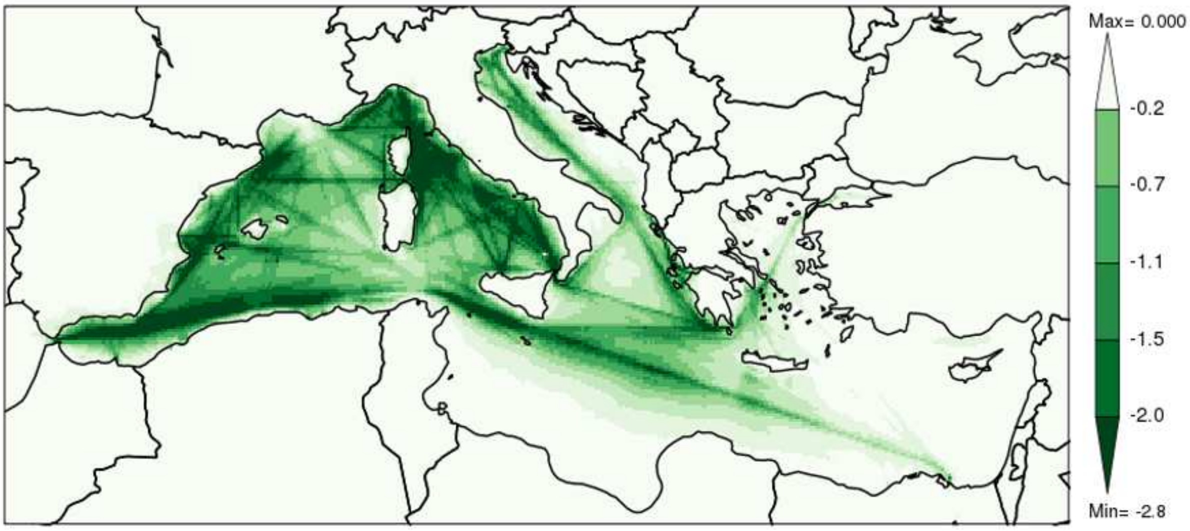


Figure 16 Absolute SO_2 annual mean concentration differences between SN100 and REF_MGO scenarios (in µg/m^3)

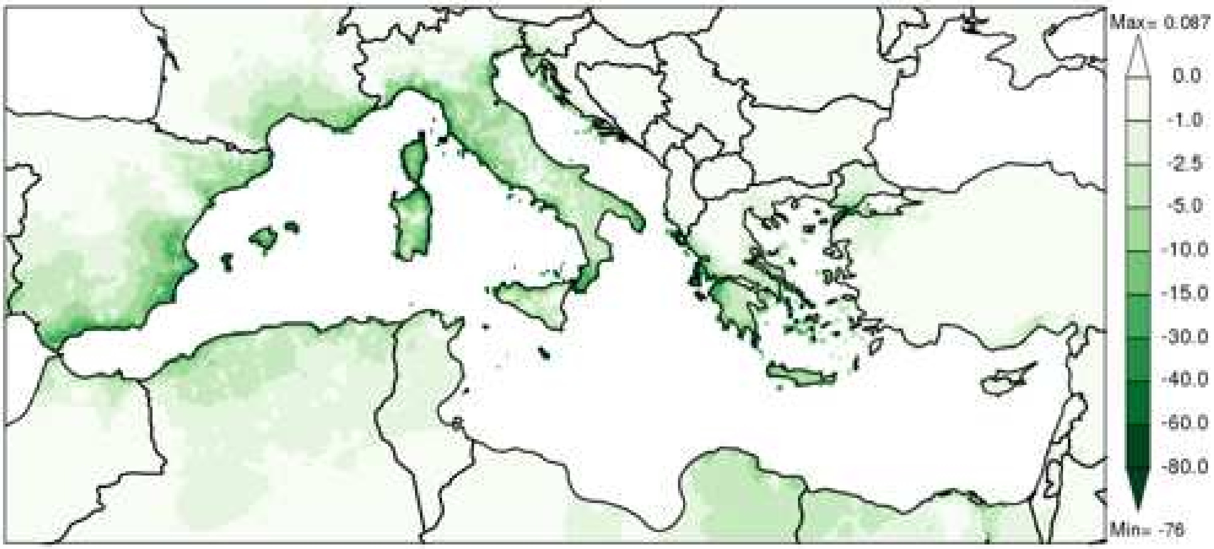


Figure 17 Relative SO_2 annual mean concentration differences between SN100 and REF_MGO scenarios (in %). Focus on land territories

5.3.1.2 Nitrogen dioxide

Figure 18 and Figure 19 illustrate in absolute and relative values respectively, the impact of a SECA/NECA on nitrogen dioxide annual mean concentrations compared to the 2020 reference situation (0.5 % of sulphur content in fuels).

Note that only the NECA part of the scenario (NO_x emission reduction) has an influence on NO_2 concentrations. The reduction can be very important (until 15 µg/m^3) in some areas, especially along the ships routes. This is particularly significant in the Adriatic Sea, in the Aegean Sea and along the Maghreb coats. A focus on in-land impacts shows that they range from 5 to 70 % compared to the current reference situation, with largest impacts occurring on the eastern part of the domain (Greece, Turkey, Albania) but also in Egypt and on the Slovenian and Croatian coasts.

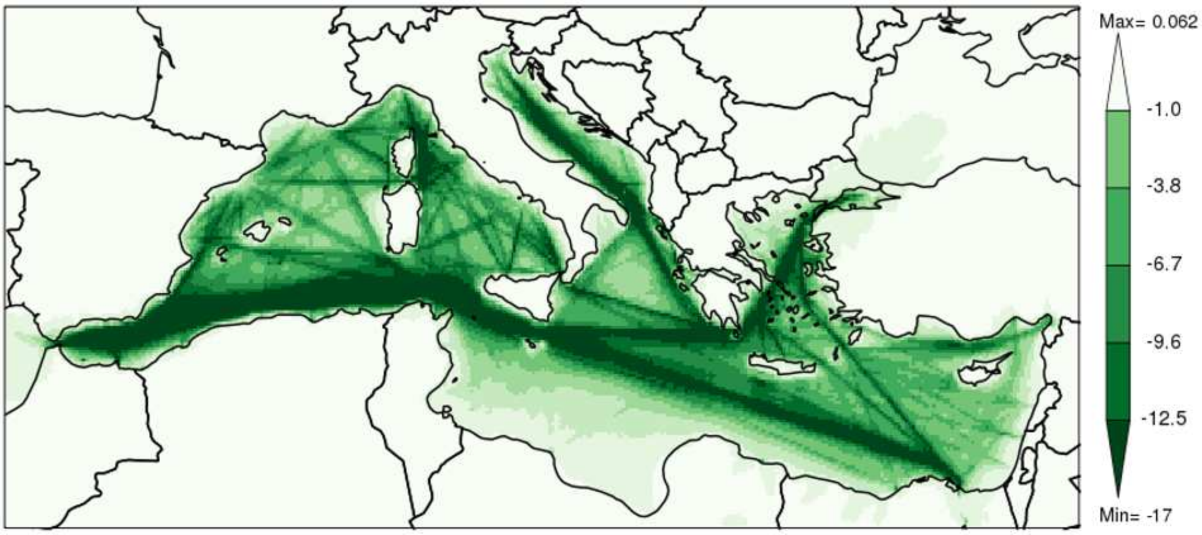


Figure 18 Absolute NO_2 annual mean concentration differences between SN100 and REF_MGO scenarios (in µg/m^3)

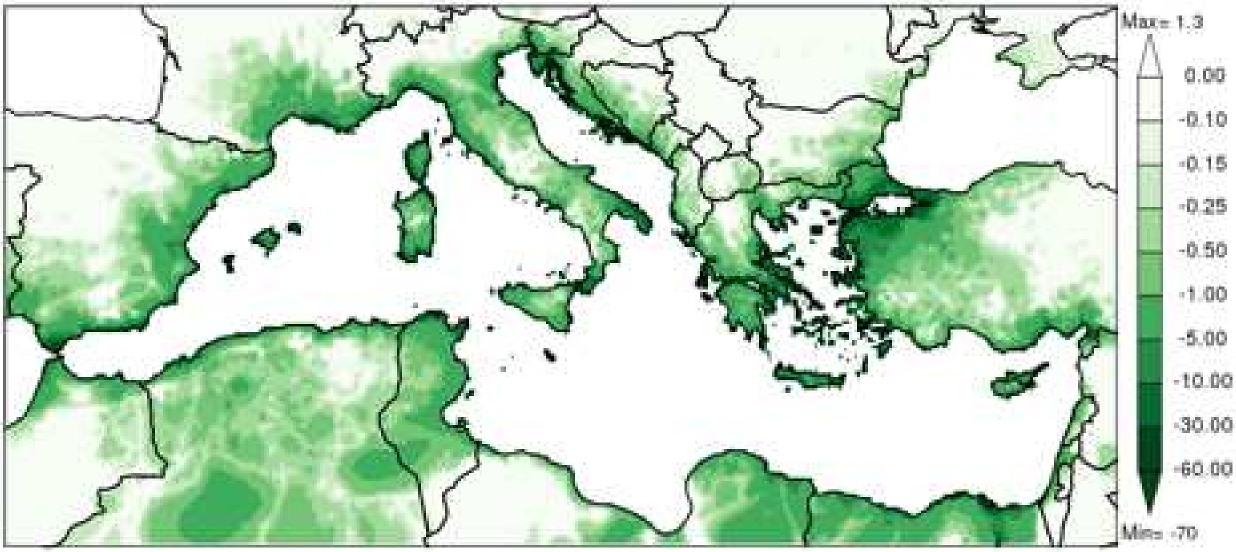


Figure 19 Relative NO_2 annual mean concentration differences between SN100 and REF_MGO scenarios (in %). Focus on land territories

5.3.1.3 Fine particulate matter ($PM_{2.5}$)

Figure 20 and Figure 21 illustrate in absolute and relative values respectively, the impact of a SECA/NECA on fine particulate matter ($PM_{2.5}$) annual mean concentrations compared to the 2020 reference situation (0.5 % of sulphur content in fuels). We focus on the in-land impact considering the role of the pollutant for health impacts of the pollutant regarding health impacts.

$PM_{2.5}$ annual mean concentrations are reduced by up to 1µg/m3 over the whole domain which means at maximum a reduction of about 11%. Reductions are the highest in Italy, along the Ligurian coast, in Spain, in Corsica and in Greece.

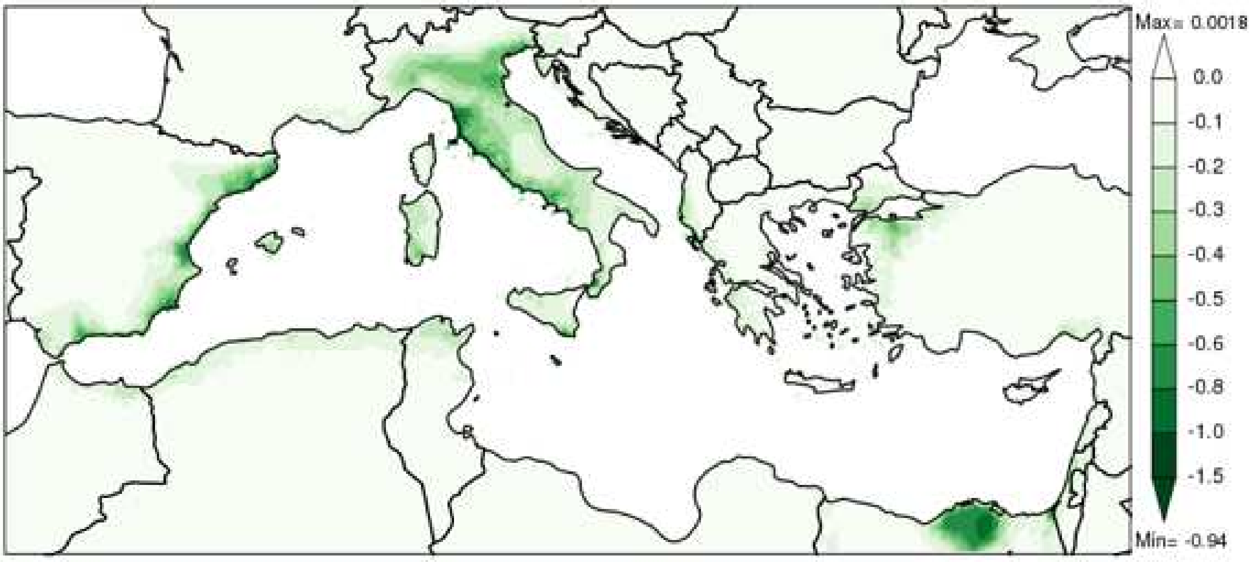


Figure 20 Absolute $PM_{2.5}$ annual mean concentration differences between SN100 and REF_MGO scenarios (in µg/m^3). Focus on land territories

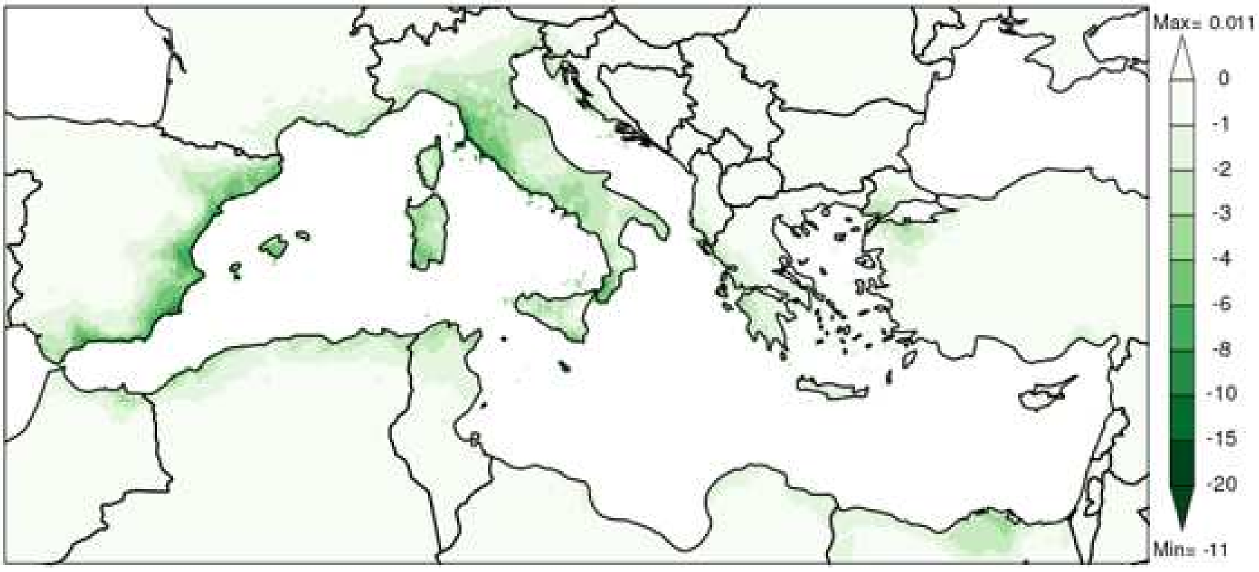


Figure 21 Relative $PM_{2.5}$ annual mean concentration differences between SN100 and REF_MGO scenarios (in %). Focus on land territories

5.3.1.4 Ozone

Figure 22 and Figure 23 illustrate in absolute and relative values respectively, the impact of a SECA/NECA on ozone (O_3) summer mean concentrations compared to the 2020 reference situation (0.5 % of sulphur content in fuels). Since ozone is a photochemical secondary pollutant produced under sunny and warm meteorological conditions, we focus on summer months for the analysis. Globally we note a general significant reduction of ozone concentrations (more than 5%) over land territories (and not only close to harbour cities). This is due to the chemical nature of ozone which is formed over long periods and potentially far away from emission sources. Ozone formation is also well-known for the complexity of its chemical cycle and its non-linear behaviour. In the ozone cycle, the so-called NOx titration effect consists of the removal of O_3 through reaction with nitrogen monoxide (NO), it occurs during night-time in the immediate vicinity of large nitrogen oxides sources. If NOx ambient concentrations decrease in those areas, the titration process can be neutralised and ozone concentrations can increase despite NOx emissions being reduced. This is the reason why we note in the maps a few areas (especially in Greece and Turkey) where ozone summer concentrations increase.

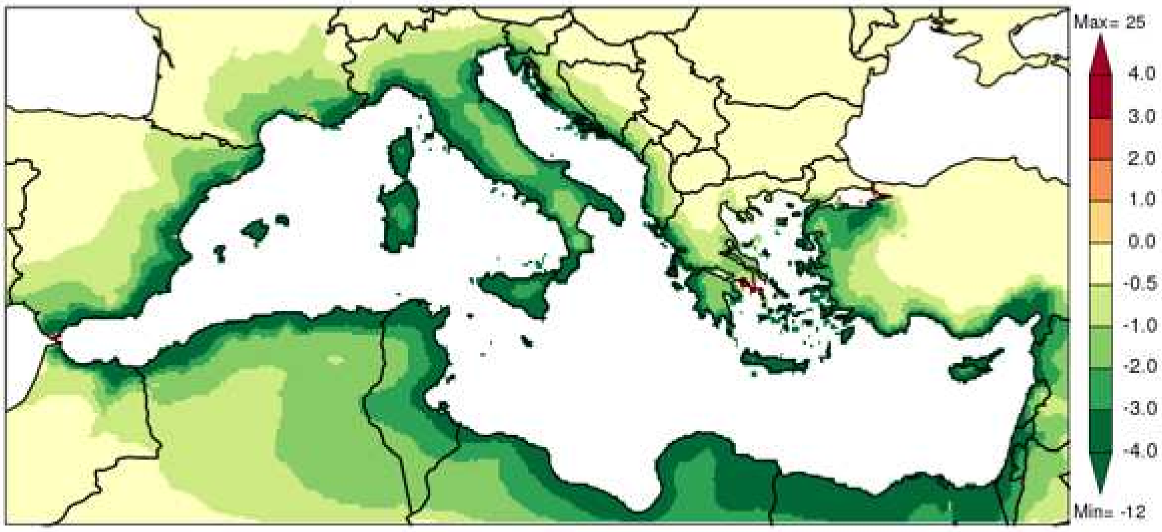


Figure 22 Absolute O_3 summer mean concentration differences between SN100 and REF_MGO scenarios (in µg/m^3). Focus on land territories

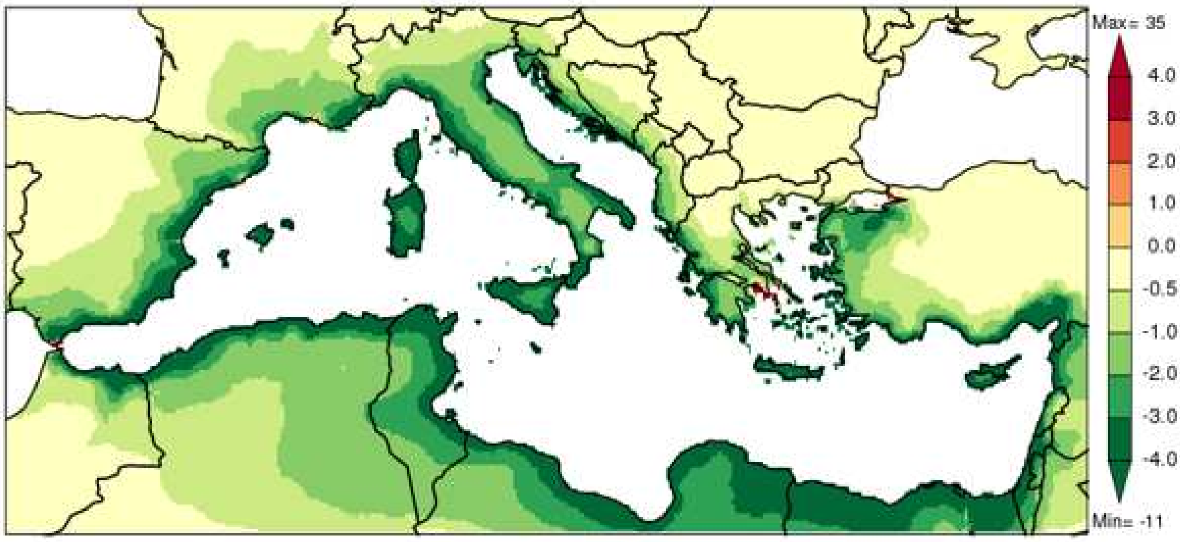


Figure 23 Relative O_3 summer mean concentration differences between SN100 and REF_MGO scenarios (in %). Focus on land territories

5.3.2 Focus on city areas

Over cities areas, modelling results can be processed (aggregating information in the cells that wrap the city domain) to draw time series that illustrate temporal variability of the impact of emission reduction scenarios on air pollutant concentrations and the period when this impact is the highest.

Impacts on annual averages can be presented as well using comprehensive histograms plots.

Figure 24 illustrates the impact of the emission reduction scenarios on annual averages for Marseille and Bastia. Considering annual averages, implementation of a SECA has a small impact on SO_2 and $PM_{2.5}$ concentrations, almost negligible for Marseille, while a NECA can reduce significantly NO_2 annual concentrations. It is interesting to note that in Marseille, SN100 reduces them by about 5.5 $\mu g/m^3$ NO_2 and SN50 by more than 4 $\mu g/m^3$. This means that the response to NO_x emission reductions is not linear, and significant improvements can already be achieved with SN50 (it represents more than half of the improvement reached with SN100).

An increase (which is almost the same for SN50 and SN100) is noted for ozone concentrations. this is due to non-linearities in the chemistry and limitation of the titration effect (destruction of Ozone by nitrogen oxides) due to reductions in NO_x emissions.

The situation is a bit different for Bastia. The impact of the SECA/NECA scenarios on NO_2 concentrations is slightly lower than for Marseille and there is almost no impact on ozone. More interesting is the impact on PM concentrations for Bastia: their annual average can be slightly reduced thanks to the implementation of a SECA (in green) but this effect is more pronounced with NECA controls (red and blue bars). The same interesting impact on PM concentrations is noted for Naples and Tunis (Figure 25) and other cities proposed in annex 3.

Figure 26 to Figure 29 plot time series of $PM_{2.5}$ concentration reductions (between REF_1516 and REF_MGO on one side and between REF_MGO and SN100 on the other side) for Marseille, Bastia, Naples and Tunis. They show the large variability of responses with daily concentration reductions that can reach 3-4 $\mu g/m^3$ in some periods (summer in particular) which is very significant. In Naples or Tunis this benefit is almost as large as the one achieved between REF_1516 and REF_MGO.

The same kind of result can be drawn for all main cities in Mediterranean countries. A few of them are presented in annex 3, but more can be extracted for interested readers on demand.

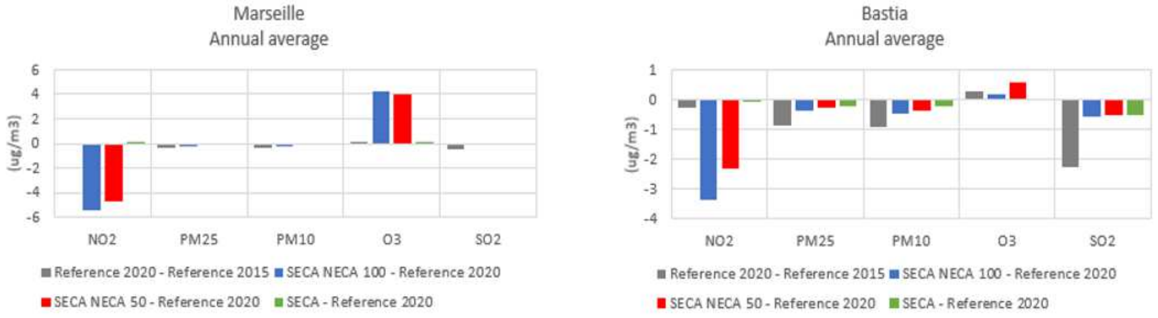


Figure 24 Differences between Air pollutant annual concentrations for various scenarios over city areas: Marseille (left) and Bastia (right). The grey bar refers to the difference between REF_1516 and REF_MGO while the others refers to differences between REF_MGO and SECA/ NECA scenarios

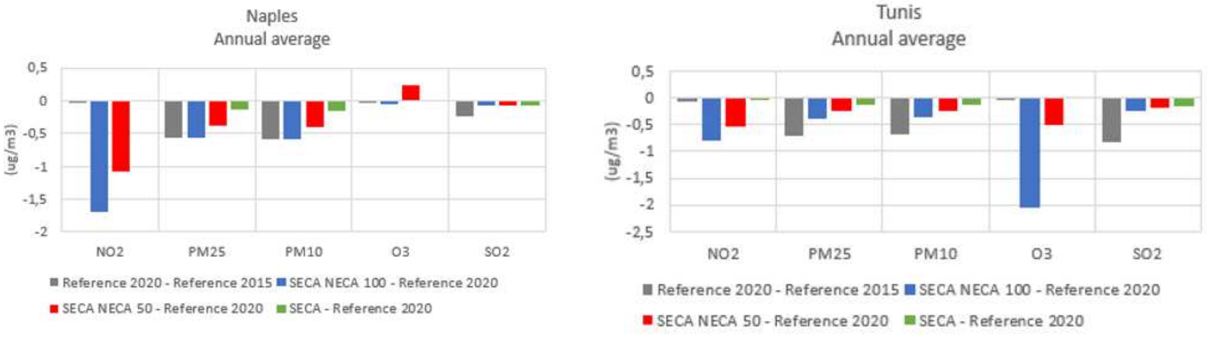


Figure 25 Differences between Air pollutant annual concentrations for various scenarios over city areas: Naples (left) and Tunis (right). The grey bar refers to the difference between REF_1516 and REF_MGO while the others refers to differences between REF_MGO and SECA/ NECA scenarios

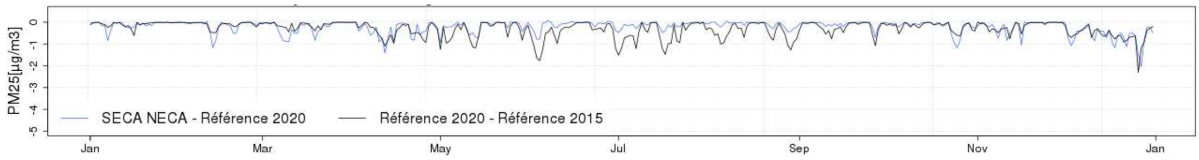


Figure 26 Time series of differences in $PM_{2.5}$ concentrations between REF_1516 and REF_MGO and REF_MGO and SN100 for Marseille

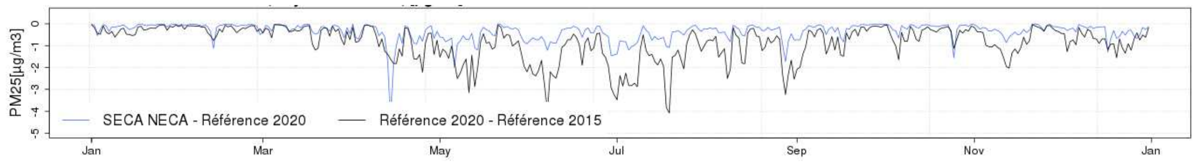


Figure 27 Time series of differences in PM2.5 concentrations between REF_1516 and REF_MGO and REF_MGO and SN100 for Bastia

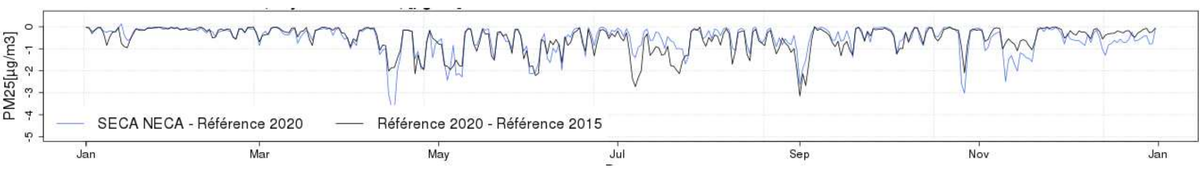


Figure 28 Time series of differences in PM2.5 concentrations between REF_1516 and REF_MGO and REF_MGO and SN100 for Naples

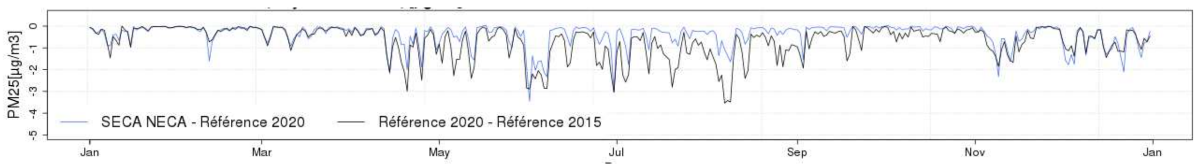


Figure 29 Time series of differences in PM2.5 concentrations between REF_1516 and REF_MGO and REF_MGO and SN100 for Tunis

5.3.3 Deposition

Nitrogen and sulphur deposition in response to emission reduction scenarios has been simulated by CHIMERE as well. Sulfur and nitrogen deposition has harmful effects on vegetation and ecosystems such as acidification and eutrophication, which can result in loss of biodiversity. Eutrophying deposition fluxes are directly correlated to nitrogen oxides emissions, and the simulations show that on the environmental point of view, implementation of an ECA leads to benefits, with nitrogen deposition on coastal ecosystems reduced by up to 40% compared to 2020 legislation. Differences of deposition between both situations is displayed on the figures below for nitrogen and Sulphur compounds respectively. They show that reduction of sulphur deposition is much more limited in intensity and geographical scope than for nitrogen compounds.

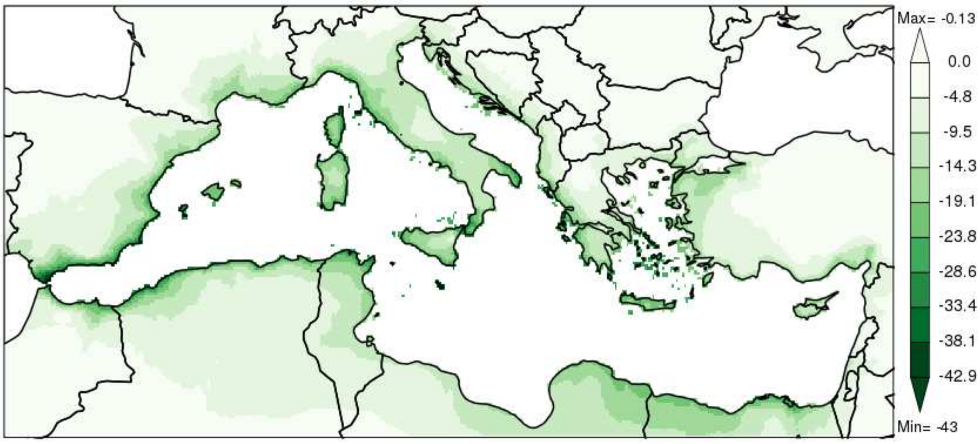


Figure 30 Relative nitrogen annual differences between SN100 and REF_MGO scenarios (in %). Focus on land territories

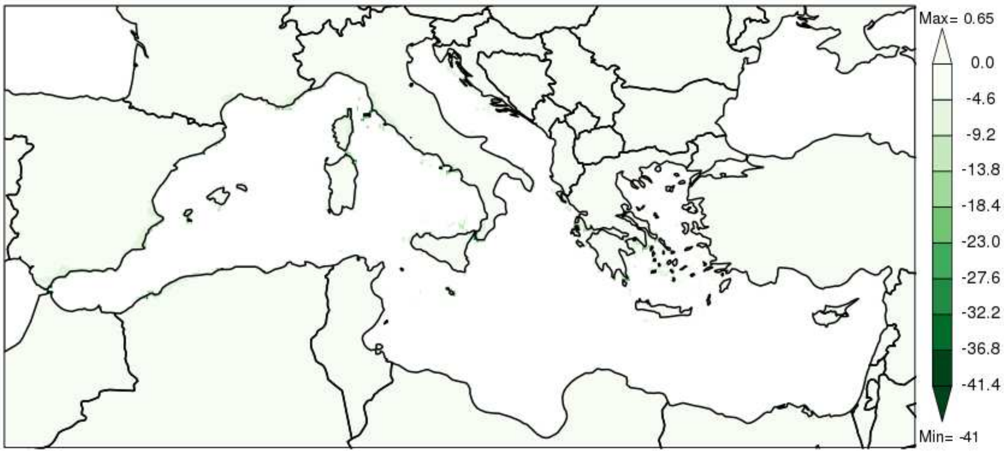


Figure 31 Relative Sulphur annual deposition differences between SN100 and REF_MGO scenarios (in %). Focus on land territories

5.3.4 Conclusions

The simulations and modelling results obtained in the framework of the ECAMED feasibility study have provided a number of relevant insights. The purpose of the study was to assess the impact of additional control measures that aim at enhancing the positive impact of the Global Sulphur Cap 2020 which will contribute to significant reductions in SO_2 and PM concentrations.

We simulated the impact of this up-coming legislation compared to the current situation and, as a first result, the benefits were shown to be significant everywhere in the domain. By the way, these simulations show the sensitivity of fine particulate concentrations to SO_x emission reductions, SO_x being precursors of inorganic secondary particulate matter (ammonium sulfate). The Mediterranean chemical regime and favourable meteorological conditions facilitate these chemical reactions.

Secondly, the results also show that additional improvements (additional to those brought about by the Global Sulphur Cap 2020) in terms of air quality can be achieved with the implementation of a joint SECA/NECA. The NECA allows to further reduce $PM_{2.5}$ ambient concentrations in several parts of the domain. Considering annual averages, this additional reduction can be even higher than the one achieved with the SECA alone. This demonstrates that aerosol chemistry in the Mediterranean region is also influenced by NO_x emissions, NO_x being precursors of ammonium nitrate particulate.

Thirdly, responses to NO_x emissions are not linear and we demonstrate that implementing a NECA with half of the vessels equipped with Tier III engines has already a significant positive impact on NO_2 and $PM_{2.5}$ concentrations. This impact is obviously increased if 100% of the engines turn to Tier III, but a lot could be already achieved with less ambitious scenarios (for instance 50% of Tier III) to reflect a more progressive process toward cleaner engines.

Finally, the ozone issue must be discussed. Simulations show an overall improvement in terms of reduction of ozone concentrations thanks to reduction in NOx emissions. Indeed, Ozone is a secondary pollutant and NO_x is one of its precursors. But ozone is driven by a complex non-linear chemistry and in certain circumstances, ozone concentrations can increase when NOx emissions are reduced, because of the limitation of the titration effect (nightly destruction of ozone where NOx emissions are very high). This is the reason why over some cities areas annual ozone concentrations can increase (this is particularly true in the Eastern part of the domain). However, considering the question globally throughout the geographical domain (see maps on Figure 22 and Figure 23) the implementation of

SECA/NECA leads to an overall reduction in ozone concentrations, especially in the countryside where ecosystems and vegetation are most exposed to ozone. Therefore, we conclude on an overall benefit for ozone as well.

6 Cost-benefits analysis

The last step of the process consists in assessing the cost of the implementation of the control measures envisaged in the scenarios and to compare them to the benefits associated to the air quality improvement. In order to directly compare the benefits to the costs, they are expressed in monetary terms, based on a set of methodological assumptions presented below. In the present study, we focused only on health benefits (avoided mortality and morbidity). Within the time frame of the project it was not possible to assess monetary benefits for ecosystems (reduction of acidification and eutrophication effects).

6.1 Costs assessment

6.1.1 Cost calculation methodology

6.1.1.1 Sulphur reduction SECA

This section describes assumptions adopted for the estimation of marine fuel prices and the estimation of additional costs caused by using low Sulphur content fuels compared to the Reference Scenario (REF_1516).

The main results are presented in terms of additional costs from marine fuel prices for the following scenarios shifts:

- From REF_1516 to REF_MGO (0.5%S)
- From REF_1516 to SECA_NECA_100
- From REF_MGO to SECA_NECA_100

Total annual costs (billion €/year) and costs per avoided unit of emissions (€/kg SOx avoided) are provided. Cost estimates are based on the prices of different marine fuels in the year 2015 and the total fuel consumption associated to each scenario. The pollutant emissions from ships and the health benefits assessment were estimated for the year 2015. Consequently, the cost assessment was calculated using fuel prices of 2015.

6.1.1.1.1 Marine fuel prices for HFO (at 2.7%, 1.5% and 0.5% S), MGO (at 0.5 and 0.1% S) and LNG for the base year 2015.

In order to estimate the costs to implement a SECA aiming at mitigating SO_x emissions, prices of various low Sulphur fuels in 2015 were considered. Total annual costs of the consumption of the various fuels have been calculated for each scenario. The difference between the annual cost for a scenario compared to the cost of the reference scenario (REF_1516) gives the additional cost to reduce SO_x emissions.

The sources of price information for HFO and MGO fuels[11] and LNG[12] report fuel prices in $USD. LNG is considered for the purpose of comparison. In 2015, the annual exchange rate[13] of the US dollar ($USD) against the euro (€) was 1.11 (as in 2016). The average LNG world price in 2015 was $9.77/MMBtu which equals to 413.8 €/t. Annual costs are expressed below in Euros of 2015.

The average worldwide prices observed in 2015 are presented in Figure 32 to Figure 35. These figures present the high fluctuation of fuel prices observed in that year between regions.

Figure 32 Price trends for LSMGO Max 0.10% Sulphur Distillate (USD$ per metric ton) in 2015

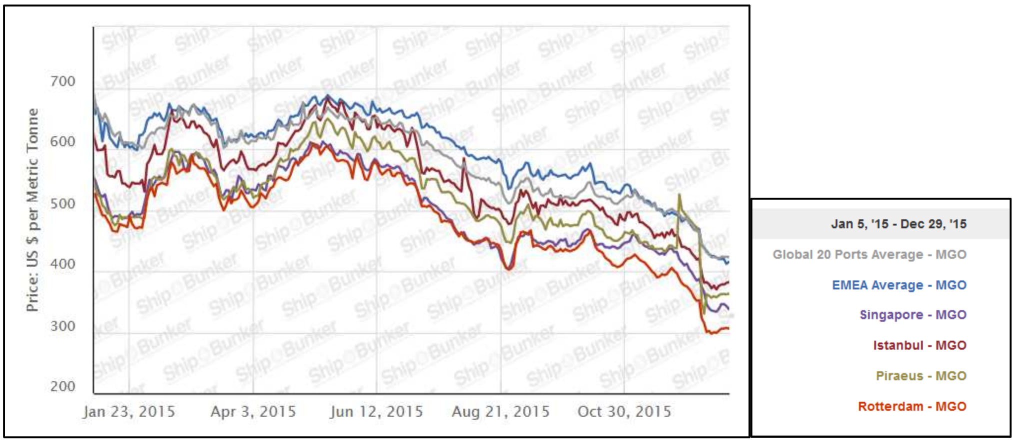


Figure 33 Price trends for MGO Max 1.50% S (USD$ per metric ton) in 2015

---

[11] www.shipandbunker.com

[12] California Air Resources Board's (CARB) (2018). Draft technology assessment: ocean-going vessels https://www.arb.ca.gov/msprog/tech/techreport/ogv_tech_report.pdf

[13] European Central Bank https://fr.statista.com/statistiques/577988/taux-de-change-moyen-annuel-du-dollar-etats-unis-contre-l-euro/

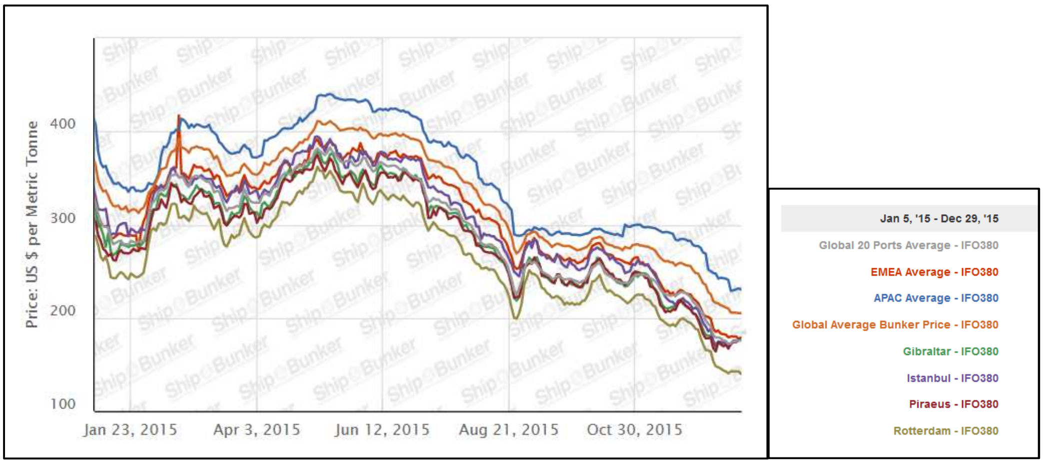


Figure 34 Price trends for IFO380 Max 3.5% Sulphur Bunkers (USD$ per metric ton) in 2015

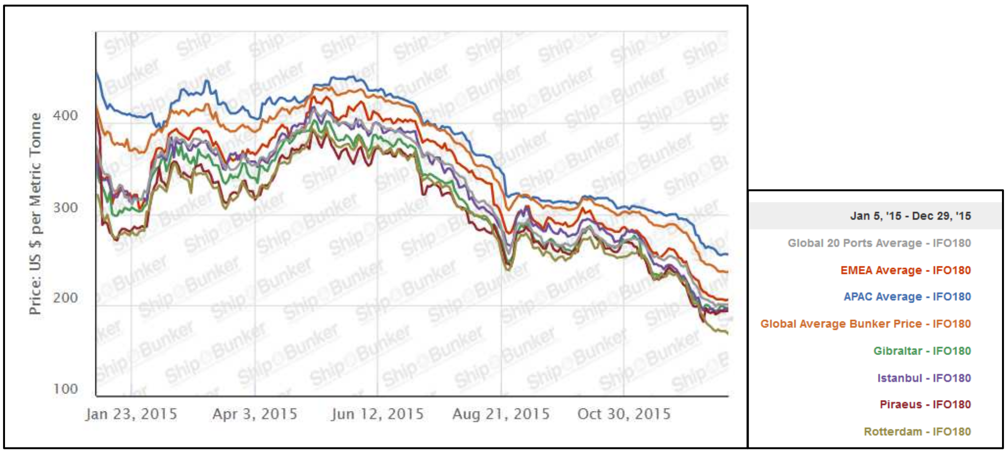


Figure 35 Price trends for IFO180 Max 3.5% Sulphur Bunkers (USD$ per metric ton) in 2015

6.1.1.1.2 Fuel prices used in the analysed scenarios

Since there is an uncertainty about the location of ship refuelling, we have developed several assumptions for fuel prices, that depend on world regions where it is sold (Table 3). These assumptions are based on disaggregated data available by region.

Calculations are made with the following 3 average price profiles according to the location of ship refuelling obtained from (Entec, 2002):

- Average World fuel prices (e.g. Global 20 Ports Average)
- Mediterranean Sea fuel average prices (e.g. Port of Gibraltar, Piraeus)
- Average prices between World and Mediterranean Sea fuel prices

For MGO at 0.1% S, prices are similar for the Mediterranean Sea and the world. MGO at 0.5% S price is more expensive in the Mediterranean Sea than the world average. Fuel oil at 2.7% is cheaper in the Mediterranean Sea compared with the worldwide average price.

It should be noted that in 2015, according to data collected, the price of HFO at 1.5%S was higher than the price of HFO at 0.5%S. With the need to reach a 0.5%S rate, the additional costs of this fuel at 1.5%S should no longer exist. We therefore developed two cases for the price of HFO at 1.5%S. The first one corresponds to the price of "MGO is Max 1.50% Sulphur"

(HFO 1.5%S high price). In the second case, the HFO price at 1.5%S is calculated by interpolating between the price of HFO 0.5%S and HFO 2.7%S. This case is called “HFO 1.5%S average price”.

Table 3 Fuel prices used in the cost calculations for each scenario

	LNG	MGO 0.1%S	MGO 0.5%S	HFO 0.5%S	HFO 1.5%S Hight Price	HFO 1.5%S Average Price	HFO 2.7%S
Price assumptions	€ 2015 / ton of fuel						
Average world prices	414	472	453	410	524	358	296
Mediterranean average prices	414	473	465	385	482	334	273
Average prices	414	472	459	398	503	346	284

6.1.1.1.3 Other considerations

It is important to mention that assumptions for cost estimates do not take into account any additional investment that would be necessary in order for the vessels to run with low sulphur fuels. The assumption was that vessels already contain enough storage tanks allowing to stock different types of marine fuels. This assumption was also applied in (Ricardo, 2017) assessment study of emissions control zones in European seas.

At this stage, the implementation costs of a SECA in the Mediterranean Sea presented hereafter are exclusively the result of the use of low sulphur marine fuels. Additional costs of scrubbers are not considered. Scrubbers can be used to reduce sulphur emissions.

The availability of 0.1% S fuels will depend directly on the evolution of refinery systems, in particular, the implementation of deep conversion of heavy fuel oils. According to experts in this sector, the costs for the adaptation in refineries are supposed to be very high and depend on the type of refinery and their specialisation. These potential costs are not taken into account in this report. This is a very complex subject that has been analysed by different sources. In fact, the strategic choices from refineries and carriers are tight up. It is important to mention that the solution from refinery companies are not well known. Figure 36 allows observing the possible future marine fuel price evolutions analysed by (Jalkaneen, 2015).

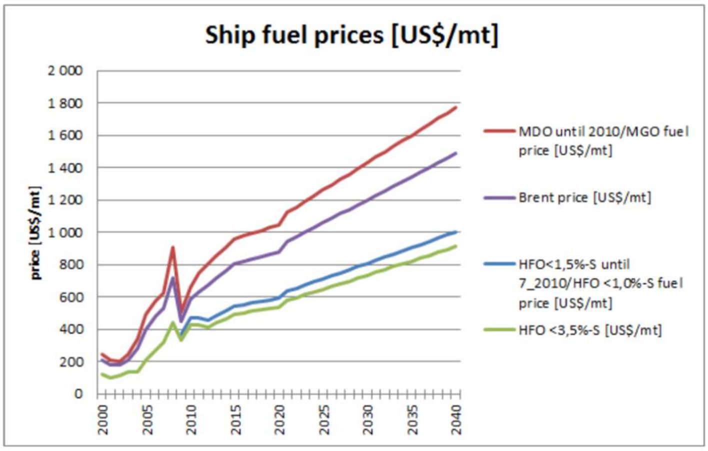


Figure 36 Scenarios of evolution of marine fuel prices from ▫

Another issue to consider is the year chosen for the cost analysis (2015). As mentioned before, fuel prices are subject to very large variations. In the future, the trend towards lower demand of HFO and higher demand of low sulphur MGO, could highly influence fuel prices and the ratio between them.

6.1.1.2 NOx reduction - NECA

The section specifies the hypotheses applied for estimating the costs of NOx abatement for the SN100 scenario in the context of a NECA implementation.

The resulting costs are presented in terms of total annual costs (billion €/year) which facilitate the comparison with the health benefits generated by reducing the impacts of emissions (calculated by INERIS), and according to the avoided NO_x emissions (i.e. Cost/effectiveness ratio expressed in €/avoided kg NO_x).

6.1.1.2.1 Available abatement technologies and assumptions

The reduction of NO_x emissions from ships can be achieved through various means briefly described below:

- **Selective Catalytic Reduction or SCR.** This is one of the most widely used NO_x gaseous effluent treatment techniques for large combustion plants and NO_x emitting processes in the industry. This technique is developing strongly for the treatment of NO_x emissions from ships (IFP, 2018). In 2013, 520 vessels were equipped with SCR and the establishment of NECA zones should further increase this number.

- **Exhaust Gas Recirculation (EGR).** This technique is based on the cooling of a part of the combustion gases from the engine (system using fresh water) and their recirculation in the engine. The reduction of the temperature in the engine and the lower oxygen content reduce the formation of NOx. Recirculating gases must be cleaned to remove PM and neutralise the water. As with the SCR, different configurations can be implemented, high or low pressure. In addition, engine manufacturers are also being able to set new engines fitted into ships already prepared to complement an EGR system anticipating the need to meet NECA standards in the future (Winnes, 2016). In fact, it is a motor technology that cannot be adapted to an existing engine. Only new engines can have an EGR device. The EGR has a fuel penalty of 0 to 4 g/kWh depending on the engine load.

- **Liquefied Natural Gas** is a fuel that meets Tier III levels. LNG engines can only use LNG in a Spark ignition engine or a combination of LNG and MGO in a dual fuel engine in a compression engine. The LNG engine requires a larger volume than the fuel oil engine (Canpling, 2012).

It is important to mention that only SCR is considered in the economic assessment of NO_x reduction carried out in this study. In fact, the scenarios are developed with identical liquid and gaseous fuel characteristics. Moreover, LNG in 2015 still represents only a very small proportion of total fuel consumption. For information, investment costs for LNG vary from 219 to 940 €/kW for new engines and from 391 to 1603 €/kW for existing engines[14]. The EGR was not taken into account in this study due to the difficulty of making assumptions

---

[14] www.seatrade-maritime.com

about its penetration rate for new engines. Its costs are estimated to be higher than those of SCR (+ 25%) according to (Jalkaanen, 2015).

6.1.1.2.2 Cost assessment principles and costs data used for the SCR technology

The annual costs of an emission reduction technology are composed of the annualized investment required for ready-to-operate equipment and its fixed and variable operating costs. The investments include the equipment itself and all the costs incurred to make it operational on site (additional equipment, installation on the ship, pipes, various structures...). The investment annualisation formula is as follows:

$$[\mathrm{A}] \quad \mathrm{Ca}\left[\frac{€}{year}\right] = \mathrm{I}[€] \cdot \frac{(1+p)^n}{(1+p)^n - 1} \cdot p$$

n: annualisation period corresponding to the service life of the equipment

p: annualisation rate (4% in this study)

$\mathrm{I}[€]$ Investment of the technology device in € 2015 (overall costs of a ready to use equipment)

$\mathrm{Ca}\left[\frac{€}{year}\right]$ Annualised investment for the equipment, € 2015/year

The total annual cost of the equipment $\mathrm{Ct}\left[\frac{€}{year}\right]$ is given by the following equation:

$$[\mathrm{B}] \quad \mathrm{Ct}\left[\frac{€}{year}\right] = \mathrm{Ca}\left[\frac{€}{year}\right] + \mathrm{Co}\left[\frac{€}{year}\right]$$

$\mathrm{Co}\left[\frac{€}{year}\right]$ annual operating costs, consisting of fixed operating costs (maintenance, insurance, etc.) and variable operating costs. They consist of consumable costs (reagents, electricity, water ...). It should be noted that savings may occur in some cases. These savings are then deducted from the annual costs.

The cost-effectiveness ratio is calculated by the following formula:

$$[C] \quad R\left[\frac{€}{\text{t Avoided NOx}}\right] = \frac{Ct\left[\frac{€}{year}\right]}{M_{\text{Avoided NOx}}\left[\frac{\text{t NOx}}{year}\right]}$$

$M_{\text{Avoided NOx}}\left[\frac{\text{t NOx}}{year}\right]$: NOx mass reduced by equipment

The annualisation rate for cost studies of public policies is usually 4% (Concawe, 2014, 2017). This rate represents a social discount rate. It was also used by IVL (Psarmo, 2017) for the study of the reduction of NOx emissions in the Baltic Sea and by VITO in the assessment for the establishment of possible new emission control areas in European seas.

A review of the latest published studies for the establishment of a NECA allowed the identification of the following cost assumptions (cf. Table 4) for SCR devices. The average values presented in www.seatrade-maritime.com and other sources are used.

Table 4 Input parameters for the cost calculation of the SCR

Cost component	Average value	Range of values
Investment €/kW □ New	59	19 to 100
Investment €/kW □ Retrofit	80	24 to 97
Urea price €/kg □	0.21	0.17 to 0.29
Urea consumption kg/kWh □	10.9	6.5 to 16.5
Replacing the catalyst €/kWh □	0.55	0.25 to 0.75
Maintenance	1,2% of investment	

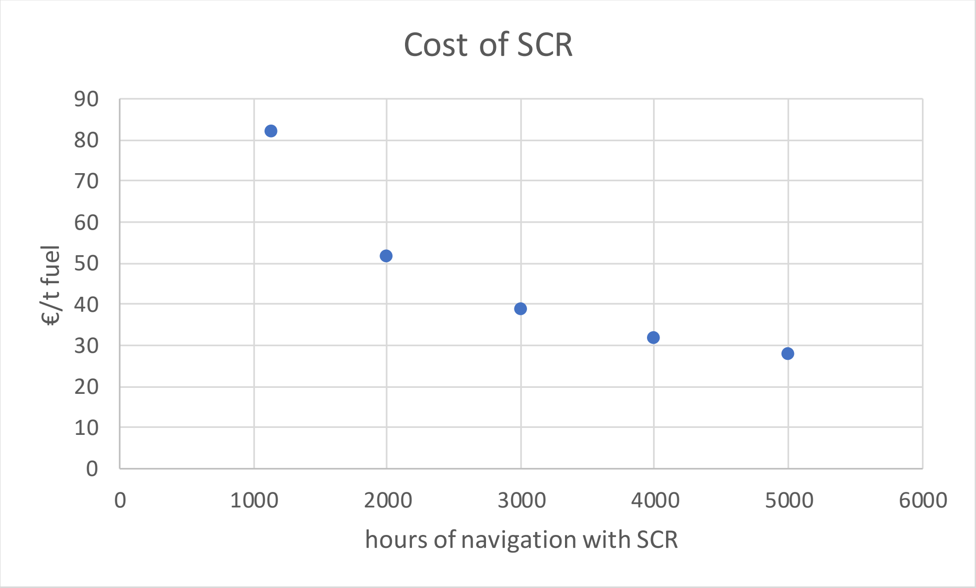
(Jalkaneen, 2015) explains that the presence of the SCR on engine flue gases induces a counter-pressure in this engine, which increases its fuel consumption by a few percentage points as described above. However, in the case of SCR, the engines can be optimised in order to save fuel. In addition, a reduction in consumption of up to 7% can be achieved under certain conditions. For the purpose of the study, a positive balance between additional consumption due to SCR and fuel economy due to engine adjustments of 1% of fuel consumption is assumed. Few studies address this subject, making it difficult to adopt a robust hypothesis in terms of fuel economy.

For this study, the annual average time spent in the Mediterranean Sea is an essential input parameter. It was calculated by CITEPA using the data provided by CEREMA for the calculation of consumption and emissions. The annual average time spent in the Mediterranean Sea was calculated by aggregating the vessels into three categories: tankers/cargos, passenger vessels and others as shown in Table 5.

Table 5 Time of presence in the Mediterranean Sea according to the processing of ship tracking data

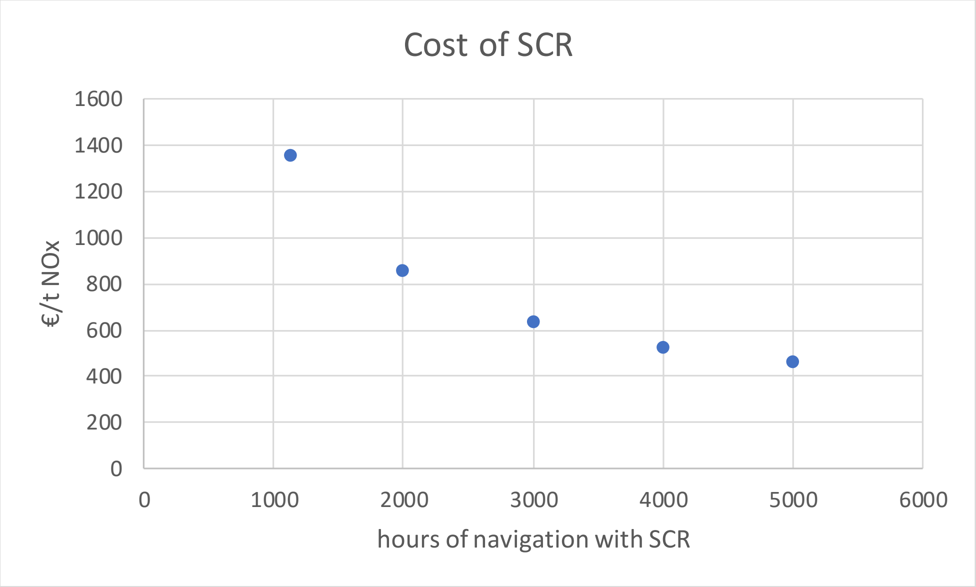
	Annual average times spent in the Mediterranean Sea - Hours/year
Tankers-cargos	1135
Passengers	1310
Others	735

As done in the recent reviewed studies (www.seatrade-maritime.com), it is assumed that outside the NECA zone, the vessels turn their SCR off. The costs are then related to less significant emissions reduction and consequently the cost-effectiveness ratio of the measure is less important. Figure 37 shows the additional cost of the SCR on the price of fuels used in the ship for different annual average times in the NECA zone. Figure 38 shows the cost-effectiveness ratio of the SCR for the reduction of NO_x (in the case of a new tanker with a 12 MW engine and a 20-year amortisation period for the investment).



Calcul-coûts-SCR-v2

Figure 37 Impact of SCR on the price of fuel MGO 0.1% S (€/t fuel) for different annual average times spent in the NECA zone



Calcul-coûts-SCR-v2

Figure 38 Cost-effectiveness ratio of the SCR (€/Avoided t NOx) for different annual average times spent in the NECA zone

To avoid double counting, NO_x emissions reduction caused by the use of an MGO fuel instead of an HFO fuel should not be attributed to the presence of the SCR (the price of the HFO to MGO was already considered in the cost of SO_x emissions reduction).

It is noted that depending on the MGO price at 0.1% S of € 472/t or € 597/t[15], the additional cost of NOx reduction may represent the following price increase for a vessel with 12 MW engines (Table 6):

Table 6 Economic impacts of the NOx emissions reduction on the fuel price by annual average times spent in NECA

Annual average time in the NECA (hours)	€/t fuel	Additional costs for a fuel Price of 472 €/t fuel	Additional costs for a fuel Price of 597 €/t fuel
1135	82	17%	14%
2000	51.6	11%	9%
3000	38.4	8%	6%
4000	31.7	7%	5%
5000	27.8	6%	5%

It should be noted that the additional cost of the SCR on the price of MGO fuels decreases with the increase in the annual average time spent in the NECA. With an annual time of 5000 hours in a NECA zone the additional cost is up to 5% to 6% only.

---

[15] See section about SO_x emissions reduction costs

6.1.1.2.3 Applied assumptions for the calculation of total cost

Investment data for new vessels are taken into account (Table 4). In fact, only new vessels must be in accordance with the limits of the NECA.

Calculations are made with the annual average times spent in the Mediterranean NECA zone from Table 7, but also with alternatives assumptions of 2000 h (T2) and of 5000 h (T3) that would correspond to the implementtion of NECA zones all over the world (according to OECD, 2016, this "5000 h" corresponds to the average annual time spent at sea for all vessels).

Table 7 Presence times in the Mediterranean NECA zone used in the calculations

	Duration in NECA zone (hours)		
Hypotheses	T1	T2	T3
Tankers-cargos	1135	2000	5000
Passengers	1310	2000	5000
Other	735	2000	5000

Calculations are also made for life times of 20 and 25 years (V1 and V2) since this parameter influences the annualised investment cost. We therefore have tested the following hypotheses: T1V1, T1V2, T2V1, T2V2, T3V1, T3V2. All calculations are made assuming an engine efficiency of 50%. Calculations are made for the three categories of vessels and their average characteristics. Table 8 to Table 10 show examples of results.

Table 8 Investment and operating costs of SCR for a type tanker/cargo ship with a 12 MW engine

Nominal power	MW	12
Presence time in the NECA	h/year	1135
Annualisation period	Year	20
Motor load charge	%	74
Fuel consumption in SECA	t/year	874
Investment	**€**	**715 965**
Annualised investment	**€/year**	**52 682**
Fixed operating costs	€/year	8 592
Urea consumption	€/year	11 665
Catalyst replacement	€/year	2 803
Total operating costs	**€/year**	**23 059**
Fuel economy	€/year	4 123
Total annual costs	**€/year**	**71 618**
Annual costs/t Fuel	**€/t fuel**	**82**

Table 9 Investment and operating costs of SCR for a passenger-type vessel with an 8-MW engine

Nominal power	MW	8
Presence time in the NECA	h/ year	1 310
Annualisation period	Year	20
Motor load charge	%	68
Fuel consumption in SECA	t/year	620
Investment	**€**	**479 080**
Annualised investment	**€/year**	**35 252**
Fixed operating costs	€/year	5 749
Urea consumption	€/year	8 279
Catalyst replacement	€/year	1 989
Total operating costs	**€/year**	**16 017**
Fuel economy	€/year	2 926
Total annual costs	**€/year**	**48 342**
Annual costs/t Fuel	**€/t fuel**	**78**

Table 10 Investment and operating costs of SCR for other types of vessels

Nominal power	MW	4
Presence time in the NECA	h/year	730
Annualisation period	Year	20
Motor load charge	%	56
Fuel consumption in SECA	t/year	149
Investment	**€**	**250 455**
Annualised investment	**€/year**	**18 429**
Fixed operating costs	€/year	3 005
Urea consumption	€/year	1 986
Catalyst replacement	€/year	477
Total operating costs	**€/year**	**5 469**
Fuel economy	€/year	702
Total annual costs	**€/year**	**23 196**
Annual costs/t Fuel	**€/t fuel**	**155.9**

Since the fuel consumption corresponding to each group of vessels is known, the cost of reducing NO_x expressed in terms of fuel mass is used to estimate the total annual cost of emission reduction. The input data used are presented in Table 11.

Table 11 Input data for annual cost calculations

	Number of Vessels	Consumption of MGO 0.1% kt/year	NOx Emissions REF_MGO 0.5% kt/year	NOx Emissions SN100 kt/year	Avoided NOx Emissions for SN100 kt/year
Tankers-cargos	13 459	12.4	922	222	701
Passenger vessels	2 000	4.2	272	64	207
Other	1 274	0.4	25	6	19
Total	16 733	17.04	1219	292	927

6.1.2 Cost results

6.1.2.1 Costs of a SECA in the Mediterranean Sea

The reduction in SO_x emissions obtained by the various scenarios is presented in Table 12. It is necessary to remember that the reduction in the Sulphur content of fuels has a co-benefit on PM and BC emissions.

Table 12 Avoided SO_x emissions by scenarios and associated avoided emissions of NO_x, PM_{10}, $PM_{2.5}$ and BC

	Avoided Emissions				
Scenario shift	**SOx (kt)**	**PM_{10} (kt)**	**$PM_{2,5}$ (kt)**	**BC (kt)**	**NOx (kt)***
REF_15 > REFMGO 0.5%S	584	60	54	2.9	65 (MGO 0.5%)
REF_15 > SN100	698	68	61	4.9	65 (MGO 0.1%)
REF_MGO 0.5% S > SN100	114	7	6	2.0	65 (MGO 0.1%) + 927 (SCR)

Figure 39 shows the cost of fuel consumption of the 3 scenarios, based on the 3 price assumptions and with an average price of HFO 1.5% S as mentioned in table 3.

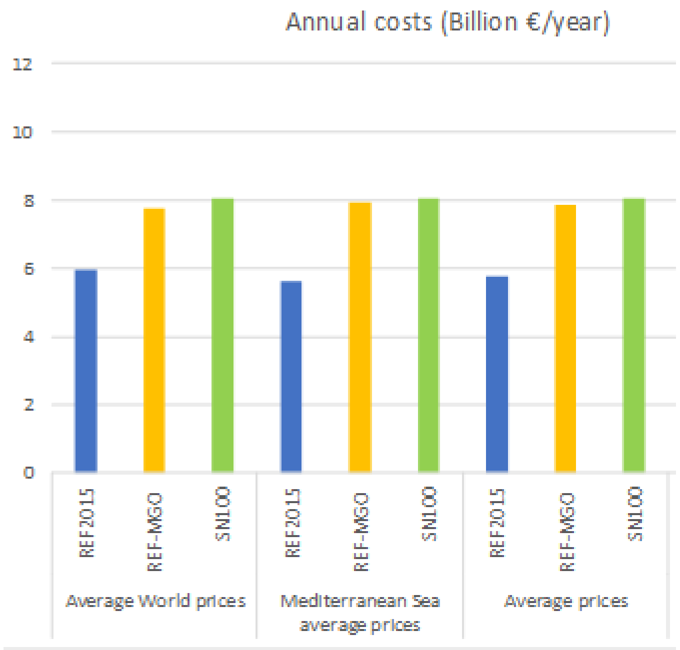


Figure 39 Marine fuel costs for scenarios and price assumptions with an average price for HFO 1.5%S

SO_x emission reductions are obtained with the following costs (Table 13), in the case of an average price for HFO 1.5%S.

Table 13 Costs of reducing SOx emissions for scenario and price hypothesis with an average price for HFO 1.5%S

Price hypotheses	**Scenario**	**Total annual costs Billion €**	**Cost efficiency ratio Avoided €/kg of SOx**
World □	REF15 > REFMGO	1.81	3.1
	REFMGO > SN100	0.27	2.4
	REF15 > SN100	2.08	3.0
Mediterranean □	REF15 > REFMGO	2.33	4.0
	REFMGO > SN100	0.10	0.9
	REF15 > SN100	2.44	3.5
Average □	REF15 > REFMGO	2.07	3.5
	REFMGO > SN100	0.19	1.7
	REF15 > SN100	2.26	3.2

Figure 40 shows the cost of fuel consumption of the 3 scenarios, based on the 3 price assumptions with high price of HFO 1.5% S.

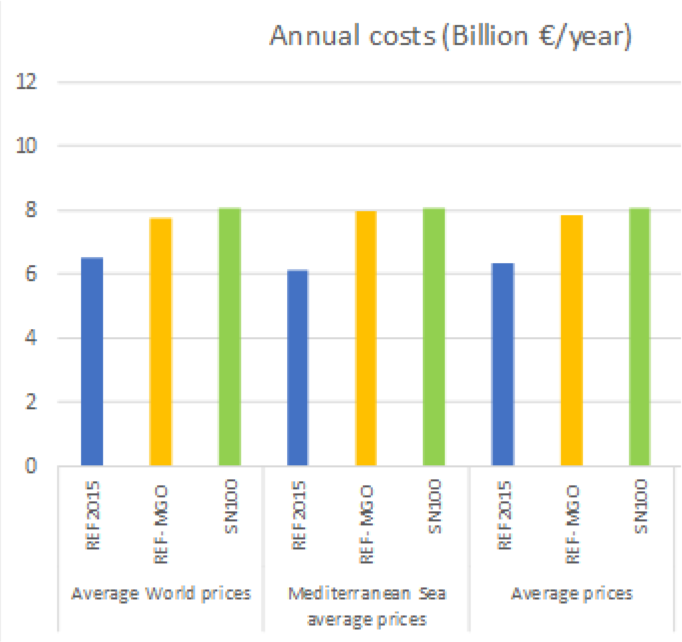


Figure 40 Marine fuel costs for scenarios and price assumptions with high price for HFO 1.5% S

SO_x emission reductions are obtained with the following costs (Table 14), in the case of high price for HFO 1.5%S.

Table 14 Costs of reducing SOx emissions per scenario and price hypothesis with high price for HFO 1.5%S

Price hypotheses	**Scenario**	**Total annual costs Billion €**	**Cost efficiency ratio Avoided €/kg of SOx**
World ▫	REF1516 > REFMGO	1.25	2.1
	REFMGO > SN100	0.27	2.4
	REF1516 > SN100	1.52	2.2
Mediterranean ▫	REF1516 > REFMGO	1.83	3.1
	REFMGO > SN100	0.10	0.9
	REF1516 > SN100	1.94	2.8
Average ▫	REF1516 > REFMGO	1.54	2.6
	REFMGO > SN100	0.19	1.7
	REF1516 > SN100	1.73	2.5

The additional costs of switching to fuels at 0.5% S (REF_MGO) and 0.1% S (SN100) are lower in the case of the high price hypothesis for HFO 1.5% S (which only affects the cost of REF_1516). The cost-effectiveness ratio of scenarios shifts from REF1516 to REF_MGO and to SN100 is thus better.

The cost of implementing a SECA zone in the Mediterranean Sea depends on the price differential of marine fuels at 0.1% S and 0.5% S.

It appears that applying average marine fuel prices derived from (Entec, 2002), the implementation of a SECA zone in the Mediterranean Sea would have a "relatively" low additional cost compared to the scenario REF_MGO 0.5% S (which corresponds to MARPOL VI), from €0.10 to €0.27 billion/year. The costs are 1.25 to 1.83 billion €/year to shift scenarios from the REF_15 to REF_MGO 0.5% S.

These additional costs are higher if the fuel price differentials from REMPEC's MGO/HFO fuels are considered. The additional cost of the SECA (or SN100) scenario compared to the REF MGO 0.5% S scenario is then 1.25 billion €/year and the cost is 2.05 billion €/year to switch from REF_15 to REF_MGO 0.5% S (Table 14).

The cost-effectiveness ratio varies from 2.2 to 2.8 €/kg avoided SOx for the scenario shift SN100 / REF 2015 and from 0.9 to 2.4 €/kg avoided SOx for the scenario shift SN100 / REF MGO 0.5% S with prices from (Entec, 2002). According to this information, the average price differentials between MGO 0.1% and HFO in 2015 are not very high.

Marine fuel prices will change significantly in the near future, which will affect the cost-effectiveness ratio. This should be kept in mind when considering the results obtained in this study.

6.1.2.2 Costs of a NECA for various scenarios and synthesis

The estimated costs for the 6 groups of assumptions presented in paragraph 6.1.1.2.3 are presented in Table 15.

Table 15 Annual costs by hypotheses in terms of annual average time spent in the NECA and life time (T1V1, T1V2, T2V1, T2V2, T3V1, T3V2)

	T1V1	T1V2	T2V1	T2V2	T3V1	T3V2
Total annual costs of reducing NOx emissions (Billion €/year)						
Tankers-cargos	1.017	0.919	0.640	0.585	0.345	0.322
Passengers	0.331	0.300	0.234	0.213	0.124	0.115
Others	0.062	0.056	0.026	0.023	0.013	0.012
Total	1.410	1.274	0.899	0.822	0.482	0.450
Cost efficiency ratio (€/Avoided kg NOx)						
Tankers-cargos	1.45	1.31	0.91	0.83	0.49	0.46
Passengers	1.60	1.44	1.13	1.03	0.60	0.56
Others	3.28	2.94	1.36	1.23	0.69	0.64
Total	1.52	1.37	0.97	0.89	0.52	0.48

The annual cost changes depend on the assumptions taken into account. The hypotheses T1V1, T1V2, T2V1 and T2V2 give the possible ranges for the Mediterranean NECA zone. Hypotheses T3V1 and T3V2 test a case in which NECA would be implemented in many zones of the world (5000 h in NECA Zone).

The annual costs of setting up a NECA zone in the Mediterranean Sea range from 1.274 to 1.41 billion Euros per year. The cost-effectiveness ratio ranges from 1.37 to 1.52 €/avoided kg NOx. In fact, with larger and more NECA zones around the world, the annual costs decrease, and consequently the cost-effectiveness ratio becomes better.

These costs are available in the following figures:

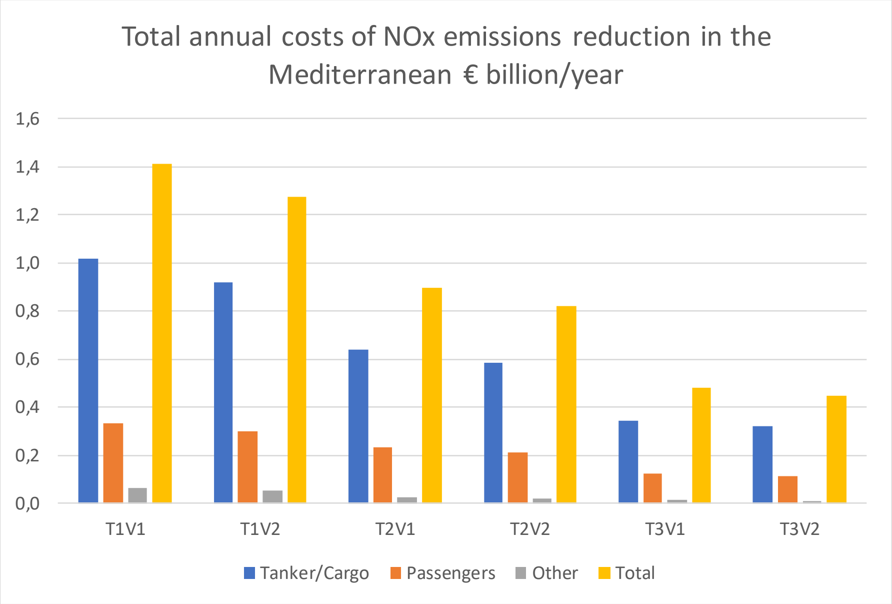


Figure 41 Total annual costs per hypotheses for calculating the annual costs of NOx emission reductions

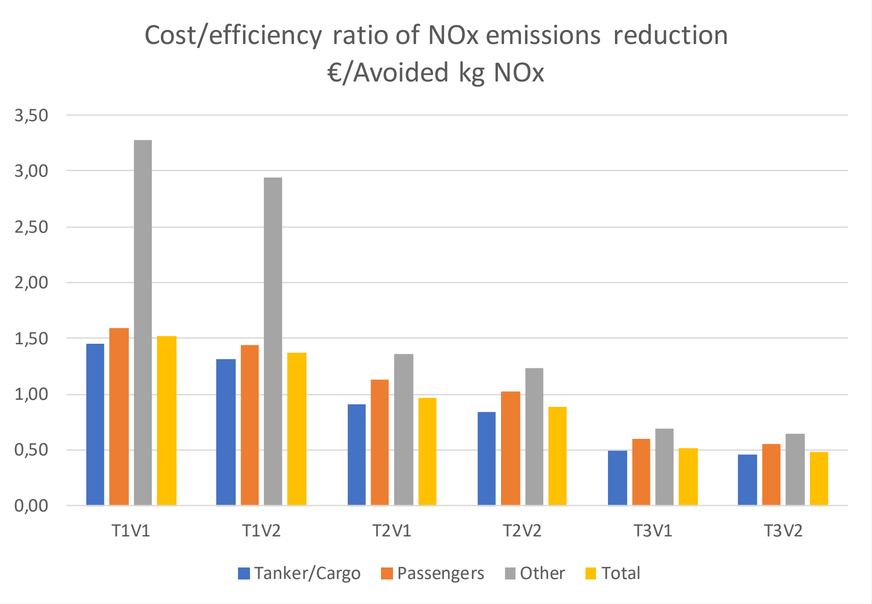


Figure 42 Cost/efficiency ratio per hypotheses for calculating the annual costs of NOX emission reductions

Cost-effectiveness ratios are comparable to those obtained by IVL (Psarmo, 2017) of 0.69 to 1.87 €/avoided kg NOx to establish a NECA in the Baltic and North Seas. IVL estimates cost-effectiveness ratios between 0.16 to 0.74 €/avoided kg NO_x, in the case of more extended NECA zones in the world. VITO estimates the ratio of 1.10 €/avoided kg NO_x in a European Seas study. This ratio is valid on average and for the case of Black Sea and the Mediterranean.

6.2 Health impact assessment and benefits

Air quality results from CHIMERE presented in paragraph 5 are combined with data on population densities to calculate population exposure to different pollutants. These data are then used in the health impact assessment (HIA) to calculate health impacts associated with each scenario and monetised health benefits from reduced exposure to fine particulate matter, ozone and nitrogen dioxide. The benefits are then compared with the mitigation costs estimated in the previous section.

6.2.1 Methodology

The HIA tool used for the ECAMED study is the Alpha-RiskPoll (ARP)[16] model which is regularly used in European Policy analyses such as the CAFE (Clean Air For Europe) programme. ARP uses the methods for benefits assessment that were first developed under the EC funded ExternE project (External cost of Energy[17]) during the 1990s. These methods have been applied since the end of the 1990s to cost-benefit assessments of EC and UNECE[18] policies and were thoroughly reviewed (WHO, 2013a and b). The methodology is extensively documented in Holland et al. (2014a and 2014b), and the above cited reviews. The methods developed in and applied in ARP comprise concentration-response functions (CRFs) linking levels of pollutant exposure to specific health impacts (also called “end-points” in terms of mortality and morbidity), as well as monetary indicators and values as explained below and synthesised in Table 16.

Table 16 Synthesis of health impacts (mortality and morbidity) considered in the ECAMED HIA and their monetary unit values

Health impact	**Impact unit**	**Pollutant**	**Unit valuation (€ price base 2015)**
Acute Mortality (All ages) median VOLY*	Premature deaths	O_3	66 728
Respiratory hospital admissions (>64)	Cases		2 567
Cardiovascular hospital admissions (>64)	Cases		2 567
Minor Restricted Activity Days (MRADs all ages)	Days		49
Chronic Mortality (All ages) LYL median VOLY	Life years lost	$PM_{2.5}$	66 728
Chronic Mortality (30yr +) deaths mean VSL**	Premature deaths		2 567 364
Infant Mortality (0-1yr) mean VSL	Premature deaths		3 851 047
Chronic Bronchitis (27yr +)	Cases		61 987
Bronchitis in children aged 6 to 12	Cases		680
Respiratory Hospital Admissions (All ages)	Cases		2 567
Cardiac Hospital Admissions All ages)	Cases		2 567
Restricted Activity Days (all ages)	Days		106
Asthma symptom days (children 5-19yr)	Days		49
Lost working days (15-64 years)	Days		150
Bronchitis in children aged 5 to 14	Cases	NO_2	680
Respiratory Hospital Admissions (All ages)	Cases		2 567
Chronic Mortality (All ages) LYL median VOLY	Life years lost		66 728
Chronic Mortality (30yr +) deaths mean VSL	Premature deaths		2 567 364
(*) VOLY = Value of Life Year ; (**) VSL = Value of Statistical Life ; values for the willingness to pay by society to reduce the risk of premature mortality.			
Concentrations response functions according to WHO/Europe (2013) - HRAPIE study - Health Risks of Air Pollution in Europe. 67% of NO_2 chronic mortality accounted for in monetary cost (benefit) to avoid risk of double counting with $PM_{2.5}$ chronic mortality.			

---

[16] Developed by EMRC (Michael Holland and Joseph Spadaro).

[17] http://www.externe.info/externe_d7/

[18] United Nations Economic Commission for Europe.

The health impact assessment tool ARP quantifies and monetises morbidity and mortality amongst the population from exposure to ozone (acute effects), nitrogen dioxide (chronic and acute effects) and $PM_{2.5}$ (chronic and acute effects). ARP's data bases comprise population data by country and age class, and for each health end point country specific incidence rates.

The level of health effects related to a given air quality (e.g. of a given scenario in the present study) is assessed by applying the pollutant specific concentration-response functions to the respective population exposure. The quantification of health impacts is specific to the age classes for which concentration response functions were developed based on epidemiological studies. No distinction is made between different income groups in the quantification of health impacts. The monetary equivalent of the health impacts is then calculated by applying the health effect specific constant monetary unit values. In line with common practice in the EU, average unit damage costs are used. They are established on Willingness To pay (WTP) studies that are based on the results of surveys distributed to a representative sample of the (heterogeneous) population. The WTP values used are specific to health impacts caused by air pollution. The monetary value employed for costs of absenteeism to employers is independent of the reason for the absence; and the costs for healthcare are specific to the morbidity type assessed and not to its origin (air pollution or other causes). These unit costs are multiplied with the annual cases caused by air pollution.

In the present study, concentration-response functions issued from epidemiological studies considered relevant for Europe (WHO 2013a and WHO 2013b) have been applied to all countries in the ECAMED domain (including non-EU countries). Similarly, monetary unit values established from European studies have been used for all countries, reflecting the need for a common decision for all countries.

There is an ongoing discussion about which of two alternative metrics should preferably be used to quantify mortality effects from air pollution: loss of life expectancy expressed as total number of years of life lost (YOLL) per year across the population and valued using the metric Value of Life Year (VOLY); or premature deaths brought forward expressed as number of deaths per year and valued using the Value of Statistical Life (VSL). Following the recommendations of expert review teams involved in EU health assessment studies, attributable deaths, valued by VSL, are therefore used alongside estimates based on YOLL in current European policy analyses.

A further methodological discussion exists around the question of whether to use mean or median estimates issued from WTP surveys. While mean values fully summarise the heterogeneity of values in the sample, median values are more robust, being not influenced by outliers, which can be prevalent in stated preference studies.

Current assessments of benefits of proposals for European air quality policies (Holland et al., 2011a, Amann et al., 2017) mainly focus on the use of the median VOLY in order to provide a baseline for the assessment, because it is a conservative measure (the median being lower than the mean). These studies nevertheless put the results obtained also into perspective with the higher end estimate using the mean VSL. We follow this approach in ECAMED.

Following the recommendation of WHO (2013a) via the HRAPIE study, ARP uses a set of linear concentration response functions with no effective threshold for $PM_{2.5}$ at the population level (. For ozone also, linear response functions are adopted against the metric SOMO35. The 35ppb baseline for SOMO35 was considered in the HRAPIE report not to be a threshold, but to be a 'cut-point' for analysis, above which estimates of impact could be quantified with higher confidence than below. However, for the purposes of the CBA the effect of a ‘cut-point’ or a threshold is the same.

All details of the methodology can be found in (Schucht et al., 2015, Holland 2014 a and b, and Amann et al., 2017).

Population data comes from the UN database[19] established in 2017 for the year 2015. The population by country and the part of this population included and considered in the ECAMED geographical domain are given in Table 17.

Table 17 Population data used in the ECAMED health impact assessment (UN, 2017)

Country	Total population	Percentage of population considered in ECAMED	Size of population considered in ECAMED
Austria	8 678 657	8,9%	770 346
Bulgaria	7 177 396	100,0%	7 177 396
Croatia	4 236 016	100,0%	4 236 016
Cyprus	1 160 985	100,0%	1 160 985
France	64 457 201	41,5%	26 756 122
Greece	11 217 800	100,0%	11 217 800
Hungary	9 783 925	25,1%	2 457 200
Italy	59 504 212	100,0%	59 504 212
Malta	427 616	100,0%	427 616
Romania	19 876 621	81,9%	16 272 408
Slovenia	2 074 788	100,0%	2 074 788
Spain	46 397 664	69,2%	32 107 852
Albania	2 923 352	100,0%	2 923 352
Bosnia and Herzegovina	3 535 961	100,0%	3 535 961
TFYR Macedonia	2 079 308	100,0%	2 079 308
Moldova	4 065 980	33,4%	1 358 114
Russian Federation	143 888 004	3,7%	5 374 169
Serbia and Montenegro (incl. Kosovo)	9 479 458	100,0%	9 479 458
Switzerland	8 319 769	36,3%	3 017 673
Turkey	78 271 472	93,1%	72 906 928
Ukraine	44 657 704	13,2%	5 906 991
Palestina	4 662 884	100,0%	4 662 884
Algeria	39 871 528	100,0%	39 871 528
Egypt	93 778 172	66,6%	62 489 925
Georgia	3 951 524	1,4%	56 704
Iraq	36 115 649	0,0%	17 227
Israel	12 727 431	94,9%	12 072 850
Jordan	9 159 302	100,0%	9 159 302
Lebanon	5 851 479	100,0%	5 851 479
Libya	6 234 955	92,0%	5 735 925
Morocco	34 803 322	9,7%	3 363 460
Saudi Arabia	31 557 144	1,2%	391 452
Syria	18 734 987	94,4%	17 684 277
Tunisia	11 273 661	100,0%	11 273 661
ECAMED domain	**840 935 927**	**52,4%**	**443 375 369**

---

[19] UN (2017) World Population Prospects – Medium Projections

6.2.2 Results

All the end-points presented in Table 16 have been quantified and monetised for various ECAMED scenarios and for each country (considering the part of population within the domain, cf. Table 17).

6.2.2.1 Health benefits

A selection of results are presented below for the whole domain and country by country, highlighting the impact of the Global Sulphur Cap 2020 compared to the current situation, and additional impacts attributable to the implementation of a SECA/NECA.

Figure 43 and Figure 44 present impacts in terms of reduced mortality (years of life lost) attributable to $PM_{2.5}$ exposure. The first one shows results aggregated over the ECAMED domain and the other provides the same information country by country. Health impacts (benefits) of the SECA/NECA are reduced (increased) by more than an additional third compared to the impact of the 2020 sulphur regulation. Algeria, Egypt, Italy and Turkey are the main beneficiaries in terms of life years gained.

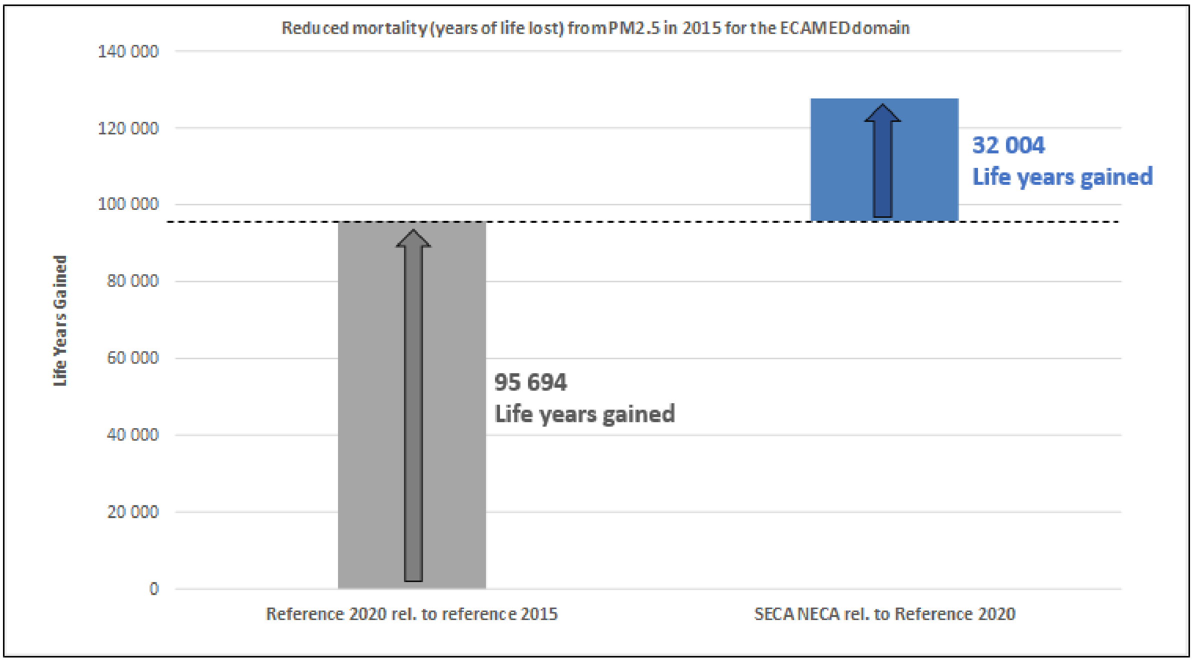


Figure 43 Reduction in $PM_{2.5}$ mortality (life years) - overall ECAMED domain

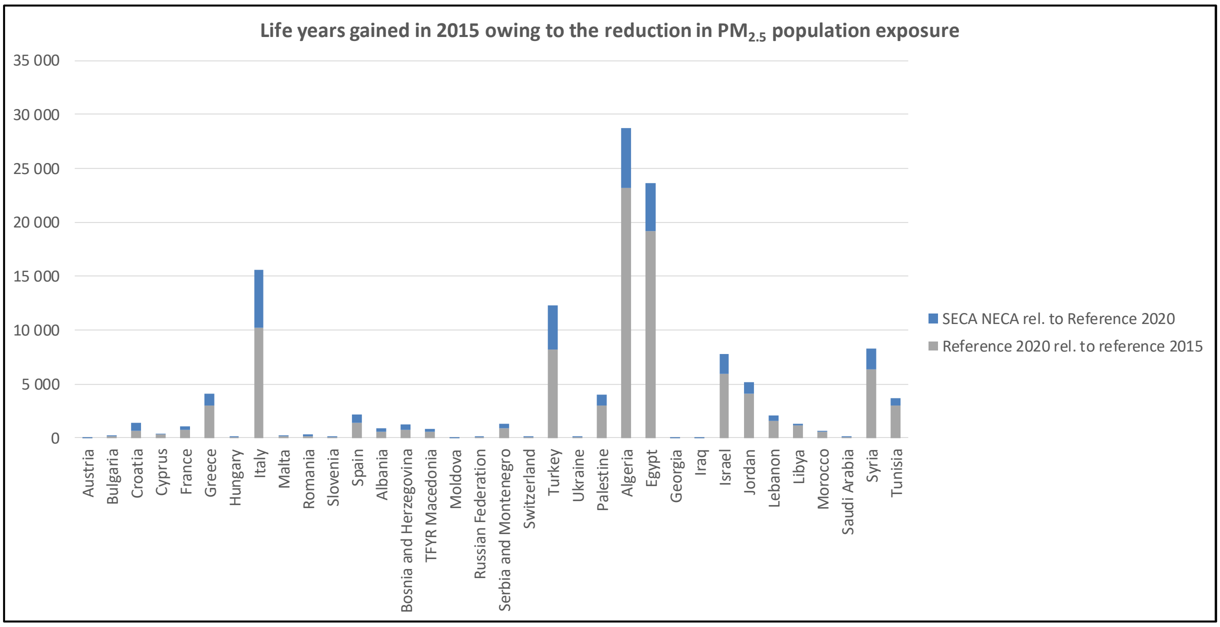


Figure 44 Reduction in $PM_{2.5}$ mortality (life years) – ECAMED domain per country

Figure 45 and Figure 46 show the results for the second (alternative) indicator to assess mortality: the impact expressed in terms of premature deaths. The same conclusions as in the previous figures hold: implementation of a SECA/NECA brings additional benefits with about 40% additional avoided premature deaths compared to the impact of the 2020 legislation.

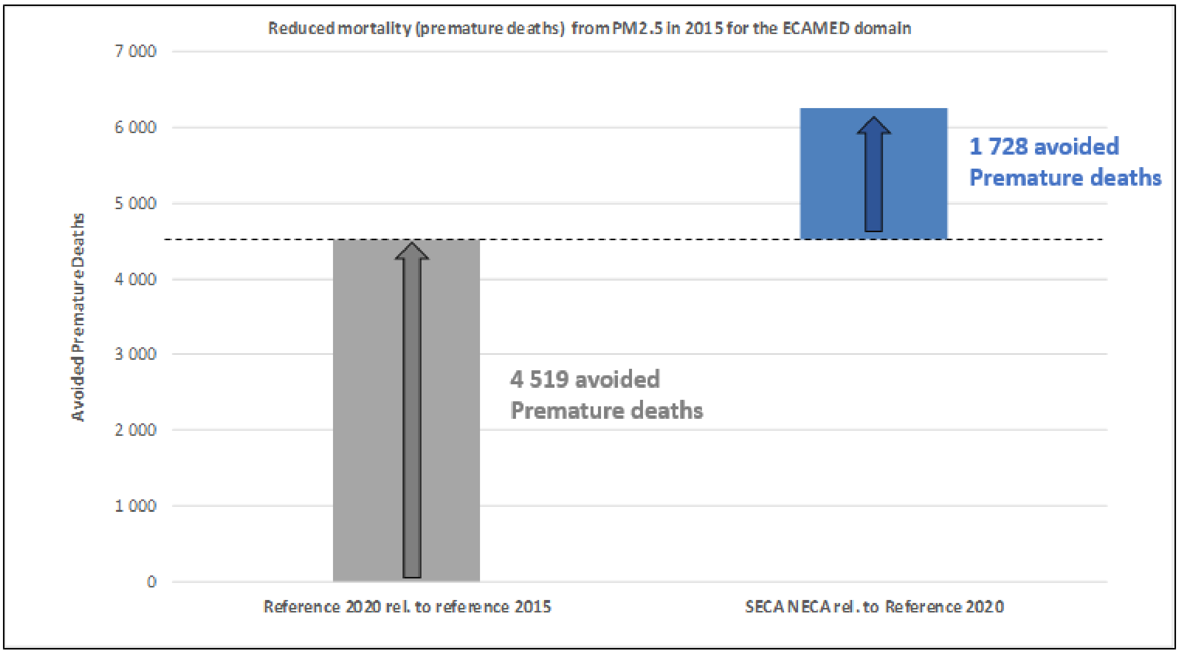


Figure 45 Reduction in $PM_{2.5}$ mortality (premature deaths) – overall ECAMED domain

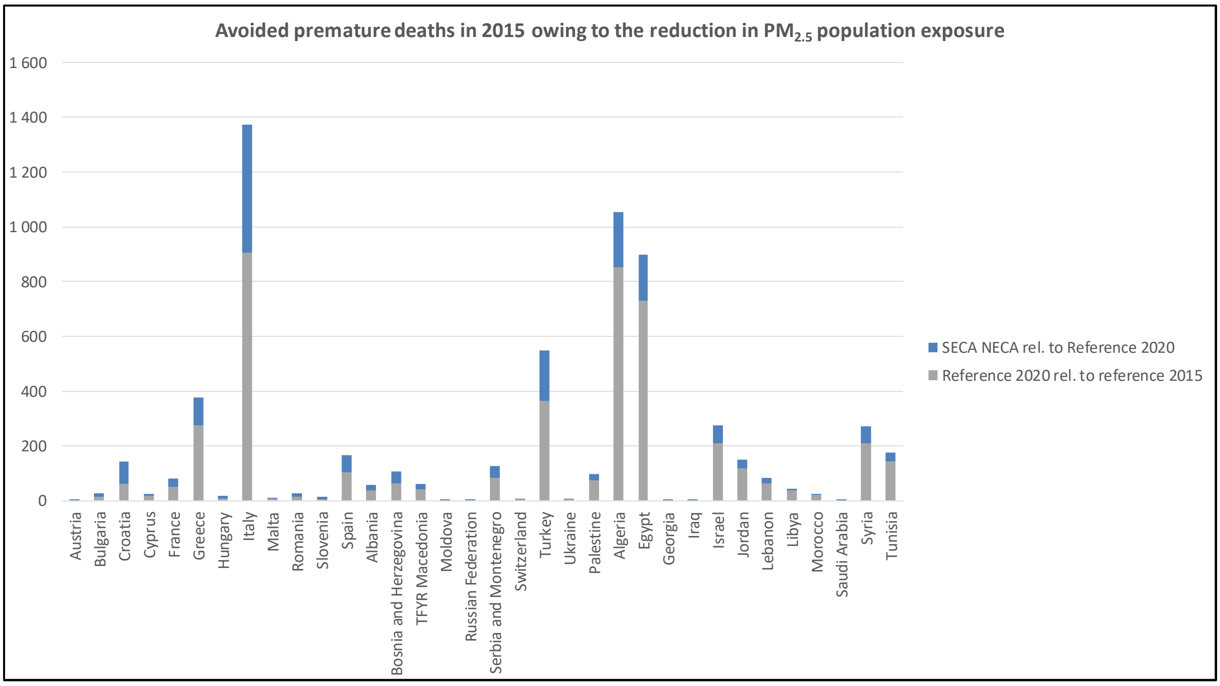


Figure 46 Reduction in $PM_{2.5}$ mortality (premature deaths) – ECAMED domain per country

Figure 47 to Figure 50 illustrate examples of results related to selected morbidity indicators attributable to $PM_{2.5}$ exposure (results for the other pollutants and other end-points are also available): reduced work days loss and avoided cases of chronic bronchitis. The results are given for the overall ECAMED domain and by country. They show significant additional benefits attributable to the SECA/NECA strategy compared to the 2020 legislation.

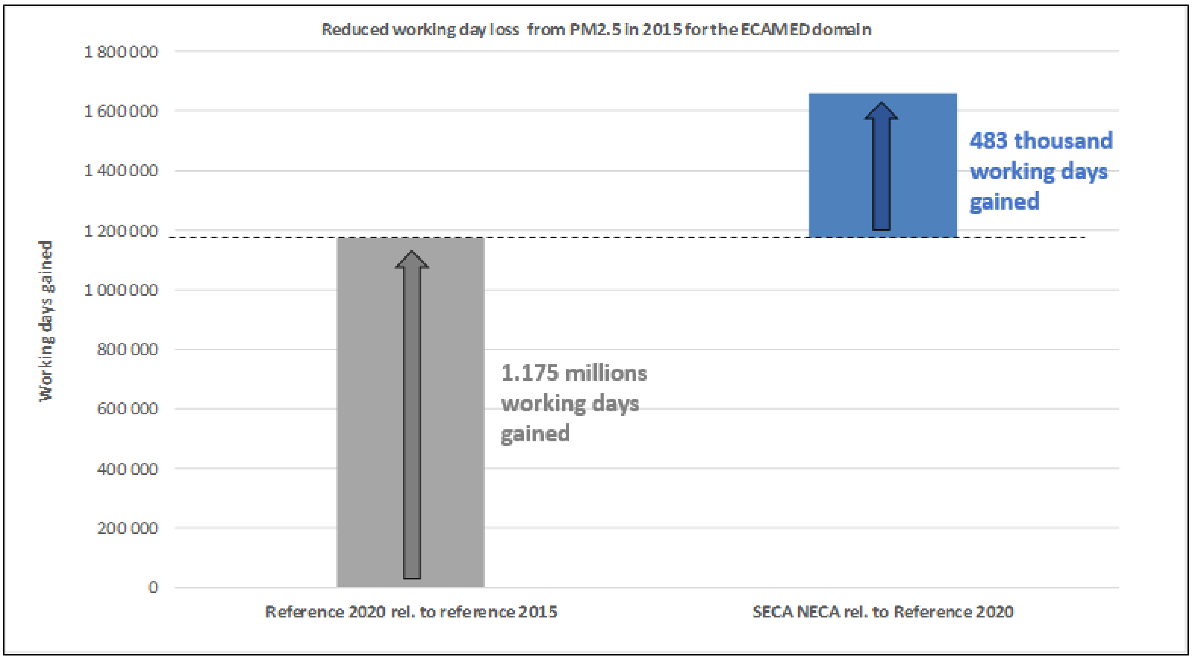


Figure 47 Reduction in working days lost from $PM_{2.5}$ – ECAMED domain

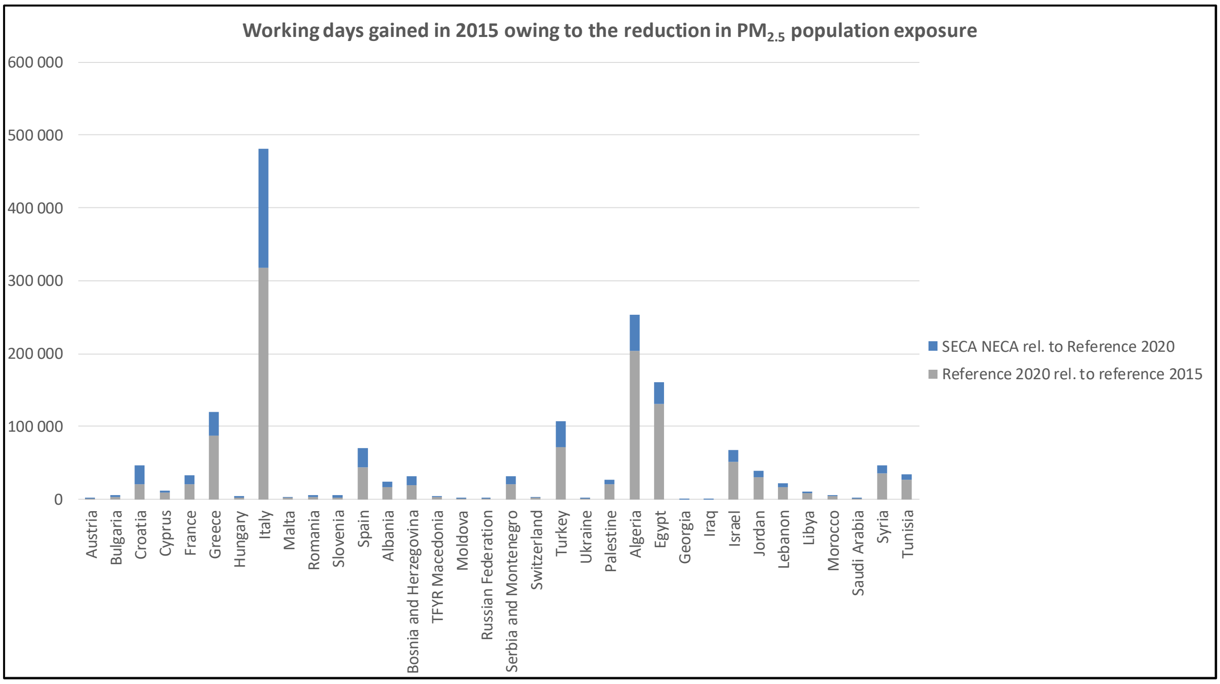


Figure 48 Reduction in working days lost from $PM_{2.5}$ – ECAMED domain per country

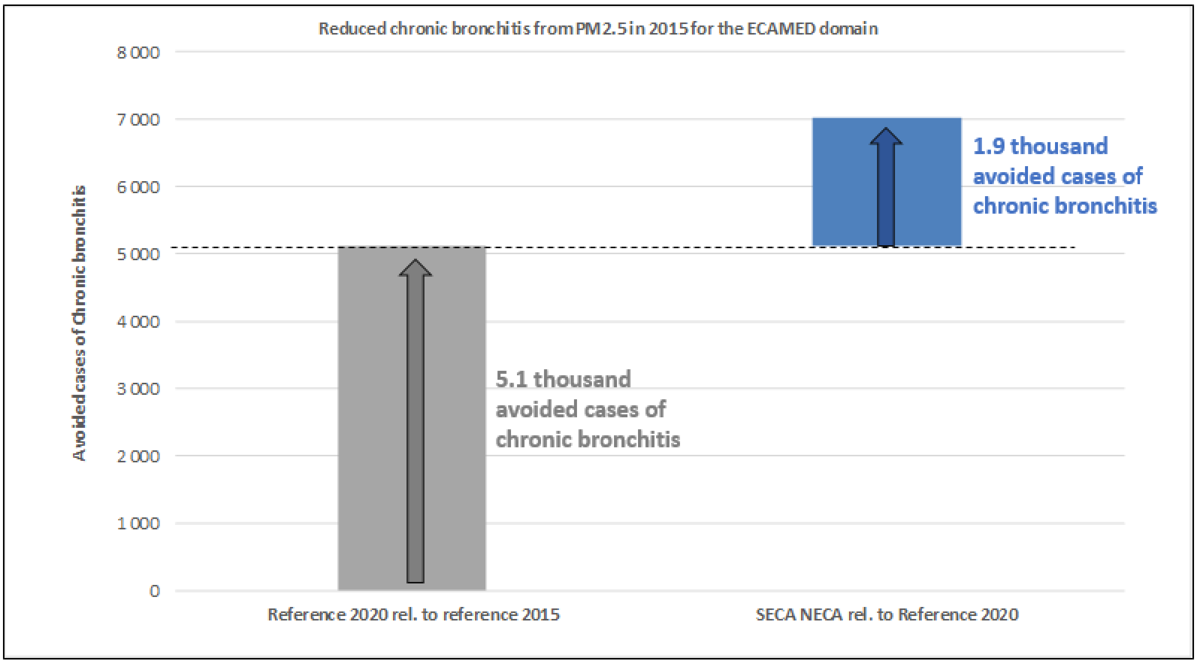


Figure 49 Reduction in chronic bronchitis from $PM_{2.5}$ – ECAMED domain

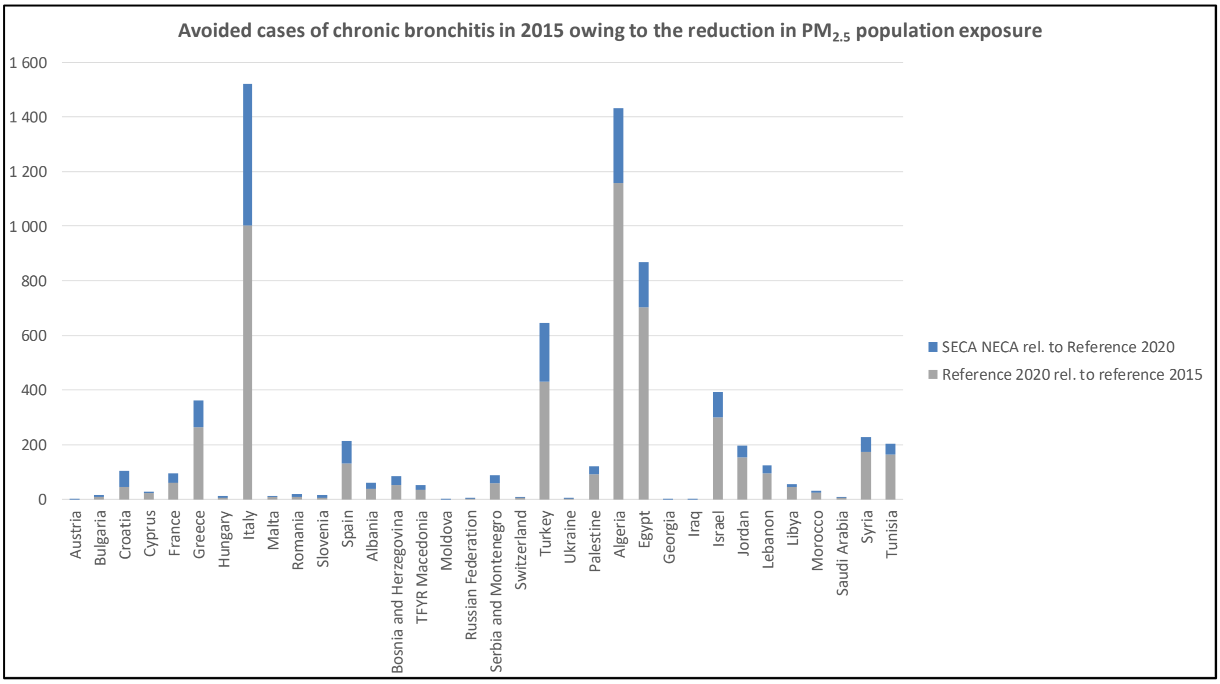


Figure 50 Reduction in chronic bronchitis from $PM_{2.5}$ – ECAMED domain per country

6.2.2.2 *Monetised health benefits*

The previous results from the HIA can be translated into monetary values using the reference unit values presented in Table 16.

As examples Figure 51 and Figure 52 illustrate the monetary benefits (expressed in 2015 price base) that represent avoided premature deaths and a reduced number of cases of chronic bronchitis. In both cases additional benefits of 40%, compared to the benefits achieved with the implementation of the 2020 regulation, are expected.

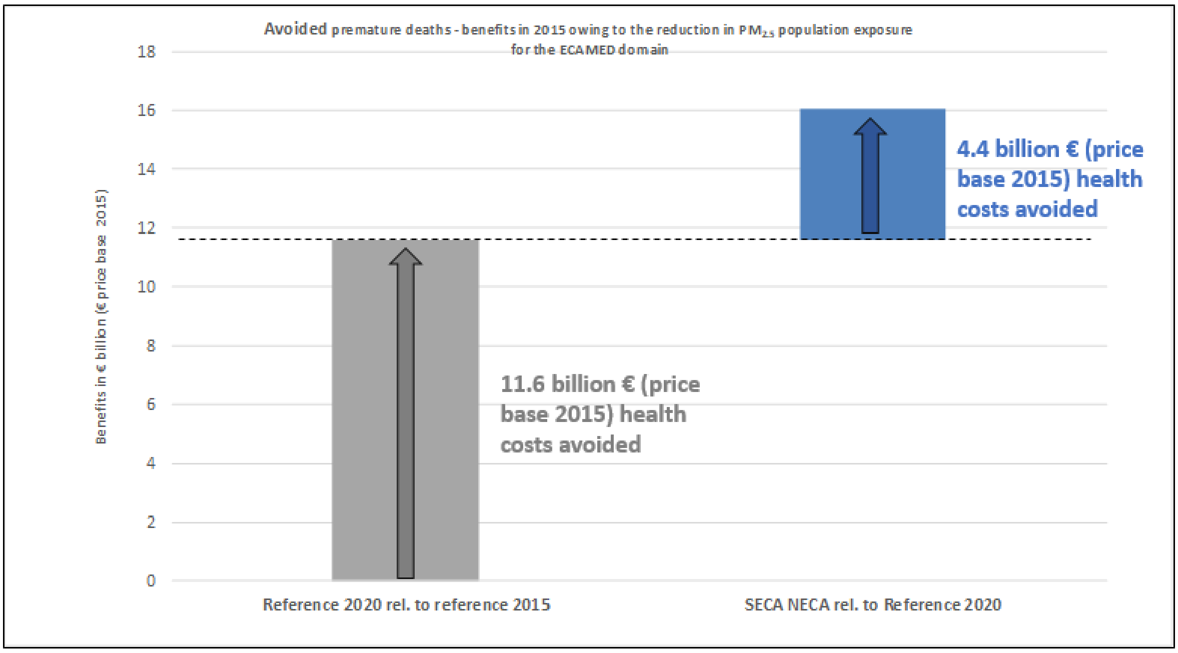


Figure 51 Avoided premature deaths – benefits from reduced exposure to $PM_{2.5}$ in the ECAMED domain

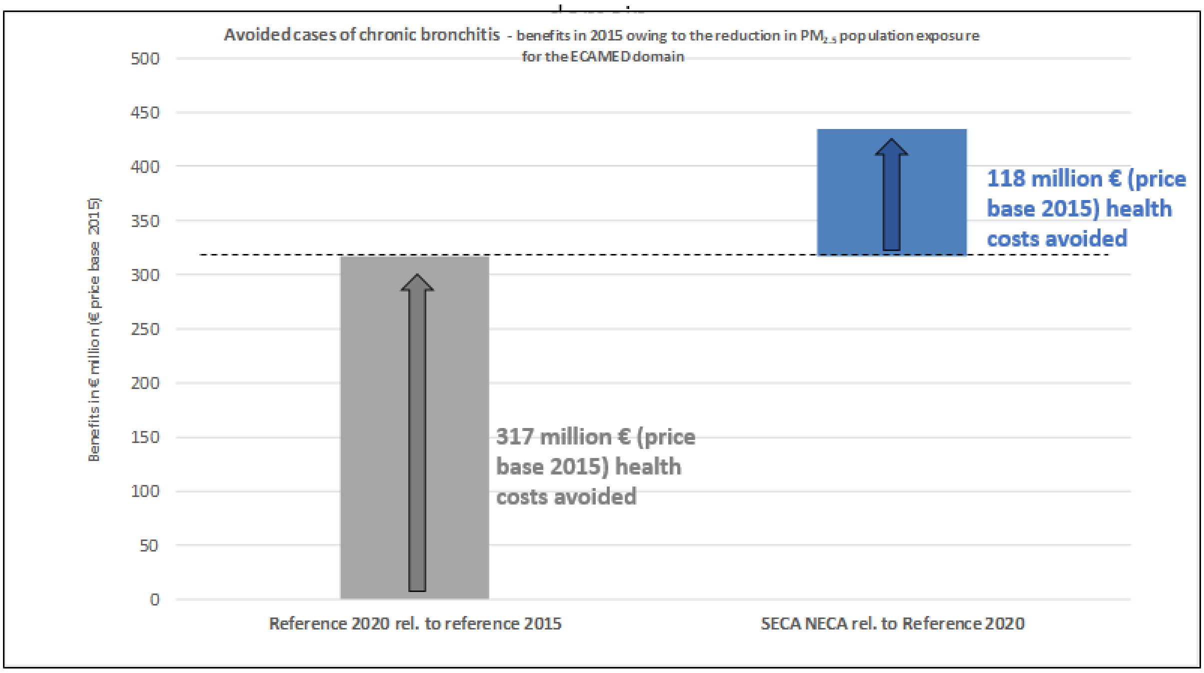


Figure 52 Avoided cases of chronic bronchitis - benefits from reduced exposure to $PM_{2.5}$ in the ECAMED domain

The aggregated results for mortality and morbidity associated with exposure to $PM_{2.5}$, ozone and NO_2 are given in Figure 53 and commented below.

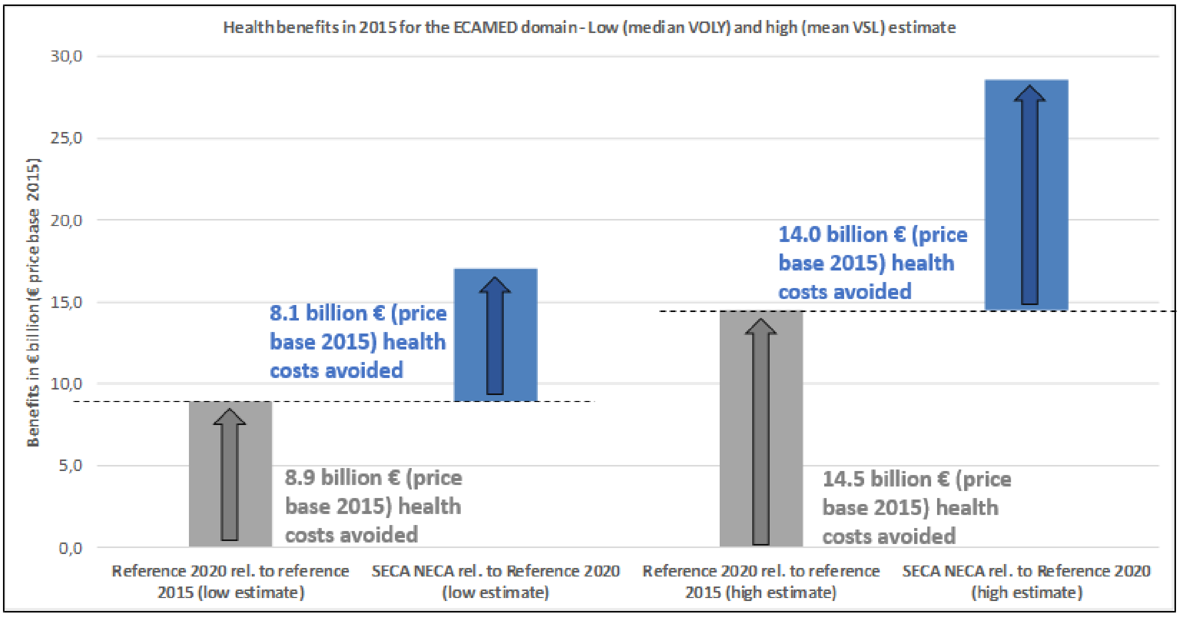


Figure 53 Aggregate health benefits - overall ECAMED domain

Figure 53 illustrates the monetized benefits results aggregated over all health end-points and the whole ECAMED domain. As explained in the methodology description (paragraph 6.2.1), two estimates are proposed: a low estimate which uses the reduction of life expectancy as mortality end-point and monetizes it with the lower median unit value, and the high estimate which uses the number of premature death as mortality indicator and monetizes it with the higher mean unit value for this end-point. The conclusions are robust across the two indicators:

- Additional benefits attributed to the implementation of a SECA/NECA are very significant,
- In monetary terms, additional benefits are of the same order as the benefits expected from the implementation of the Global Sulphur Cap in 2020.

Such encouraging results can be explained by several reasons:

- Additional reduction of $PM_{2.5}$ exposure due not only to SO_x emissions reductions but also NO_X emissions reductions, since NO_X are precursors of PM formation as well,
- Additional benefits due to a reduction in exposure to NO_2 and to ozone.

These results highlight the essential need to develop combined SECA and NECA strategies to maximise achievable health benefits.

Table 18 details the aggregate monetary health benefit results country by country. The same results are displayed in histogram graphs for the low and high estimates in Figure 54 and Figure 55, respectively.

Algeria, Egypt, Italy and Turkey are found to be the main beneficiaries of the SECA/NECA policies considering raw results, but the picture changes a bit when the numbers are scaled by the number of inhabitants impacted in each country. Figure 56 and Figure 57 illustrate per capita benefits by country, for low and high estimates respectively. With this perspective, the benefits are more evenly distributed across the ECAMED countries. For countries boarding the Adriatic Sea (Croatia, Bosnia and Herzegovina, Albania), Greece, Cyprus, Malta but also Tunisia, Israel, Palestine and Syria, the health benefits become much more visible. Same indicators can be mapped to highlight categories of countries with respect with the benefits gained from the ECA implementation. Row benefits by country and benefits per capita for each Mediterranean country are displayed on Figure 58 and Figure 59.

Table 18 Health benefits – low and high estimate – ECAMED domain per country

Benefits, in million € (€ 2015)	**Reference 2020 rel. to reference 2015**		**SECA NECA rel. to Reference 2020**	
Low and high estimate	**median VOLY**	**mean VSL**	**median VOLY**	**mean VSL**
Austria	1	1	1	3
Bulgaria	11	40	11	35
Croatia	54	173	98	326
Cyprus	27	52	12	20
France	65	149	43	93
Greece	278	807	169	460
Hungary	6	19	9	26
Italy	1 011	2 805	1 243	3 695
Malta	11	22	3	6
Romania	13	38	13	37
Slovenia	6	14	10	24
Spain	126	302	96	230
Albania	55	113	35	68
Bosnia and Herzegovina	68	196	90	268
TFYR Macedonia	50	123	30	68
Moldova	0	1	1	1
Russian Federation	2	7	2	4
Serbia and Montenegro	76	232	66	196
Switzerland	4	9	3	6
Turkey	747	1 166	1 078	1 761
Ukraine	4	12	3	8
Palestine	221	213	499	475
Algeria	2 331	3 057	2 555	3 539
Egypt	1 645	2 240	500	640
Georgia	0	0	0	0
Iraq	0	0	0	0
Israel	662	850	776	1 027
Jordan	358	386	143	153
Lebanon	142	198	58	76
Libya	97	119	26	30
Morocco	47	65	11	15
Saudi Arabia	7	7	6	6
Syria	533	646	306	369
Tunisia	277	456	222	385
ECAMED domain	**8 936**	**14 521**	**8 117**	**14 048**

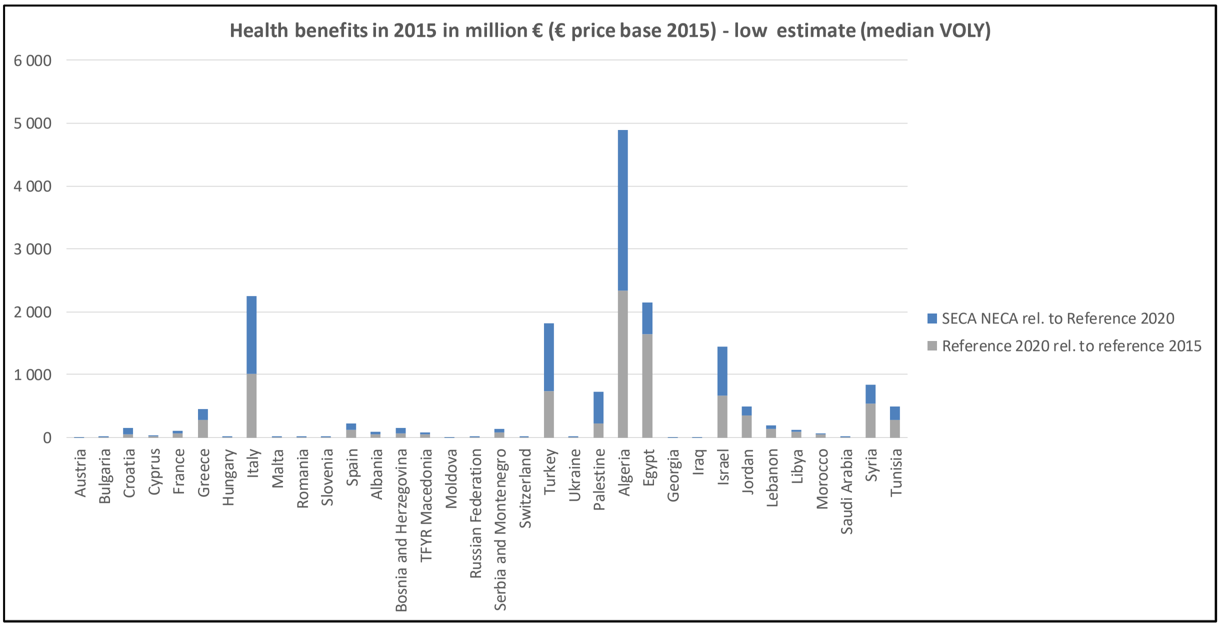


Figure 54 Health benefits - low estimate - ECAMED domain per country

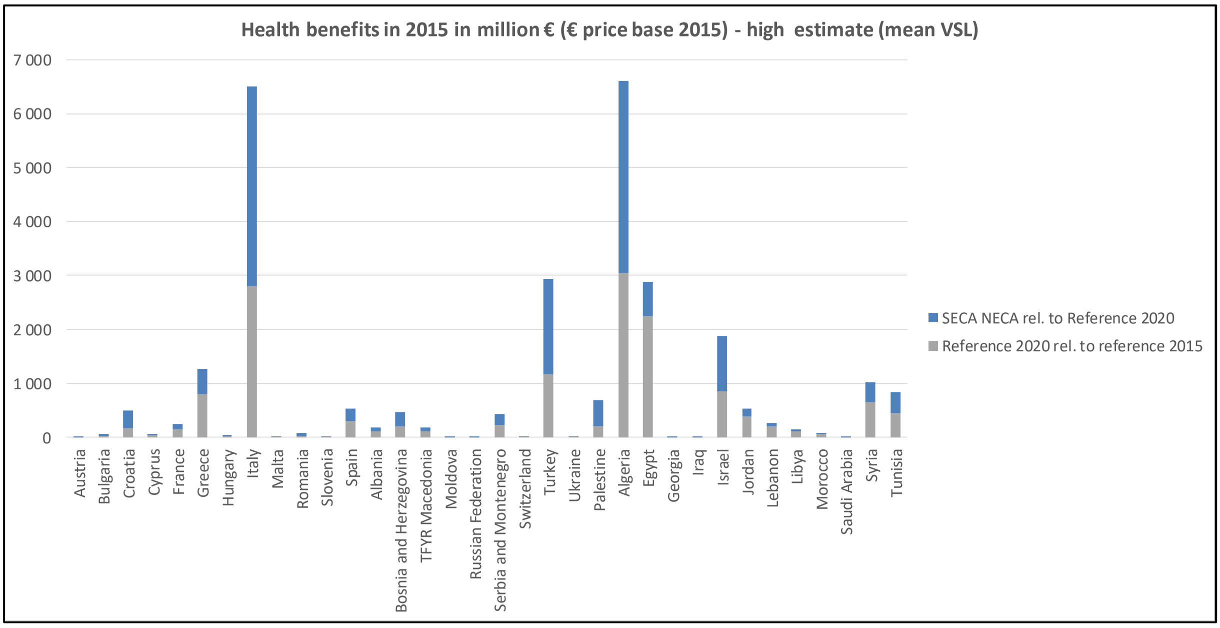


Figure 55 Health benefits - high estimate - ECAMED domain per country

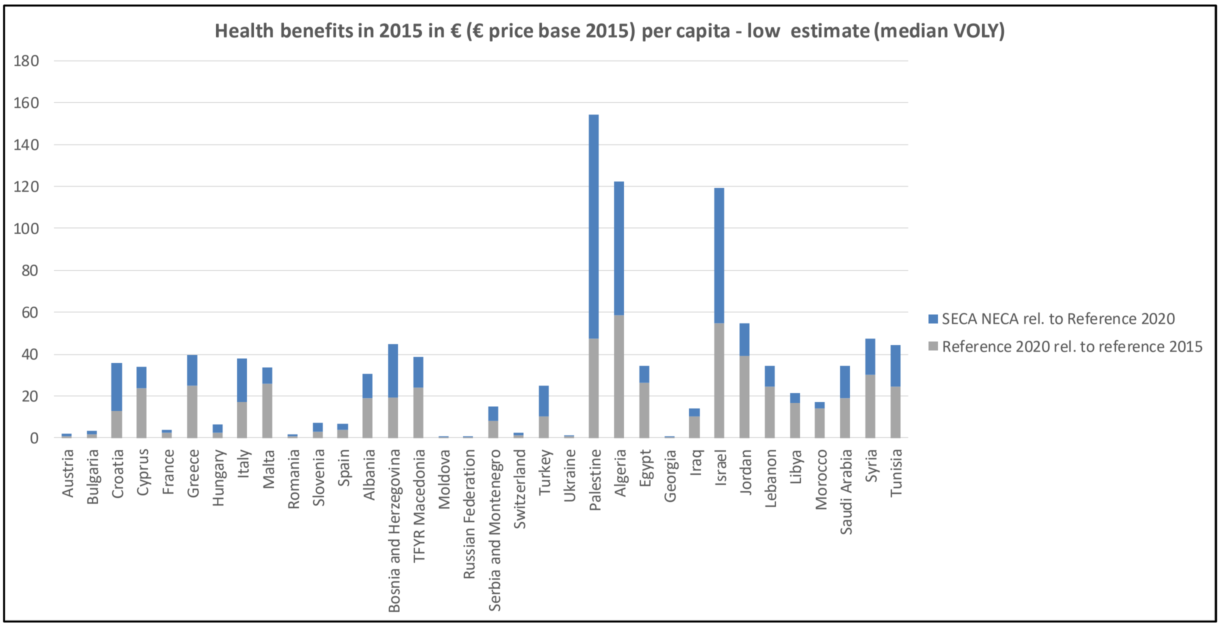


Figure 56 Health benefits per capita - low estimate - ECAMED domain per country

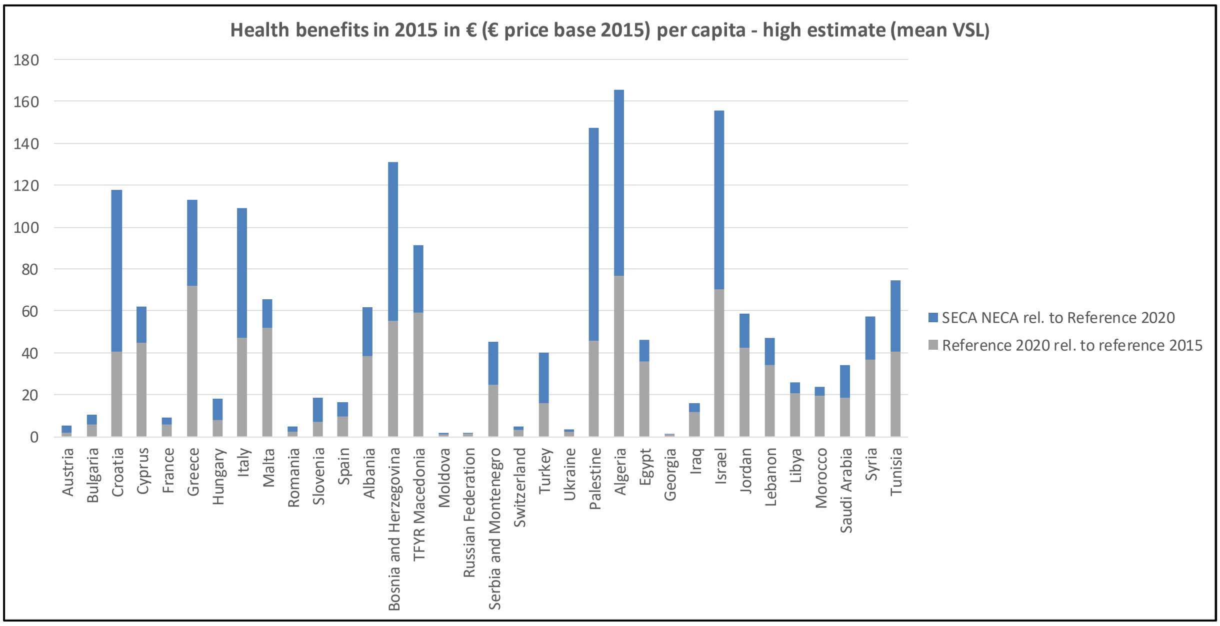


Figure 57 Health benefits per capita - high estimate - ECAMED domain per country

Figure 58 Health benefits of the implementation of the SECA/NECA compared to 2020 legislation (Meuros/year)

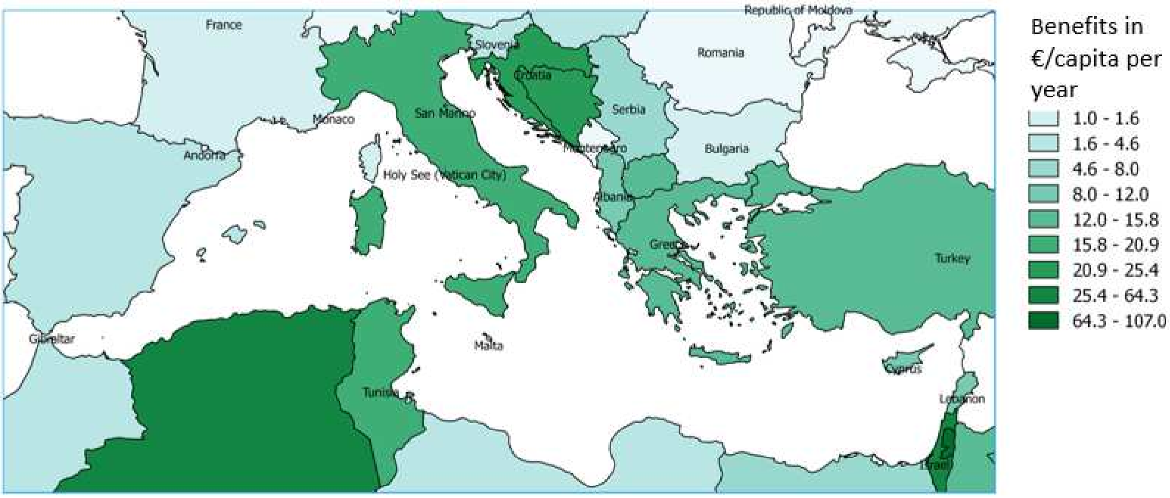


Figure 59 Health benefits per capita of the implementation of the SECA/NECA compared to 2020 legislation (euros/capita/year)

6.3 Cost-benefits analysis

The last step is the comparison between the annualised cost of the scenarios detailed in 6.1 and the annual health benefits assessed in 6.2. This last step aims at concluding on the relevance of the implementation of SECA/NECA strategies regarding economic and health effects. Policies whose benefits exceed their costs can be considered acceptable from a societal point of view. For costs and benefits, low and high estimates are provided in the benefit cost ratios presented below.

Whatever the mitigation scenario, benefits (even those established with low estimates) are always significantly higher than the cost (Figure 60). The annual costs (low and high estimated) associated respectively with the implementation of SECA, NECA and SECA/NECA areas are represented by the six first bars, while the benefits (low and high estimates) are represented by the two last ones.

The highest estimate for the implementation of a SECA/NECA in the Mediterranean Sea would lead to a cost of about 2.7 billion €/year while the benefits induced by this mitigation strategy for the Mediterranean countries would amount to at least about 8.1 billion €/year. This clearly demonstrates the relevance and the efficiency of this emission reduction strategy to limit the health effects of exposure to shipping air pollutant emissions in the Mediterranean countries.

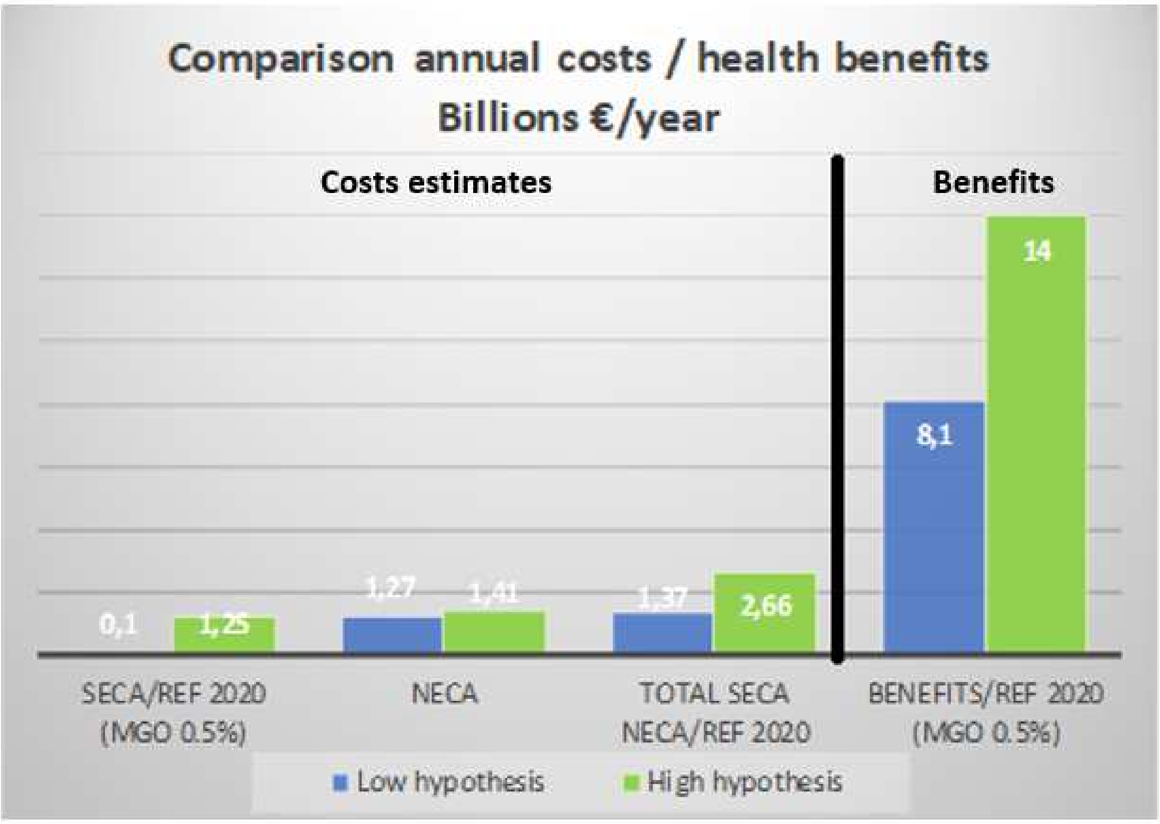


Figure 60 Final results of the cost-benefits analysis

7 References

- Allemand N. et al. 2016. Aide à la décision pour l'élaboration du PREPA. CITEPA-INERIS-AJBD pour le MTES. https://www.ecologique-solidaire.gouv.fr/sites/default/files/06-1_PREPA_Synth%C3%A8se_-_aide_a_la_decision_pour_l_elaboration_du_PREPA.pdf
- Amann, M., Holland, M., Maas, R., Vandyck, T. & B. Saveyn (2017), Costs, benefits and economic impacts of the EU Clean Air Strategy and their implications on innovation and competitiveness. IIASA report. (http://gains.iiasa.ac.at)
- Markus Amann and alls. The Final Policy Scenarios of the EU Clean Air Policy Package. TSAP Report #11- Version 1.1a. IIASA 2014. http://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP_11-finalv1-1a.pdf
- Astrom and all. The cots and benefits of a nitrogen emission control areas in the Baltic and North seas. Transport Research Part D. 59 – 2018 (223-236)
- Briggs J.. The impact of Tier III NOx regulation on the shipping industry. International Association for Catalytic Control of Ship Emissions to Air. 2013
- Canpling P and All. Specific evaluation of emissions from shipping including assessment for the establishment of possible new emission control areas in European seas. 2013. DG Environment, European Commission (ENV.C3/SER/2011/0009)
- Concawe 2014. Developments in EU refining: looking ahead to 2020 and beyond. Concawe review. Volume 23 • Number 1 • Spring 2014
- Concawe 2017. The EU refining industry and the challenge of the IMO global sulphur limit for bunker fuels. Concawe review. Volume 26 • Number 2 • December 2017
- J J . Corbett , J . J . Winebrake , E. Green , P. Kasibhatla, V . Eyring , and A. Lauer, Mortality from shipping emissions: a global assessment, *Environ. Sci. Technol.* **2007**, *41*, 8512-8518
- Holland M, Wagner A, Hurley F, et al. (2011a). Cost Benefit Analysis for the Revision of the National Emission Ceilings Directive: Policy Options for revisions to the Gothenburg Protocol to the UNECE Convention on Long-Range Transboundary Air Pollution. In: Technology, A. (Ed.).
- Holland, M. (2014a) Implementation of the HRAPIE Recommendations for European Air Pollution CBA work. http://ec.europa.eu/environment/air/pdf/CBA%20HRAPIE%20implement.pdf.
- Holland, M. (2014b) Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air Package, Version 2, Corresponding to IIASA TSAP Report #11, Version 2a. http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf.
-
- Hudda Winnes and alls. NOx controls for shipping in EU seas. IVL and CE Delt for Transport and Environment. Report U 5552. June 2016
- IFP Energies nouvelles (2018). Panorama. La réduction des émissions de soufre dans le transport maritime: un défi économique et technologique. http://www.ifpenergiesnouvelles.fr/Publications/Analyses-technico-economiques/Notes-de-synthese-Panorama/Panorama-2018
- Jalkaneen J.P.. The price of sulphur reductions in the Baltic Sea and the North Sea. BSR Inno ship project partly funded by the EU. No date. https://croceanx.com/wp-content/uploads/2015/09/COSTS-OF-MARPOL.pdf
- OECD-International Transport forum. Reducing sulphur emissions from ships. The impact of international regulation © OECD/ITF 2016
- Parsmo R. and alls. NOx abatement in the Baltic sea. An evaluation of different policies. IVL. May 2017.

- Schucht, S. Colette, S. Rao, M. Holland, W. Schoepp, P. Kolp, Z. Klimont, B. Bessagnet, S. Szopa, R. Vautard, J.-M. Brignon and L. Rouïl, Moving towards ambitious climate policies: Monetised health benefits from improved air quality could offset mitigation costs in Europe, *Environmental Science & Policy* **50**(2015), pp. 252-269.
- WHO (2013a). Health risks of air pollution in Europe – HRAPIE – Summary of recommendations for question D5 on “Identification of concentration-response functions” for cost-effectiveness analysis. In: health., W.E.C.f.e.a. (Ed.).
- WHO (2013b). Review of evidence on health aspects of air pollution – REVIHAAP – First results. In: Europe, W.R.O.f. (Ed.).

Annex 1: Files elaborated by the CEREMA to describe ship activity data

Input files[20], received from CEREMA have the following structure:

- 1 file containing the ship's characteristics:
  - **MMSI:** Ship's MMSI number
  - IMO: Ship's IMO number
  - **DateOfBuild**: 'AAAAMM': Build year and month
  - **KeelLaidDate**: 'AAAAMMJJ': Keel laid date:
  - **ShiptypeLevel5**: ship's type
  - NumberofMainEngines: number of main engines
  - NumberOfPropulsionUnits: number of propulsion units (motorisation + propeller)
  - PropulsionType: propulsion type
  - **MainEngineRPM**: Main engine RPM
  - **Powerkwmax**: Max power of the main engine
  - Powerkwservice: Service power of the main engine
  - **FuelType1Code**: fuel type 1
  - FuelType2Code: fuel type 2
  - NumberOfAuxiliaryEngines: Number of auxiliary engines
  - NumberOfAllEngines: Number of all engines
  - Speedmax: max speed
  - Speedservice: Speed in service
  - TotalPowerOfAuxiliaryEngines: total power of auxiliary engines
  - TotalPowerOfAllEngines: total power of all engines
- 1 file containing the ship's dynamic data
  - **MMSI**: Ship MMSI number
  - **Date(k)**: Date/time of the location of the ship
  - **Lon(k)**: Ship's longitude
  - **Lat(k)**: Ship's latitude
  - **EEZ(k)**: ship in UE-EEZ
  - **Sog(k)**: instantaneous speed of the ship
  - **Nav(k)**: phase of the trip (cruise, hotelling, manoeuvring)
  - **f_chargeME(k)**: Load of the main engine (%)
  - **f_chargeAUX(k)**: Total power of the auxiliary engines
  - **f_chargeBOIL(k)**: Total power of the boilers

All fields marked in bold are used in the calculations.

---

[20] 2 files per day (731 days for 2015 and 2016) and per zone (8 zones) = 5 848 files

Annex 2: emission factors used for the calculation of emissions

Specific fuel oil consumptions (SFOC) and emission factors (EF) are obtained from the literature review.

In order to facilitate the comprehension of the present report, the following abbreviations are consistently used:

- Engine speed/type:
    - Otto: Otto-cycle for LNG-powered engines
    - GT: Gas Turbine
    - HSD: High Speed Diesel (for RPM > 800)
    - MSD: Medium Speed Diesel (300<RPM<800)
    - SSD: Slow Speed Diesel (RPM<300)
    - ST: Steam Turbine
- Fuel type:
    - BFO: Bunker Fuel Oil
    - HFO: Heavy Fuel Oil
    - MDO: Marine Diesel Oil
    - MGO: Marine Gas Oil
    - LNG: Liquified Natural Gas
- Engine type:
    - ME: Main engine
    - Aux: Auxiliary

Specific fuel oil consumption

Table 19 Specific fuel oil consumption for the different engines, fuel and navigation phases.

Engine speed/ type	*Fuel type*	*Engine type*	*Navigation phase*	SFOC	unit	*source*
Otto	LNG	*ME*	*All*	166	g/kWh	[3]
Otto	LNG	*AE*	*All*	166	g/kWh	[3]
GT	BFO	*ME*	*Cruise*	305	g/kWh	0
GT	MDO	*ME*	*Cruise*	290	g/kWh	0
HSD	BFO	*ME*	*Cruise*	213	g/kWh	0
HSD	MDO	*ME*	*Cruise*	203	g/kWh	0
MSD	BFO	*ME*	*Cruise*	213	g/kWh	0
MSD	MDO	*ME*	*Cruise*	203	g/kWh	0
SSD	BFO	*ME*	*Cruise*	195	g/kWh	0
SSD	MDO	*ME*	*Cruise*	185	g/kWh	0
GT	BFO	*ME*	*manoeuvring*	336	g/kWh	0
GT	MDO	*ME*	*manoeuvring*	319	g/kWh	0
HSD	BFO	*ME*	*manoeuvring*	234	g/kWh	0
HSD	MDO	*ME*	*manoeuvring*	223	g/kWh	0
MSD	BFO	*ME*	*manoeuvring*	234	g/kWh	0
MSD	MDO	*ME*	*manoeuvring*	223	g/kWh	0
SSD	BFO	*ME*	*manoeuvring*	215	g/kWh	0
SSD	MDO	*ME*	*manoeuvring*	204	g/kWh	0
HSD	BFO	*AE*	*All*	227	g/kWh	0
HSD	MDO	*AE*	*All*	217	g/kWh	0
MSD	BFO	*AE*	*All*	227	g/kWh	0
MSD	MDO	*AE*	*All*	217	g/kWh	0

Main pollutants (NOx, Particulates, SOx and Black Carbon)

NOx

Table 20 NOx emission factors for the different engines, engine years, fuel types and navigation phases.

Engine speed/ type	***Fuel type***	***Engine type***	***Engine year***	***Navigation phase***	***EF***	***Unit***
Otto	LNG	*ME/AE*	All	*All*	1.29978	g/kWh
GT	BFO	*ME*	2000	*cruise*	6.1	g/kWh
GT	MDO	*ME*	2000	*cruise*	5.7	g/kWh
HSD	BFO	*ME*	2000	*cruise*	12.7	g/kWh
HSD	MDO	*ME*	2000	*cruise*	12	g/kWh
MSD	BFO	*ME*	2000	*cruise*	14	g/kWh
MSD	MDO	*ME*	2000	*cruise*	13.2	g/kWh
SSD	BFO	*ME*	2000	*cruise*	18.1	g/kWh
SSD	MDO	*ME*	2000	*cruise*	17	g/kWh
ST	BFO	*ME*	2000	*cruise*	2.1	g/kWh
ST	MDO	*ME*	2000	*cruise*	2	g/kWh
GT	BFO	*ME*	2000	*manoeuvring*	3.1	g/kWh
GT	MDO	*ME*	2000	*manoeuvring*	2.9	g/kWh
HSD	BFO	*ME*	2000	*manoeuvring*	10.2	g/kWh
HSD	MDO	*ME*	2000	*manoeuvring*	9.6	g/kWh
MSD	BFO	*ME*	2000	*manoeuvring*	11.2	g/kWh
MSD	MDO	*ME*	2000	*manoeuvring*	10.6	g/kWh
SSD	BFO	*ME*	2000	*manoeuvring*	14.5	g/kWh
SSD	MDO	*ME*	2000	*manoeuvring*	13.6	g/kWh
ST	BFO	*ME*	2000	*manoeuvring*	1.7	g/kWh

ST	MDO	*ME*	2000	*manoeuvring*	1.6	g/kWh
HSD	BFO	*AE*	2000	*All*	11.6	g/kWh
HSD	MDO	*AE*	2000	*All*	10.9	g/kWh
MSD	BFO	*AE*	2000	*All*	14.7	g/kWh
MSD	MDO	*AE*	2000	*All*	13.9	g/kWh
GT	BFO	*ME*	2005	*cruise*	5.9	g/kWh
GT	MDO	*ME*	2005	*cruise*	5.5	g/kWh
HSD	BFO	*ME*	2005	*cruise*	12.3	g/kWh
HSD	MDO	*ME*	2005	*cruise*	11.6	g/kWh
MSD	BFO	*ME*	2005	*cruise*	13.5	g/kWh
MSD	MDO	*ME*	2005	*cruise*	12.8	g/kWh
SSD	BFO	*ME*	2005	*cruise*	17.5	g/kWh
SSD	MDO	*ME*	2005	*cruise*	16.4	g/kWh
ST	BFO	*ME*	2005	*cruise*	2	g/kWh
ST	MDO	*ME*	2005	*cruise*	1.9	g/kWh
GT	BFO	*ME*	2005	*manoeuvring*	3	g/kWh
GT	MDO	*ME*	2005	*manoeuvring*	2.8	g/kWh
HSD	BFO	*ME*	2005	*manoeuvring*	9.9	g/kWh
HSD	MDO	*ME*	2005	*manoeuvring*	9.3	g/kWh
MSD	BFO	*ME*	2005	*manoeuvring*	10.8	g/kWh
MSD	MDO	*ME*	2005	*manoeuvring*	10.2	g/kWh
SSD	BFO	*ME*	2005	*manoeuvring*	14	g/kWh
SSD	MDO	*ME*	2005	*manoeuvring*	13.1	g/kWh
ST	BFO	*ME*	2005	*manoeuvring*	1.6	g/kWh
ST	MDO	*ME*	2005	*manoeuvring*	1.6	g/kWh
HSD	BFO	*AE*	2005	*All*	11.2	g/kWh
HSD	MDO	*AE*	2005	*All*	10.5	g/kWh
MSD	BFO	*AE*	2005	*All*	14.2	g/kWh
MSD	MDO	*AE*	2005	*All*	13.5	g/kWh
GT	BFO	*ME*	2010	*cruise*	5.7	g/kWh
GT	MDO	*ME*	2010	*cruise*	5.3	g/kWh
HSD	BFO	*ME*	2010	*cruise*	11.8	g/kWh
HSD	MDO	*ME*	2010	*cruise*	11.2	g/kWh
MSD	BFO	*ME*	2010	*cruise*	13	g/kWh
MSD	MDO	*ME*	2010	*cruise*	12.3	g/kWh
SSD	BFO	*ME*	2010	*cruise*	16.9	g/kWh
SSD	MDO	*ME*	2010	*cruise*	15.8	g/kWh
ST	BFO	*ME*	2010	*cruise*	2	g/kWh
ST	MDO	*ME*	2010	*cruise*	1.9	g/kWh
GT	BFO	*ME*	2010	*manoeuvring*	2.9	g/kWh
GT	MDO	*ME*	2010	*manoeuvring*	2.7	g/kWh
HSD	BFO	*ME*	2010	*manoeuvring*	9.5	g/kWh
HSD	MDO	*ME*	2010	*manoeuvring*	8.9	g/kWh
MSD	BFO	*ME*	2010	*manoeuvring*	10.4	g/kWh
MSD	MDO	*ME*	2010	*manoeuvring*	9.9	g/kWh
SSD	BFO	*ME*	2010	*manoeuvring*	13.5	g/kWh
SSD	MDO	*ME*	2010	*manoeuvring*	12.7	g/kWh
ST	BFO	*ME*	2010	*manoeuvring*	1.6	g/kWh
ST	MDO	*ME*	2010	*manoeuvring*	1.5	g/kWh
HSD	BFO	*AE*	2010	*All*	10.8	g/kWh

HSD	MDO	*AE*	2010	*All*	10.2	g/kWh
MSD	BFO	*AE*	2010	*All*	13.7	g/kWh
MSD	MDO	*AE*	2010	*All*	13	g/kWh

Source : [3] for Otto and [2] for other

For ships/engines constructed after January 1st, 2016, the NOx emission factor is reduced by 75% compared to the ships/engines constructed after 2010, as per IMO Marpol Annex VI.

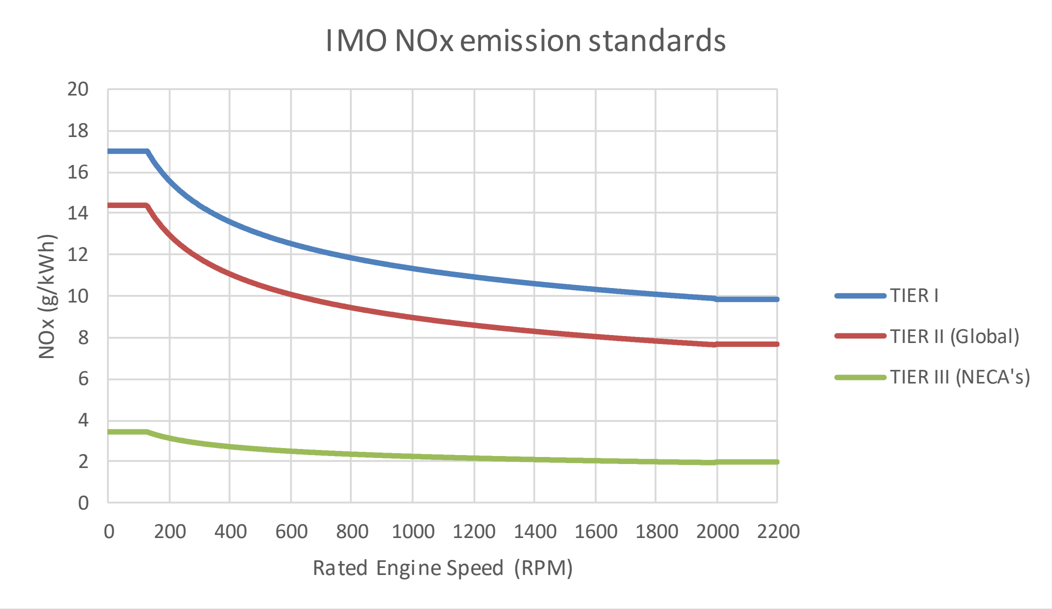


Figure 61 IMO NOx emission standards.

Fuel *sulphur* content

Fuel oil sulphur content depends on:

- the navigation phase (at berth, cruise, manoeuvring),
- the type of ships (passenger or other)
- the ship geographical location (in UE-EEZ or outside)
- the scenario

For each case, the fuel oil sulphur content is described in chapters **Erreur ! Source du renvoi introuvable.** and 4.1.3.

Particulates/Black Carbon

The following TSP emission factors are given for HFO at 2.7% of S and MDO at 0.5% of S.

Different publications confirm that emission of particulates are particularly affected by the sulphur content of fuels The next table gives the reduction factors for different changes in sulphur content of fuels in order to have the TSP emission factors for different sulphur content.

Table 21 TSP emission factors for the different engines, fuel types and navigation phases.

engine speed/ type	***Fuel type***	***Engine type***	***Navigation Phases***	***EF***	***unit***
GT	BFO	*ME*	*cruise*	0.1	g/kWh
GT	MDO	*ME*	*cruise*	0	g/kWh
HSD	BFO	*ME*	*cruise*	0.8	g/kWh
HSD	MDO	*ME*	*cruise*	0.3	g/kWh
MSD	BFO	*ME*	*cruise*	0.8	g/kWh
MSD	MDO	*ME*	*cruise*	0.3	g/kWh
SSD	BFO	*ME*	*cruise*	1.7	g/kWh
SSD	MDO	*ME*	*cruise*	0.3	g/kWh
ST	BFO	*ME*	*cruise*	0.8	g/kWh
ST	MDO	*ME*	*cruise*	0.3	g/kWh
GT	BFO	*ME*	*manoeuvring*	1.5	g/kWh
GT	MDO	*ME*	*manoeuvring*	0.5	g/kWh
HSD	BFO	*ME*	*manoeuvring*	2.4	g/kWh
HSD	MDO	*ME*	*manoeuvring*	0.9	g/kWh
MSD	BFO	*ME*	*manoeuvring*	2.4	g/kWh
MSD	MDO	*ME*	*manoeuvring*	0.9	g/kWh
SSD	BFO	*ME*	*manoeuvring*	2.4	g/kWh
SSD	MDO	*ME*	*manoeuvring*	0.9	g/kWh
ST	BFO	*ME*	*manoeuvring*	2.4	g/kWh
ST	MDO	*ME*	*manoeuvring*	0.9	g/kWh
HSD	BFO	*AE*	*All*	0.8	g/kWh
HSD	MDO	*AE*	*All*	0.3	g/kWh
MSD	BFO	*AE*	*All*	0.8	g/kWh
MSD	MDO	*AE*	*All*	0.3	g/kWh
Otto	LNG	*ME*	*All*	0.02988	g/kWh
Otto	LNG	*AE*	*All*	0.02988	g/kWh

Source : [3] for Otto and [2] for the others

Table 22 Reduction factors to obtain TSP emission factors for different Sulphur content.

Change in sulphur content	Reduction factor
2.7% -> 0.5%	3.1
2.7 %-> 1.5%	1.7
1.5% -> 0.5%	1.8
0.5% -> 0.1%	1.5

The particle speciation (PM_{10} and $PM_{2.5}$) is considered to be (0):

- PM_{10}=TSP
- $PM_{2.5}$=90%xTSP

Fraction of PM (f-BC) is 0.12 for BFO and 0.31 for MDO/MGO (0) compared to TSP.

Other pollutants (GHG, CO, NMVOC, NH_3, Dioxins/Furans, HCB, PCB, PaH)

Table 23 GHG emission factors for different engines, fuel types and navigation phases.

pollutant	***engine speed/type***	***fuel type***	***engine type***	***Navigation phase***	***EF***	***unit***
CO_2	All	BFO	*All*	*All*	3114	kg/t
	All	MDO	*All*	*All*	3206	kg/t
	All	LNG	*All*	*All*	2750	kg/t
N_2O	SSD	BFO	*AE*	*All*	0.008	g/kWh
	SSD	BFO	*ME*	*All*	0.0312	g/kWh
	SSD	MDO	*ME*	*All*	0.029328	g/kWh
	HSD	BFO	*AE*	*All*	0.036	g/kWh
	HSD	MDO	*AE*	*All*	0.03384	g/kWh
	GT	BFO	*ME*	*All*	0.0488	g/kWh
	GT	MDO	*ME*	*All*	0.04512	g/kWh
CH_4	SSD	MDO	*ME*	*cruise*	0.006	g/kWh
	SSD	BFO	*ME*	*cruise*	0.005948	g/kWh
	MSD/HSD	MDO/BFO	*ME*	*cruise*	0.004	g/kWh
	GT/ST	MDO/BFO	*ME*	*cruise*	0.002	g/kWh
	SSD	MDO/BFO	*ME*	*manoeuvring*	0.012	g/kWh
	MSD/HSD	MDO/BFO	*ME*	*manoeuvring*	0.008	g/kWh
	GT	MDO/BFO	*ME*	*manoeuvring*	0.01	g/kWh
	ST	MDO/BFO	*ME*	*manoeuvring*	0.004	g/kWh
	MSD	MDO/BFO	*AE*	*in port*	0.004	g/kWh
	HSD	MDO/BFO	*AE*	*in port*	0.01	g/kWh

Source : [5] for CH_4 and [3] for CO_2 and $N2_O$

Table 24 AEP emission factors for different engines, fuel types and navigation phases.

pollutant	**Engine speed/type**	**fuel type**	***Engine type***	***Navigation phase***	**EF**	**unit**
NMVOC	GT	BFO/MDO	*ME*	*cruise*	0.1	g/kWh
	HSD	BFO/MDO	*ME*	*cruise*	0.2	g/kWh
	MSD	BFO/MDO	*ME*	*cruise*	0.5	g/kWh
	SSD	BFO/MDO	*ME*	*cruise*	0.6	g/kWh
	GT	BFO/MDO	*ME*	*manoeuvring*	0.5	g/kWh
	HSD	BFO/MDO	*ME*	*manoeuvring*	0.6	g/kWh
	MSD	BFO/MDO	*ME*	*manoeuvring*	1.5	g/kWh
	SSD	BFO/MDO	*ME*	*manoeuvring*	1.8	g/kWh
	HSD	BFO/MDO	*AE*	*All*	0.4	g/kWh
	MSD	BFO/MDO	*AE*	*All*	0.4	g/kWh
	Otto	LNG	*ME/AE*	*All*	0.49966	g/kWh
CO	All	*All*	*All*	*All*	7.4	kg/t
	SSD	BFO/MDO	*ME*	All	0.54015	g/kWh
	MSD	BFO/MDO	*ME*	All	0.53965	g/kWh
	MSD	BFO/MDO	*AE*	All	0.5355	g/kWh
	HSD	BFO/MDO	*AE*	All	0.5355	g/kWh
	Otto	LNG	*ME/AE*	All	1.29978	g/kWh
	GT	BFO	*ME*	All	0.10065	g/kWh
	GT	MDO	*ME*	All	0.099	g/kWh
NH_3	SSD/MSD/HSD	MDO/ BFO	*ME*	*cruise*	0.003	g/kWh

	GT/ST	MDO/ BFO	*ME*	*cruise*	0.004	g/kWh
	SSD/MSD/HSD	MDO/ BFO	*ME*	*manoeuvring*	0.003	g/kWh
	GT/ST	MDO/ BFO	*ME*	*manoeuvring*	0.004	g/kWh
	MSD/HSD	MDO/ BFO	*AE*	*in port*	0.003	g/kWh

Source : [3] for CO, [5] for NH_3 and [2] for NMVOC

Table 25 POPs emission factors for different engines, fuel types and navigation phases.

pollutant	**fuel type**	**EF**	**unit**
PCDD/F	BFO	0.47	ug TEQ/t
	MDO	0.13	ug TEQ/t
HCB	BFO	0.14	mg/tonne
	MDO	0.08	mg/tonne
PCB	BFO	0.57	mg/tonne
	MDO	0.038	mg/tonne
BaP	BFO	44.20	mg/tonne
	MDO	46.41	mg/tonne

Source:[3] for BaP, and [2] for PCDD/F, HCB and PCB

[1] Entec, 2002. Quantification of emissions from ships associated with ship movements between ports in the European Community. http://ec.europa.eu/environment/air/pdf/chapter1_ship_emissions.pdf and http://ec.europa.eu/environment/air/pdf/chapter2_ship_emissions.pdf

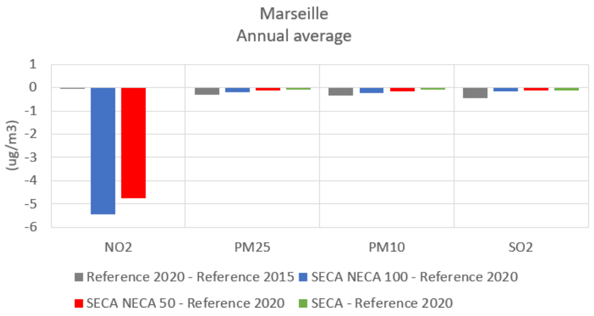
[2] EMEP/EEA air pollutant emission inventory guidebook 2016. 1.A.3.d Navigation (shipping). https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-d-navigation/at_download/file

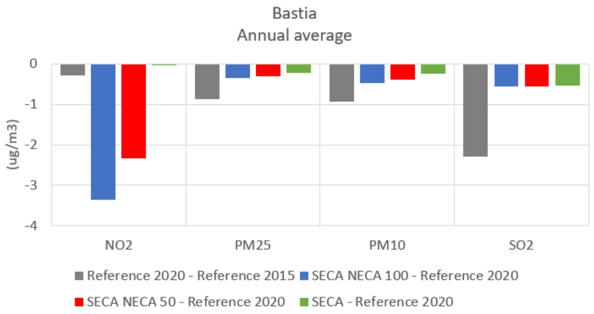
[3] EMEP/EEA air pollutant emission inventory guidebook 2016. 1.A.3.b Road transport. https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-b-i/at_download/file

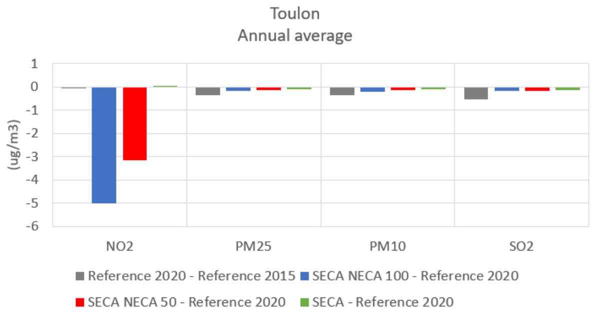
[4] Ricardo, 2017. A review of the NAEI shipping emissions methodology. Final report

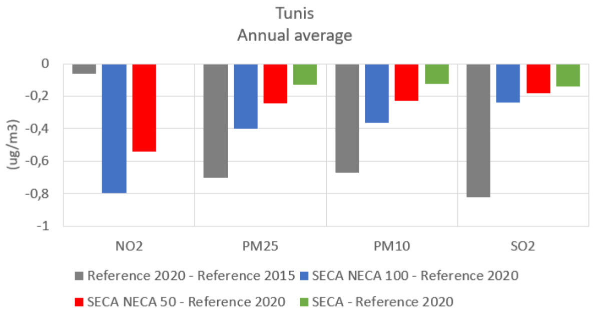
[5] IVL, 2004, Methodology for calculating emissions from ships. 1. Update of emission factors. https://www.diva-portal.org/smash/get/diva2:1117198/FULLTEXT01.pdf

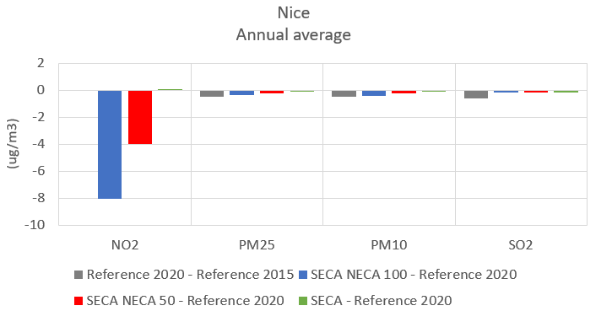
Annex 3: plots of results (annual averages) over cities

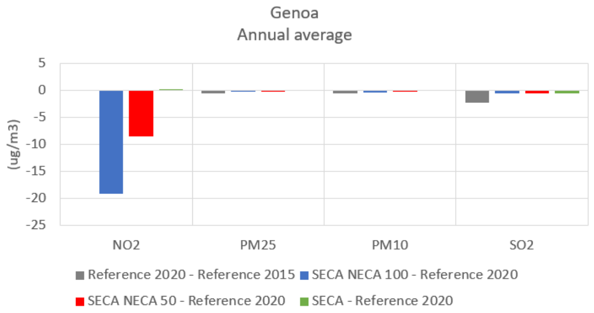


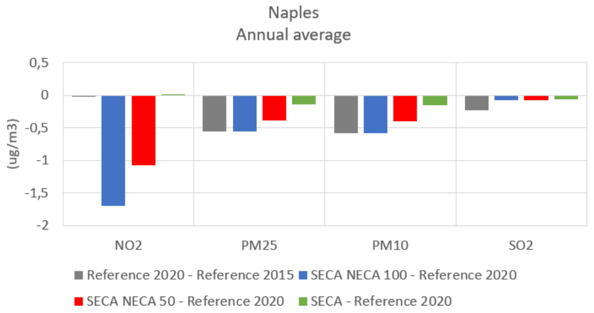


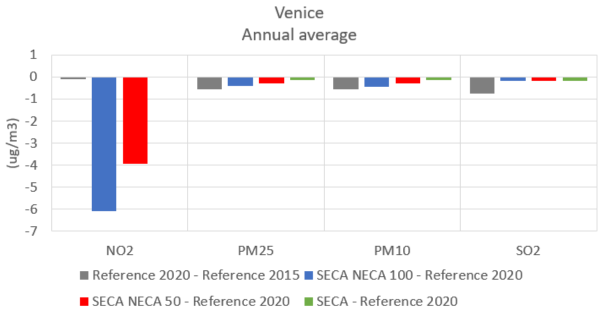


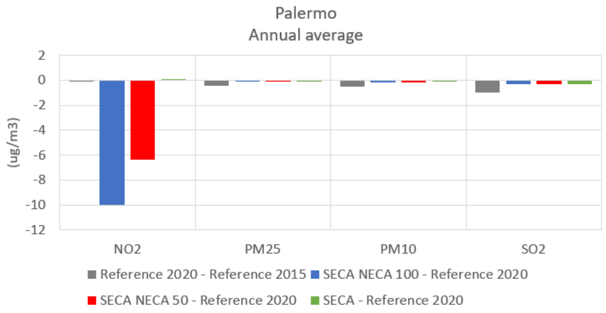


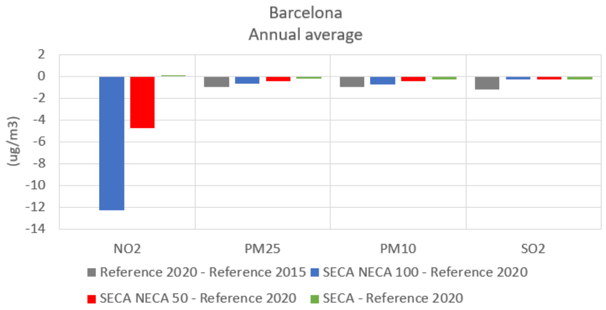


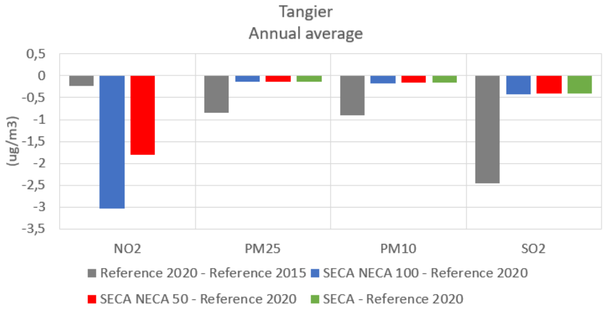


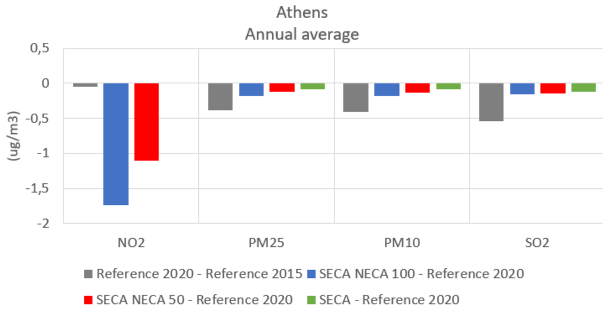


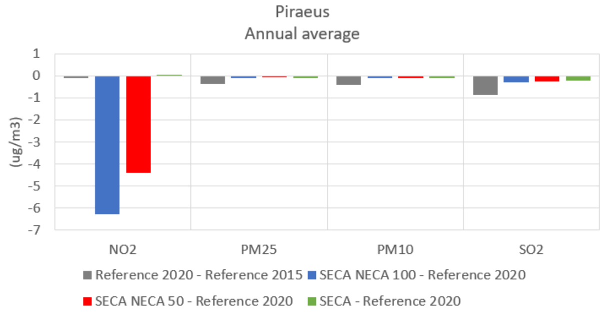


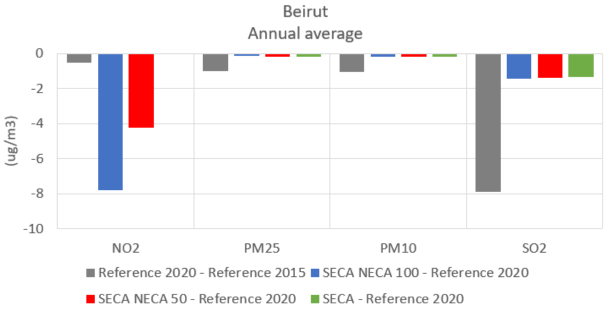

Palermo
Annual average
(ug/m3)
2
0
-2
-4
-6
-8
-10
-12
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

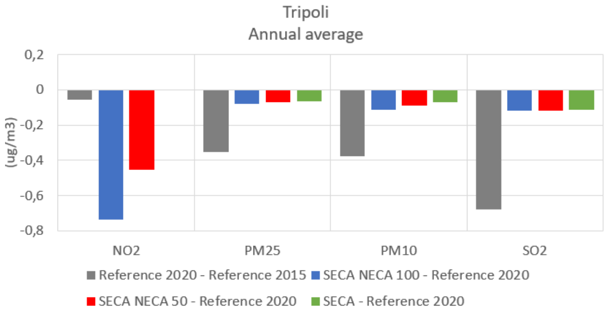

Barcelona
Annual average
(ug/m3)
2
0
-2
-4
-6
-8
-10
-12
-14
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

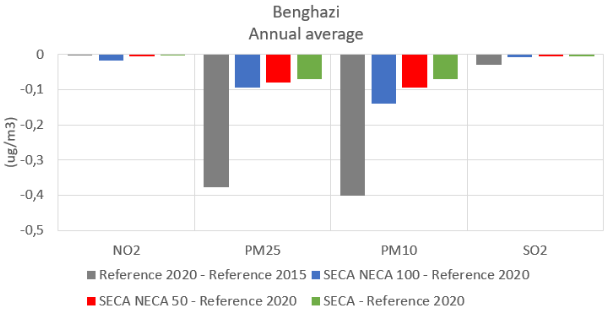

Tangier
Annual average
(ug/m3)
0,5
0
-0,5
-1
-1,5
-2
-2,5
-3
-3,5
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

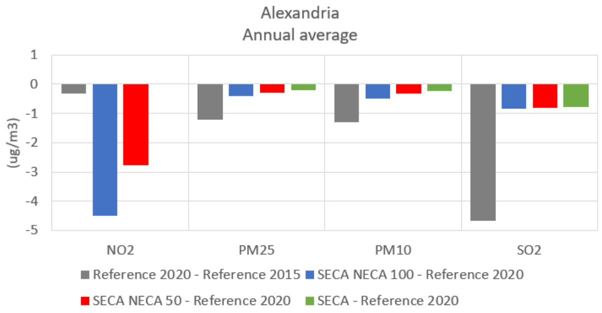

Athens
Annual average
(ug/m3)
0,5
0
-0,5
-1
-1,5
-2
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

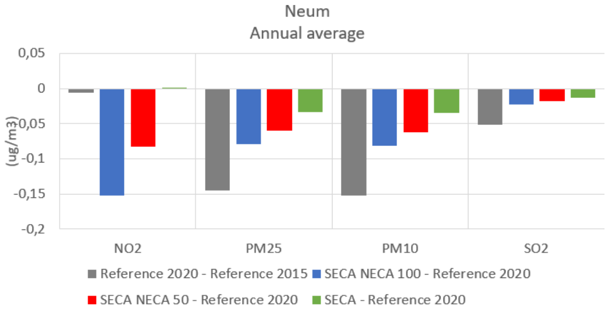

Piraeus
Annual average
(ug/m3)
1
0
-1
-2
-3
-4
-5
-6
-7
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

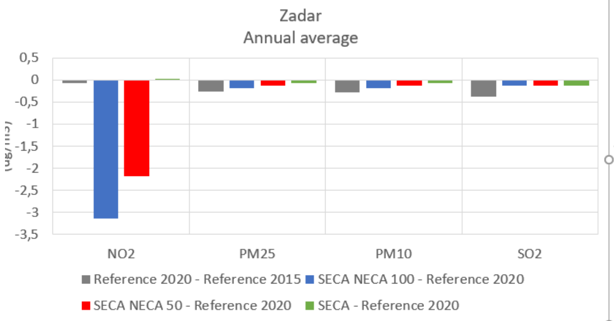

Beirut
Annual average
(ug/m3)
0
-2
-4
-6
-8
-10
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

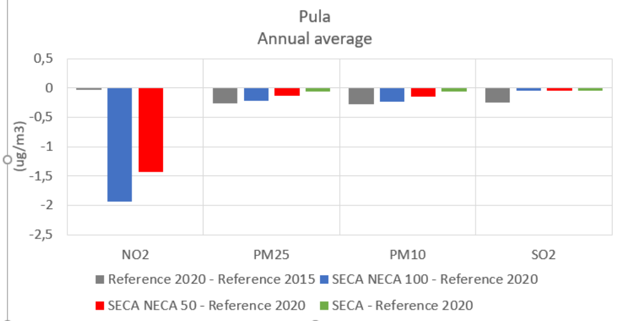

Tripoli
Annual average
(ug/m3)
0,2
0
-0,2
-0,4
-0,6
-0,8
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

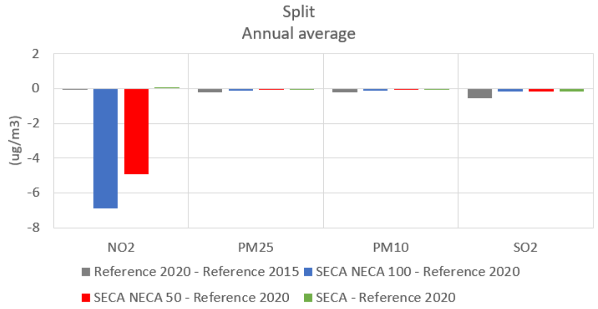

Benghazi
Annual average
(ug/m3)
0
-0,1
-0,2
-0,3
-0,4
-0,5
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

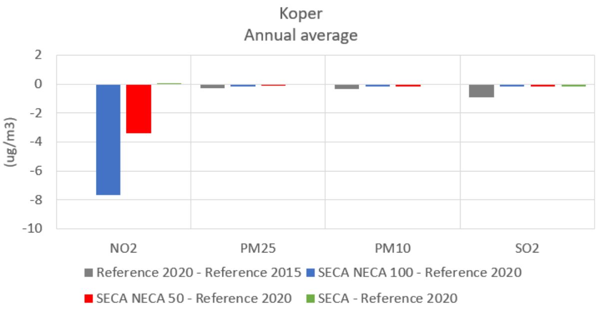

Alexandria
Annual average
(ug/m3)
1
0
-1
-2
-3
-4
-5
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

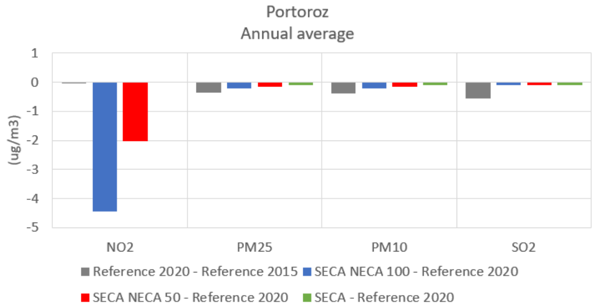

Neum
Annual average
(ug/m3)
0,05
0
-0,05
-0,1
-0,15
-0,2
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

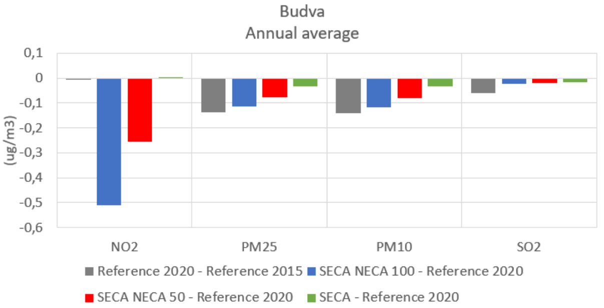

Zadar
Annual average
(ug/m3)
0,5
0
-0,5
-1
-1,5
-2
-2,5
-3
-3,5
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

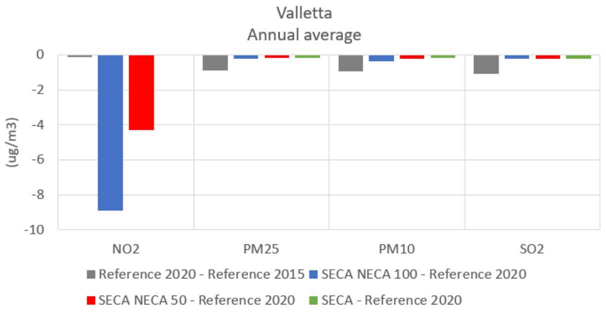

Pula
Annual average
(ug/m3)
0,5
0
-0,5
-1
-1,5
-2
-2,5
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

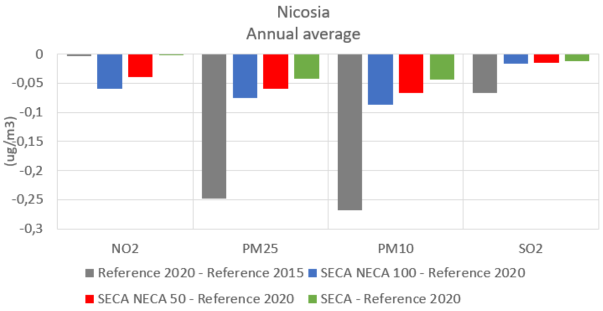

Split
Annual average
(ug/m3)
2
0
-2
-4
-6
-8
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

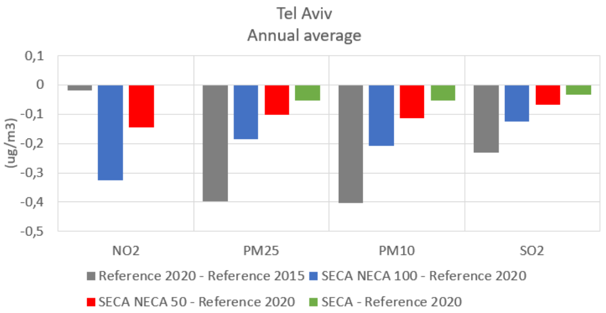

Koper
Annual average
(ug/m3)
2
0
-2
-4
-6
-8
-10
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

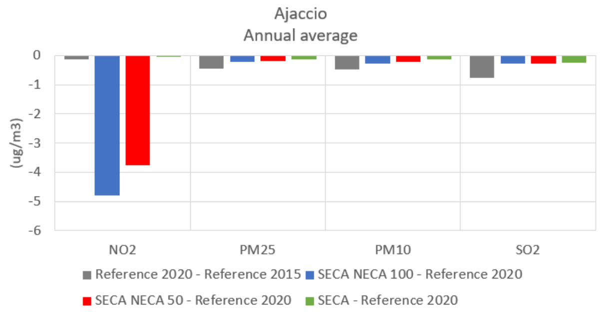

Portoroz
Annual average
(ug/m3)
1
0
-1
-2
-3
-4
-5
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

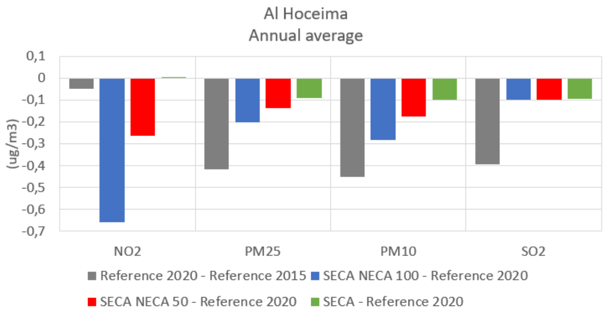

Budva
Annual average
(ug/m3)
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
-0,6
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

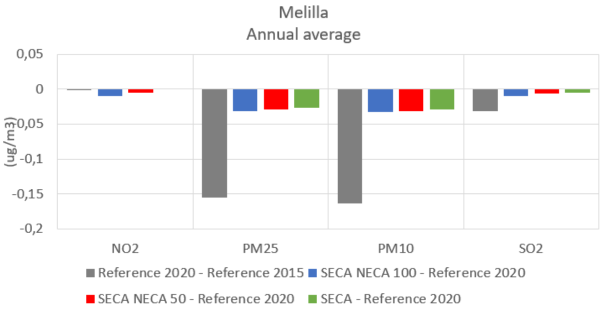

Valletta
Annual average
(ug/m3)
0
-2
-4
-6
-8
-10
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020


Nicosia
Annual average
(ug/m3)
0
-0,05
-0,1
-0,15
-0,2
-0,25
-0,3
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020


Tel Aviv
Annual average
(ug/m3)
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020


Ajaccio
Annual average
(ug/m3)
0
-1
-2
-3
-4
-5
-6
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020


Al Hoceima
Annual average
(ug/m3)
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,5
-0,6
-0,7
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020


Melilla
Annual average
(ug/m3)
0,05
0
-0,05
-0,1
-0,15
-0,2
NO2
PM25
PM10
SO2
Reference 2020 - Reference 2015
SECA NECA 100 - Reference 2020
SECA NECA 50 - Reference 2020
SECA - Reference 2020

INERIS

controlling risks
for sustainable development

Institut national de l'environnement industriel et des risques

Parc Technologique Alata
BP 2 - 60550 Verneuil-en-Halatte

Tél. : +33 (0)3 44 55 66 77 - Fax : +33 (0)3 44 55 66 99

E-mail : ineris@ineris.fr - **Internet :** http://www.ineris.fr