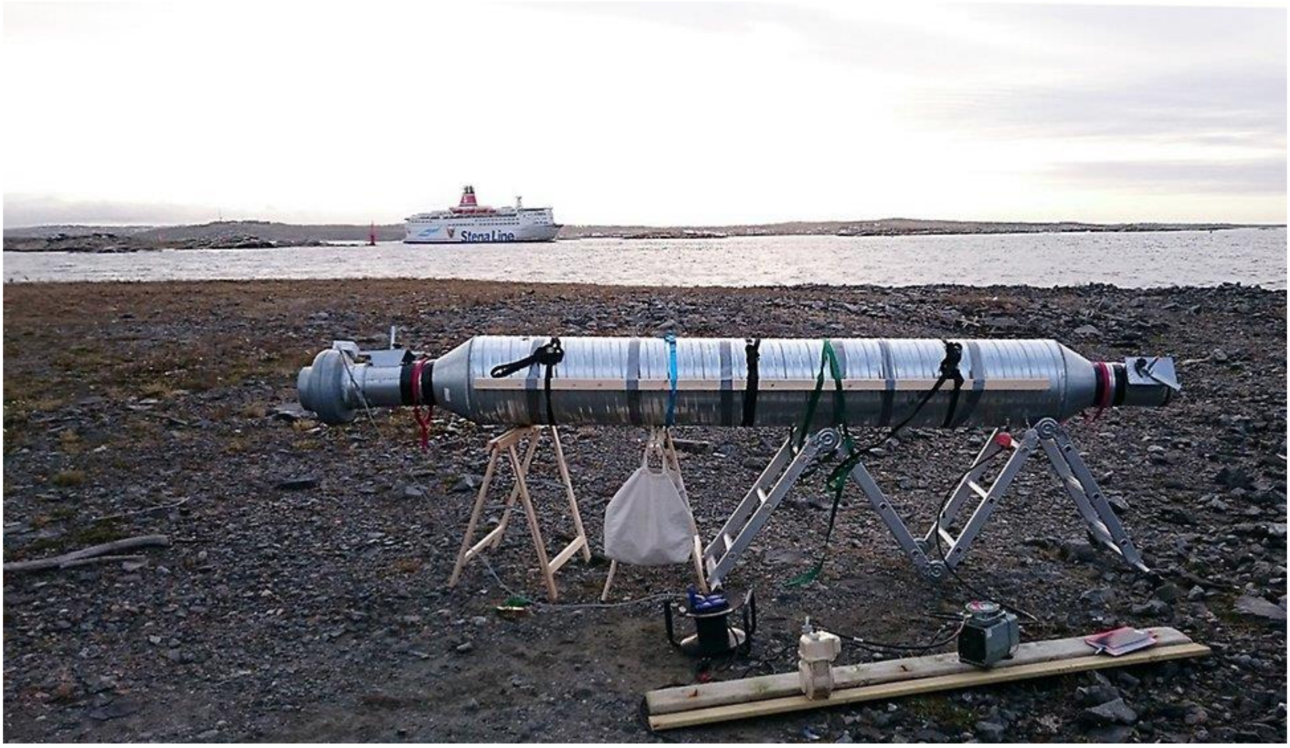
Emission to air

This leaflet contains information related to air emissions from shipping based on research work within the BONUS SHEBA project. The purpose is to populate knowledge and experience established from science and make the information more available. It has been prepared by Karl Jivén, IVL, on behalf of the Interreg CSHIPP project platform.



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THE BONUS SHEBA PROJECT

The BONUS project SHEBA brought together lead experts from the fields of ship emissions, atmospheric, acoustic and oceanic modelling, atmospheric and marine chemistry logistics and environmental law to provide an integrated and in-depth analysis of the ecological, economic and social impacts of shipping in the Baltic Sea and to support development of the related policies on EU, regional, national and local levels.

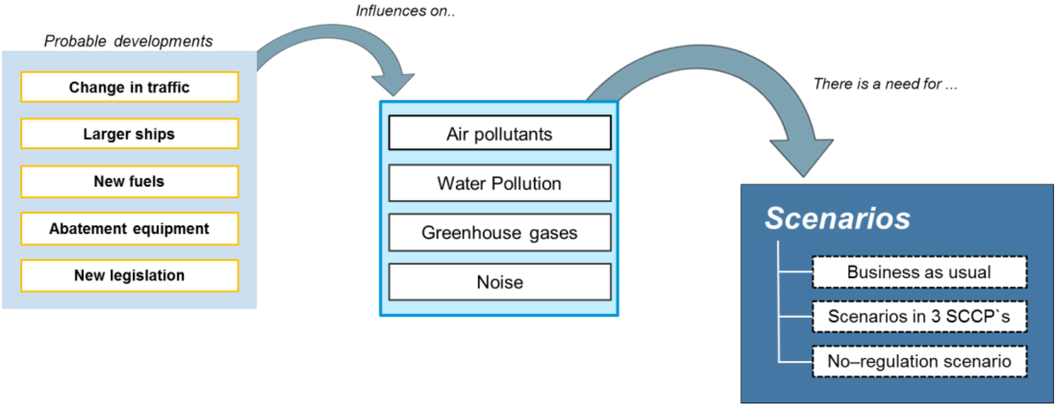


Figure 1 The model used for finding what the future air emissions will look like.

The Baltic Sea is one of the world's most trafficked sea areas and of great importance for both global and regional seaborne trade. Various ship types are constantly in route with cargo from or to the area. Also, passenger traffic in the Baltic Sea is extensive with ferries operating year-round covering many destinations. There are around 100 ports in the Baltic Sea located in fresh to salt water, of different size and with varying type of traffic. Although shipping is one of the most environmentally friendly modes of transport referring to CO_2 emissions to air per tonnes of cargo, shipping like all industries cause environmental impact which is affecting the Baltic Sea. The countries surrounding the Baltic Sea all use the area as waterway, for fishing, recreation and tourism and it is essential for their economies and development. To ensure a sustainable development of shipping in the area, a quantification of shipping's contribution to the environmental impact has been conducted within the BONUS SHEBA project.

The SHEBA project, which is an EU-BONUS funded project, has analysed the following sources and pathways of shipping induced pollution to the marine environment:

- Noise pollution
- **Emissions to air (NOx, SOx, CO_2)**
- Particulate matter (PM)
- Emissions to water (Bilge water, Ballast Water, Sewage, Grey water, Stern tube oil, Biofouling vs Antifouling paint and Food waste).

EMISSIONS TO AIR

Ships emit gases and particles into the atmosphere, among them are carbon dioxide, nitrogen oxides, sulphur oxides and soot particles. Globally, about 100,000 commercial ships are in service.

International shipping is responsible for about 2.2 % of the global CO_2 emissions, but for 15 % of the NOx and 13 % of the SO_2 emissions. In certain regions with heavy ship traffic like the Baltic Sea, they may contribute significantly to the concentrations of air pollutants. To estimate the distribution of contaminations, data – based modelling has been done within SHEBA project.

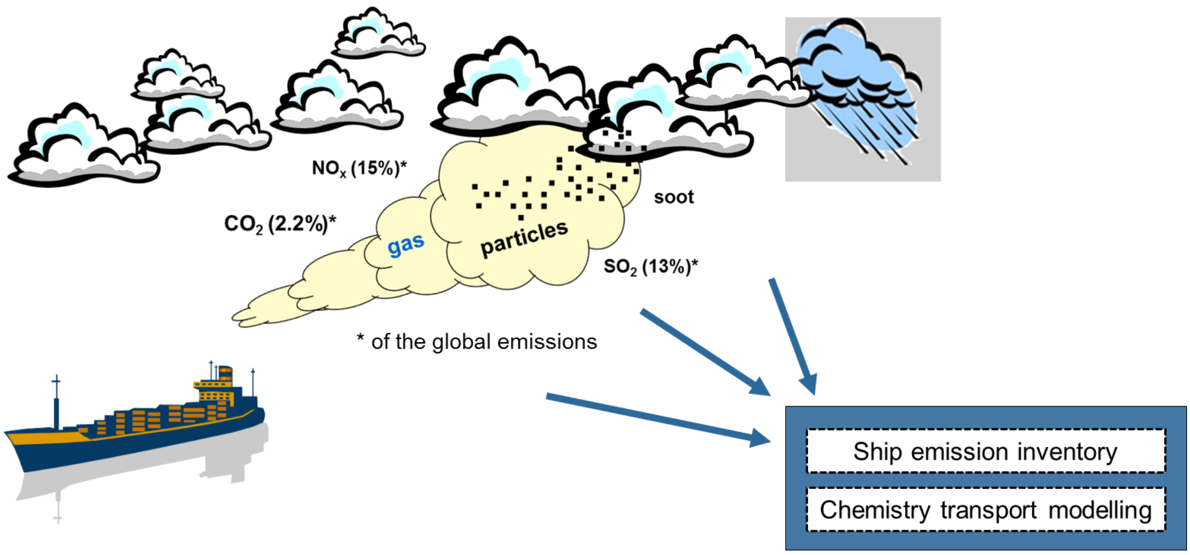


Figure 2 Air pollution modelling within the BONUS SHEBA project

Shipping emissions into air have an influence on climate (CO_2, CH_4, PM) and affect air and subsequently water quality in different ways, e.g. pollution of air with PM, NO_2 and ozone (SOx, NOx, PM), acidification (SOx, NOx) and eutrophication (NOx) of sea and fresh waters. Nitrogen oxides and sulphur from ships contribute to degradation of air quality both regionally and in coastal cities and the acid deposition over land and over the sea has negative impact on marine and terrestrial ecosystems. These gases are also precursor substances[1] for secondary aerosols and nitrogen oxides are involved in the formation of tropospheric ozone. PM, including the secondary aerosol and directly emitted black carbon (BC), sulphate, organic matter, metals and others, has negative health effects. Effect of the PM related to shipping on climate is in general a cooling one (scattering of solar radiation, and changes in cloud albedo), nevertheless BC has a warming potential due to its light absorption capabilities, both while air-born and when deposited on bright surfaces, such as ice- and snow-covered parts of the Arctic.

[1] Precursor is a compound that participates in a chemical reaction that produces another compound

QUANTIFICATION OF EMISSIONS FROM SHIPPING

Exhaust gas emissions from ships and their contribution to air quality in the Baltic Sea region has been investigated. Atmospheric chemistry transport model systems are the main tools that that has been used. The models are fed with shipping emissions from the scenarios under study. This includes current emissions as well scenario emissions for different developments in the shipping sector. Contributions from other emission sectors like industry, traffic, agriculture and households are considered as well. This is of high importance because atmospheric chemistry is highly non-linear and all interactions between different pollutants need to be considered.

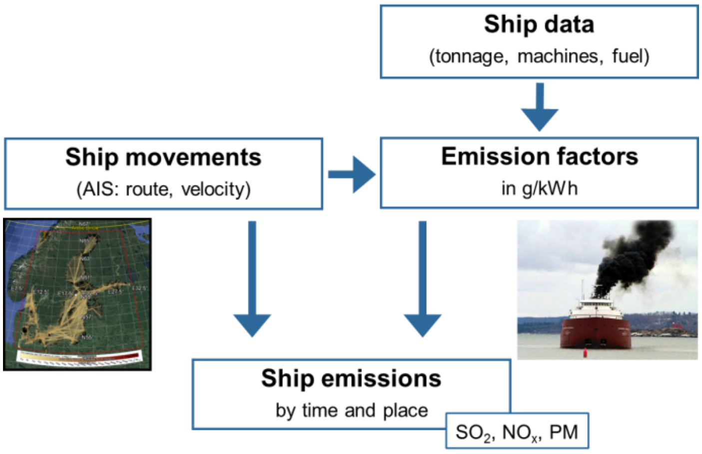


Figure 3 Ship emission inventory

Inventories for ship emissions are calculated from individual ship movements, information about the technical specifications of the ship and emission factors for certain pollutants. Ship movements can be gathered from AIS ship position data – a ship identification system that is used by all ships above a certain size.

Their route and their velocity can be calculated with high temporal and spatial resolution. Technical specifications are available in big data bases and emissions factors have been measured in laboratories and on board of ships for a number of pollutants. In combination, a very detailed shipping emission map can be constructed, like shown on the map for the Baltic

For the assessment of air pollution from shipping an ensemble of atmospheric chemistry transport models was run in BONUS SHEBA. The model simulations give a detailed picture of the current contribution of shipping to air pollution, showing e.g. that today shipping is the most important source for nitrogen dioxide (NO_2) in the atmosphere over the Baltic Sea. On annual average, NO_2 concentrations are in the order of 8 ppb over busy shipping lanes, which is a value typical for smaller cities.

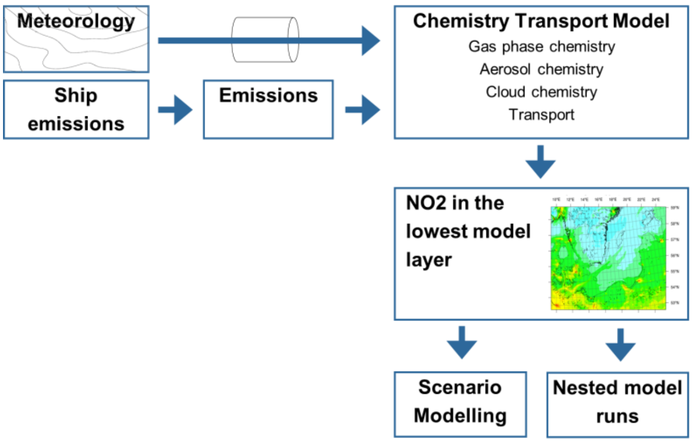
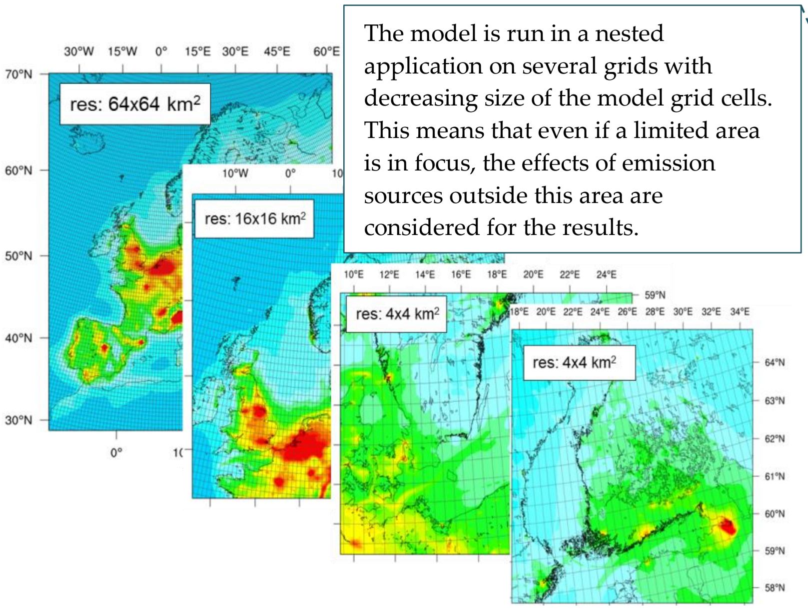


Figure 4 Chemistry transport modelling

The shipping emissions serve as one input for a chemistry transport modelling system. This combination of physical and chemical models calculates the concentrations of air pollutants in a certain area.

Meteorological data from a regional weather forecast model together with emission data from all relevant sources are fed into a chemistry transport model. This model simulates the transport and the chemical transformation of the pollutants resulting in a quasi-realistic representation of their concentrations in the atmosphere.

The model is run in a nested application on several grids with decreasing size of the model grid cells. This means that even if a limited area is in focus, the effects of emission sources outside this area are considered for the results.



In BONUS SHEBA, entire Europe for first simulated on a grid with 64 x 64 km² resolution. Then the northern part of Europe was run on a 16 x 16 km² grid and finally two grids, each with 4 x 4 km² grid size were run for the SW and the NE part of the Baltic Sea. The simulations were repeated with different emission inputs.

First, this allows to determine the fraction shipping emissions have in the resulting concentrations. Second, scenarios for future emissions can be constructed and evaluated with the help of the model system.

Figure 5 Nested model runs

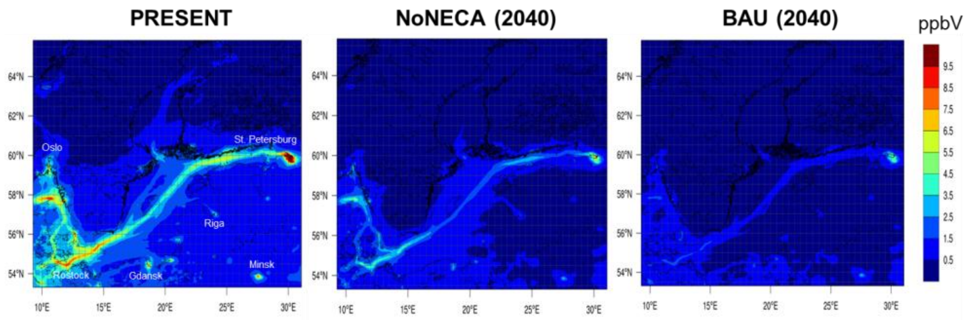
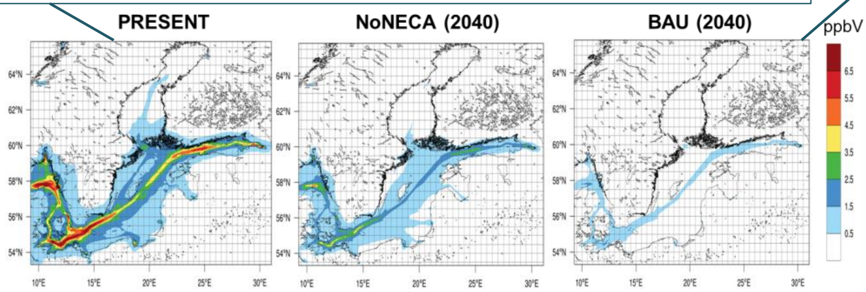


Figure 6 Total NOx emissions

The results for nitrogen dioxide in the lowest model layer demonstrate that shipping is a large contributor to the NO_2 concentrations in the Baltic Sea area.

In a model run for the current situation, the NO_2 concentrations on shipping lanes are comparable or higher than those in big cities along the Baltic Sea coastline.



When additional measures are taken to reduce NOx emissions from ships, as it is currently planned for ships built from 2021 onwards, annual average NO_2 concentrations will be below 3 ppbV in the entire Baltic Sea area in 2040.

This scenario is very optimistic, but it shows what can be achieved with respect to nitrogen dioxide concentrations if the available technical reduction measures are implemented.

In a scenario with significantly reduced fuel consumption of ships but no further exhaust gas cleaning measures, the NO_2 concentrations caused by shipping emissions will decrease considerably until 2040.

Figure 7 Shipping related NOx emissions

Propulsion of ships

Ship engines can run on different fuels, where Heavy Fuel Oil (HFO), Marine Gas Oil (MGO), and other types of distillates lead to significant emissions of NO_X, SO_X, PM and CO_2, also depending on the fuel. Fuel-types that reduce emission of these gases can be e.g. Liquid Natural Gas (LNG) or Methanol. Engines running on LNG reduce emissions of several gases (such as NO_X, SO_X, CO_2) but have emissions of unburned methane which can offset the beneficial climate impact of LNG from lower CO_2 emissions. There are several further alternatives for propulsion, like fuel cells, batteries or use of sails. There is already today battery driven short distance ferry traffic.

Ships in ports

Ships visiting a port can be responsible for large parts of the NO_2 concentrations in the respective harbour city. E.g. for Gothenburg, model simulations show that currently, almost half of the NO_2 concentrations in the northern part of the city stem from ship exhaust. In other ports, the contribution is of a similar magnitude. A measure to reduce NO_2 and particulate matter originating from burning fuel is to use onshore power supply while at berth.

Scenarios

A set of scenarios has been developed to analyse different future outcomes regarding shipping, the environment, human health and climate. These scenarios describe and forecast possible outcomes of different drivers of change. These drivers can be regulations, economic development, technical breakthroughs etc. The scenarios have been developed for the years 2030 and 2040. One scenario will be a business-as-usual scenario (BAU) to describe what will happen with current trends in development of the sector and with already decided regulations becoming implemented. There will then be a set of alternative scenarios illustrating the effect of changes in the drivers. Examples of some of the key factors influencing scenarios that has been considered include: fuel changes; the use of mitigation technologies; environmental requirements; changes in traffic volume and modal shifts; different levels of water pollution; and changes in technologies.

SCENARIO BUSINESS AS USUAL

In a Business-as-usual scenario (BAU) it is assumed that the development will follow current trends and that already decided regulations will come into force.

For the Baltic Sea this involves, e.g. the formation of a NO_X emission control area from 2021, regulated energy efficiency and restrictions on emitted waste from passenger ships. Figure 8 shows progress according to Scenario BAU.

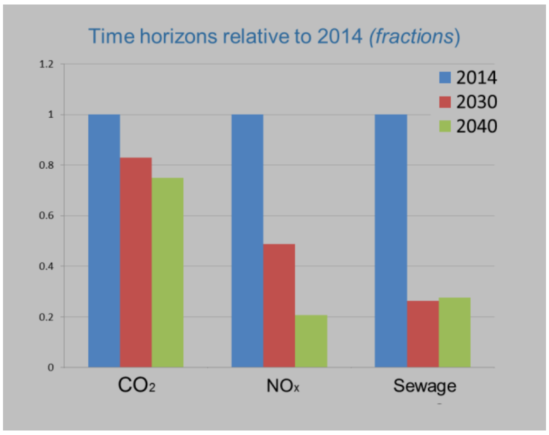


Figure 8 Business-as-usual scenario (BAU) modelling

SCENARIO SSP1 – SSP3

Also, three scenarios studied were "Sustainability SSP1", "middle of the road SSP2" and "fragmentation SSP3". These scenarios imply different development in shipping regarding volumes, types of fuel use and the introduction of environmental policies and the use of abatement methods. The emissions of CO_2, NO_x and sewage are shown with large differences between these three different futures.

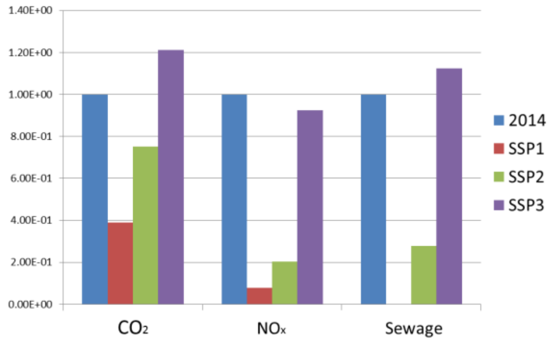


Figure 9 Different futures relative to 2014 (fractions)

WHAT IF THERE IS NO NO_X REGULATION IN THE BALTIC SEA?

The Baltic Sea will become a nitrogen emission control area (NECA). From 2021 new ships will have to follow the more stringent NO_x regulation Tier III (see Figure 11). As old ships are replaced by new ones the emissions will gradually go down. The bar graph shows this expected development and what it would look like without the NECA (see Figure 10).

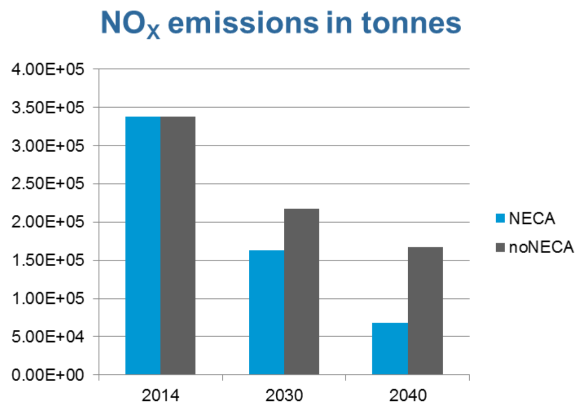


Figure 10 Calculated nitrogen oxides with and without the agreed nitrogen emission control area in the Baltic Sea.

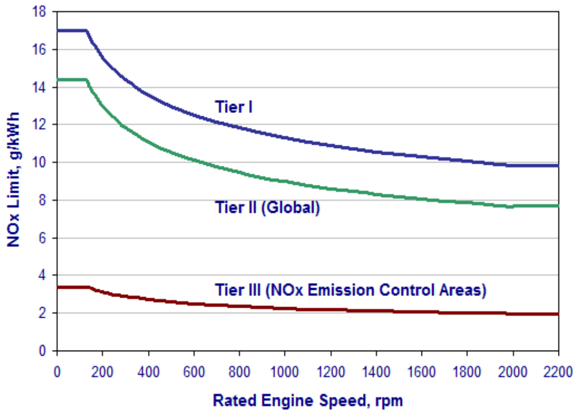


Figure 11 The allowed limits for nitrogen oxide emissions depends on Tier level and rated engine speed for the specific engines.