Gate terminal – Nitrogen Oxides study

Final report

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Summary

This report summarises the steps that were taken to assess the impact of fleet composition on the simulated emissions of oxides of nitrogen (NO_x) at the projected jetty 4 of Gate terminal. The basic idea was to follow the approach used to obtain the emission factors for AERIUS as close as possible to obtain an emission factor for NO_x in kg/km for the expected fleet and the frequency of visits at jetty 4. For validation purposes, the model used by the International Maritime Organization (IMO) in the Fourth Greenhouse Gas Study 2020 was applied in parallel. Both approaches yield a significant reduction in the distance-specific emission factors of the expected fleets compare to the AERIUS baseline. This can mostly be attributed to the fleet composition – newer vessels meeting higher environmental standards – and the operating conditions of the engines while approaching jetty 4.

Contents

Abbreviations

API	Application Programming Interface
Nbw'98	Natuurbeschermingswet 1998
Lbv-plus	Landelijke beëindigingsregeling veehouderijlocaties met piekbelasting
OPS	Operationele Prioritaire Stoffen
RIVM	Rijksinstituut voor Volksgezondheid en Milieu
Wnb	Wet natuurbescherming

1 Introduction

Gate Terminal plans to construct a new jetty at Maasvlakte 1 to handle more, smaller LNG carriers (GT 8000-18000). Since the construction (building the jetty and installation) and an increase in shipping traffic will lead to an increase in NOx emissions, and because the port entrance is located across from a Natura 2000 area, there is currently insufficient nitrogen space for this expansion according to the latest AERIUS calculations.

Gate Terminal is exploring options to modify the emission factors used for maritime and inland shipping with cleaner propulsion systems and after-treatment systems (TIER III and Stage V) and/or LNG as fuel. The permitting environmental service has indicated that if it can be substantiated that these ships indeed have a lower emission factor, these figures can be used for AERIUS calculations.

The assumptions for the possible lower NOx emissions when using LNG as fuel in combination with an SCR for maritime shipping (TIER III) and shore power were verified. This resulted in what this means for the emission factors to be used for AERIUS calculations.

In the first chapter of the report at hand an overview of AERIUS and emission factors is given. Furthermore, the two bottom-up models used in the study are presented. The introduction is followed by a detailed description of the method, the used data, and the limitations and uncertainties of the approach. The third part of the report describes the obtained results and discusses the implications. Finally, the conclusions of the study are presented concisely.

1.1 AERIUS model

The software AERIUS® [4] is used to support the granting of permits under the applicable environmental laws. It contains several modules which serve different purposes:

- AERIUS Calculator (calculates NOx and NH3 deposition),
- AERIUS Check (calculates the deposition sum of a single (reference) scenario and sees whether this sum falls above or below the threshold value of the Lbv-plus [1]),
- AERIUS Monitor (provides insight to deposition in sensitive nature areas),
- AERIUS Register (registrates projects which use nitrogen margin), and
- AERIUS Connect (API for automated AERIUS calculations).

For the purpose of this study AERIUS Calculator is the most relevant and will be described briefly below.

In AERIUS Calculator, the user can evaluate different emission scenarios. More precisely, AERIUS calculates the deposition of nitrogen emitted by different sources. New projects as well as the impact of measures can be evaluated this way. They are referred to as Project, Reference, Temporary, and Off-site reduction.

For the calculation, emission sources need to be added to the scenario. They are grouped into sector groups (Energy, Industry, Road transport, Maritime Transport, etc.) and sectors

[1] Landelijke beëindigingsregeling veehouderijlocaties met piekbelasting

(Maritime shipping: Dock; Inland route; Maritime route). Depending on the sector, the emissions can be defined as point, line, or area source. For routes, only line sources are allowed. Furthermore, emissions sources can be linked to buildings. For the calculation several situations can be combined. One of three calculation types – Process contribution, Maximum temporary effect, and Single scenario – has to be selected. Not all combinations of calculation types and scenarios are possible. Besides the calculation type, the calculation method has to be selected.

For the evaluation of the resulting deposition of NO_x and NH_3, the user can add the results of automatic selection of the assessment areas but can also define custom assessment points. In the former case, assessment areas abroad can be included optionally, and the assessment can be restricted to areas within a radius of one to 25 kilometres.

The two options are to run it according to the official method needed for the application for environmental permits or a calculation for the custom assessment points that have been set by the user. The results can be exported in different formats and can be used as input for future calculations with AERIUS. [2]

More details on how to use AERIUS can be found in the comprehensive manual [3].
The relevant data related to nitrogen deposition is collected by RIVM. It is published as part of a release of OPS[2] [5] or as open data [6]. Many other parties are involved in this process – amongst others TNO for providing emission factors – and provide data obtained from measurements and simulations. The providers of information are encouraged by RIVM to publish information on the methodology they use to obtain their specific data. For example, TNO together with MARIN provide the reports on the emission factors of seagoing vessels on a regular basis, cf. [7], [8], [9], [10], [11]. The data used in AERIUS is updated annually following a set procedure with a fixed release date in October, cf. [4, Sec. 3.1]. [4]

TNO provides emission factors and source properties of seagoing vessels depending on ship type and operation [12]. Possible operational conditions are sailing in open water, inland sailing (port areas), and staying at berth. For sailing in the harbour a factor of 1.8 is applied to the NO_x emission factors by AERIUS for a certain distance and for vessels with more than 10000 GT to take the increased power demand during manoeuvring into account. [4]

The methodology used by TNO to determine the emission factors for seagoing vessels for the period from 2014 to 2030 are described in [13]. The emission factors are listed in Annex A of the document. In 2019 an update of the emission factors for NO_x and particulate matter (PM_{10}) has been published [14]. The update also takes the impact of policy decisions like Sulphur Emission Control Areas (SECAs) and the Energy Efficiency Design Index (EEDI) into account. The updated emission factors, heat content, and stack height can be found in the annex of the report.

In AERIUS, LNG tankers are part of the category "Hoofgroep 1: Olietankers, overige tankers", [14, Tbl. 1]. There are classes depending on the gross tonnage of the ship ranging from 100 GT to above 100,000 GT [14, Tbl. 2]. The combination of category and GT class will be referred to as fleet bin in this document. The data used for the determination of the emission factors is taken from the emission inventory. The emission model that is used for the emission inventory is described in [7, App. A]. Due to the limited information on auxiliary engines, these machines are modelled as medium/high speed four-stroke engines. The model assumes that boilers are only used if ships are at berth, cf. [15], [16], [17]. The current

[2] Operationele Prioritaire Stoffen model. The core model used by AERIUS

model does not include emission factors for auxiliary engines that run on LNG, cf. [7, Tbl. A-13].

The emission factor of a fleet bin is determined by summing up the emissions of all the vessels of this bin according to the emission inventory and dividing the result by the total distance sailed. Separate calculations are done for port areas and open sea.

It is important to note that for the determination of the emission factors, grid cells in which a relatively large amount of manoeuvring takes place, are neglected. The higher emissions in these areas are then calculated by applying the manoeuvring factor in AERIUS rather than using the model for manoeuvring vessel that is applied in the emission registration. [14, p. 9]

An analogous approach is applied for ships at berth. In this case the total emissions at berth are divided by the accumulated time at berth of the vessels of a fleet bin.

For the forecast of future emission factors, the model POSEIDON is used. It provides a trend factor per year which takes the fleet development into account. The trend factors are obtained as the ratio of the emission factor determined by POSEIDON for the future and the current year. In the calculation of future emissions, the efficiency improvement due to the EEDI is taken into account by correcting the calculated engine load. The current emission factors need to be multiplied by the trend factor to obtain the emission factor of a future year. [14, pp. 7–9]

The distribution model of AERIUS takes the heat content (exhaust gas temperature) of emitting sources into account. In the case of seafaring vessels, the heat content is determined based on the calculated CO_2 emissions which directly correspond to fuel consumption. It is assumed that 25 % of the heat that is released from the fuel during combustion is emitted via the stack. A value of 3.3 MJ/kg CO_2 is used to obtain the input value for AERIUS. The height of the stack is calculated for every fleet bin based on the average GT by applying Equation 1.1 hieronder. Different values are used for sailing at sea, in port areas, and at berth. For that purpose, a correction factor K_{corr} is applied. The value used for sailing in port areas is not given in the report. [14, pp. 10–13]

Equation 1.1: Calculation of stack height [14, pp. 12–13]

$$H = c \cdot X \cdot \mathrm{GT}^n - K_{\mathrm{corr}}$$
$$c_{\mathrm{tanker}} = 0.17$$
$$X_{\mathrm{tanker}} = 9.00$$
$$n_{\mathrm{tanker}} = 0.30$$
$$K_{\mathrm{corr}} = \begin{cases} 0, & \text{sailing} \\ 9, & \text{berthed} \end{cases}$$

An overview of minor changes of the emission models for AERIUS 2021 and AERIUS 2023 are summarised in the memoranda [18] and [19]. Further information on modelling the emission of seagoing vessels, policy impact, and future developments can be found in the TNO reports [20] and [21].

2 Methods

2.1 General approach

The goal of this study is to obtain an emission factor for AERIUS by applying the bottom-up model used for the emission inventory for the expected fleet at jetty 4. The idea behind this approach is that the actual fleet composition, engine powers, sailing speeds, used fuels, and Tier levels will better represent the NO_x emissions caused by the marine traffic to and from jetty 4 than standard ARIUS emission factors.

2.2 Data from Gate terminal

For the purpose of this study, Gate terminal has provided a list of vessels that are representative for the fleet that will visit jetty 4 in the future. These ships are referred to as the "reference fleet". An overview of these vessels and the basic input data used in the calculation, is given in Table A.1 in Appendix A.1. Based on the best available knowledge, an estimation of the number of slots has been shared by Gate terminal. There are two possible scenarios – referred to as "A" and "B" – with five and ten different vessels, respectively, see Table A.2 in Appendix A.1.

2.3 Emissions of the example fleet

2.3.1 Main engine load

The emissions of the main engines of a seagoing vessel are calculated according to [7, p. A-7]. The work-specific base emission factors are multiplied with the estimated actual engine load. To take the increase in work-specific emissions at low engine loads into account, a load correction factor is applied.

The base emission factors for marine diesel engines are given in [7, Tbl. A-8], the values for engines running on LNG are given in [7, Tbl. A-11]. For all LNG engines in the reference fleet, the emission factors of the engine type medium-speed/dual-fuel (MS-DF) were used. There are no dedicated emission factors for Lean-Burn Spark-Ignited (LBSI) engines and they form an exception insofar as it was assumed that they do not switch to diesel fuel at engine loads below 20%.

Since no dedicated load correction factors for LNG-fuelled engines are available in [7, Tbl. A-14], the load correction factors for diesel engines of the applicable Tier levels were used.

The TNO model uses a fixed percentage depending on main engine power to determine the power demand and fuel consumption of auxiliary engines at sea and during manoeuvring. It is assumed that boilers are used at berth only. The model summary [7, Sec. A1.3] states that the percentages have been determined based on [22, Tbl. 14]. For the type 'LNG tanker', the values used in the model correspond to [23, Tbl. A1.8] which was used by IMO in the Second Greenhouse Gas Study[3]. This table and the assumption that boilers are only used at berth

[3] This might be the case for the whole table, but this has not been verified in the course of this project.

have, however, to be considered as outdated since the IMO used a different approach in the Third [24, Tbl. 6,7] and Fourth [25, Tbl. 17] Greenhouse Gas Studies.
Furthermore, [7, Tbl. A-13] does not provide emission factors for auxiliary engines running on LNG. The same applies for boilers.

To be able to calculate the emissions, the following assumption had to be made in addition to the ones that form a part of the model (e.g., that as few main engines as possible are running):

- The area of interest is limited to the distance between the port entry and jetty 4 (8.5 km in total).
- A speed pattern has been provided by Gate terminal, see Table A.3 in Appendix A.1. The results of the study at hand are based on this pattern. Significant changes to the speed distribution may cause different results.
- All engines that can run on LNG actually do so in the whole area of interest.
- Emissions at berth are neglected under the assumption that the power demand of the vessels will be met by onshore electrical power supply.
- For some of the vessels in the reference fleet, service speed could not be obtained from Clarksons' World Fleet Register (WFR) [26]. In these cases, service speed has been estimated by applying a regression function. For details see appendix A.2.

2.3.2 Fourth IMO Greenhouse Gas Study

The bottom-up model developed by TNO is intended to serve the emission inventory on the scale of the Dutch Continental Shelf. Applying it on the rather limited area and vessel operation at jetty 4 yields additional uncertainty. To validate the results obtained from this model, the bottom-up model that was used by the International Maritime Organisation (IMO) in the Fourth Greenhouse Gas Study was applied in parallel. The basics of both models are the same: main engine power is determined based on installed main engine power, service speed, and actual sailing speed.

There are, however, small differences:

- IMO uses a slightly different power curve to describe the relationship between vessel speed and main engine power.
- Auxiliary engine power is determined by fleet type, vessel size, and operational state. The operational states used in the Fourth IMO GHG study are: 'At berth', 'Anchored', 'Manoeuvring', and 'Sea'.
- In the Fourth GHG study it is assumed that auxiliary boilers on LNG tankers are used in all operational conditions.

2.4 Emission factor for AERIUS

The emission factors for AERIUS are calculated as a weighted average of the expected fleet by using Equation 2.1 hieronder. The total mass emissions $m_{\mathrm{NO_x},i}$ of every vessel are divided by the sailed distance of 8.5 km and multiplied by the 'manoeuvreerfactor' $f_{\mathrm{man.}}$ for the 'manoeuvreerlengte' $d_{\mathrm{man.}}$. The values of theses parameters were taken from [12]. As a consequence, no 'manoeuvreerfactor' has to be applied for the obtained emission factor (i.e., manoeuvreerfactor=1.0). The weighting factors w_i are the shares of slots per vessel as stated in Table A.2.

Equation 2.1: Calculation of weighted emission factor for reference fleet

$$EF_{\text{jetty4}} = \sum_{\substack{i\,\epsilon \\ \text{exp. fleet}}} w_i \cdot \frac{m_{\text{NO}_x,i}}{8.5} \cdot \left(\frac{\max(8.5 - d_{\text{man.}}, 0.0)}{8.5} + f_{\text{man.}} \cdot \frac{\min(d_{\text{man.}}, 8.5)}{8.5} \right)$$

2.5 Caveats of the applied method

The results obtained by applying the described method are – as with any model – only an approximation of the actual emissions of oxides of nitrogen from vessels sailing to and from jetty 4. To begin with, some factors which affect engine load and thus emissions are not modelled. One of them is weather conditions (wind, waves, current). Also, the switch of dual-fuel engines to diesel or fuel oil at lower loads is based on assumption and might be different in practice. Furthermore, there are certain aspects that are controlled by the crew, like, for example, keeping more engines running than necessary to provide propulsion and auxiliary power. As a consequence, they will operate at low load or even idle which will cause higher emissions. Last but not least, the calculation relies on compliance with the assumption on fuel use, i.e., the engines run on LNG as long as this is technically possible.

3 Results and Discussion

3.1 Contribution of the different emission sources

The model used to calculate the NO_x emissions of seagoing vessels for the Dutch emission inventory takes the emissions of main and auxiliary engines into account. IMO also assumes that boilers are used while at sea or during manoeuvring. The contributions of the different emission sources on a one-way trip to jetty 4 (8.5 km) per model are depicted in Figure 3.1 hieronder.

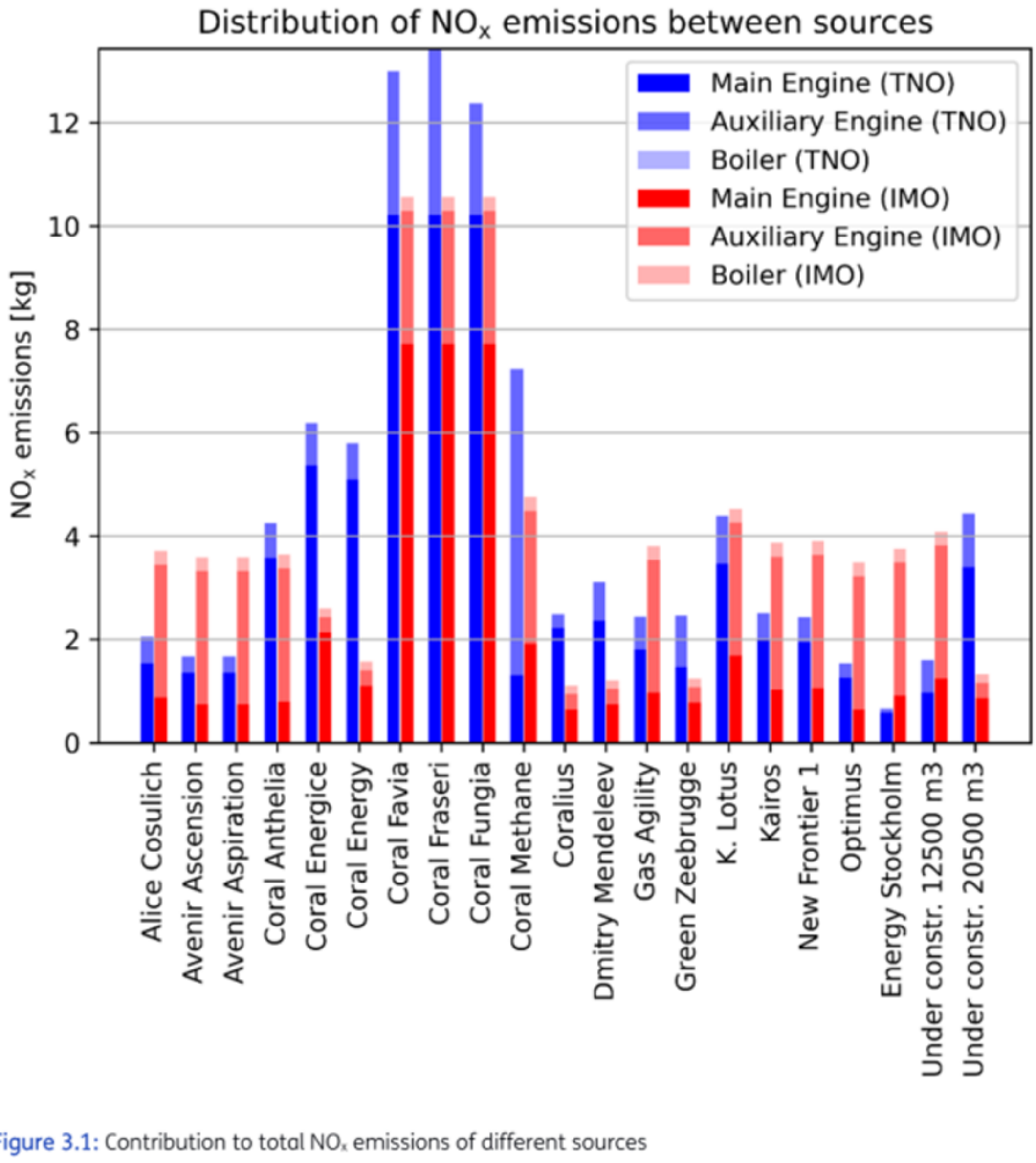

Figure 3.1: Contribution to total NO_x emissions of different sources

The results of the TNO model are shown in blue bars whilst the IMO numbers are kept in red. The calculated NO_x emissions of the main engines are usually higher in the TNO model, except for three vessels, the Coral Methane, the Energy Stockholm, and the smaller of the two ships which are currently being built. This can mainly be attributed to the higher load correction factors used by this model. For some of the vessels, in particular the smaller ones, the lower main engine emissions of the TNO model are more than outweighed by the higher emissions of the auxiliary engines in the calculation according to IMO's Fourth GHG study. NO_x emissions of auxiliary boilers (only IMO) are negligible. This is caused by the very low specific NO_x emissions of boilers used by IMO.

3.2 Comparison of emission factors

The goal of the study is to obtain an emission factor for NO_x in kg/km that better represents the expected fleet and that can be used as input in AERIUS. For that purpose, weighted averages of the NO_x emissions of the expected fleet have been calculated. The results are depicted in Figure 3.2 hieronder.

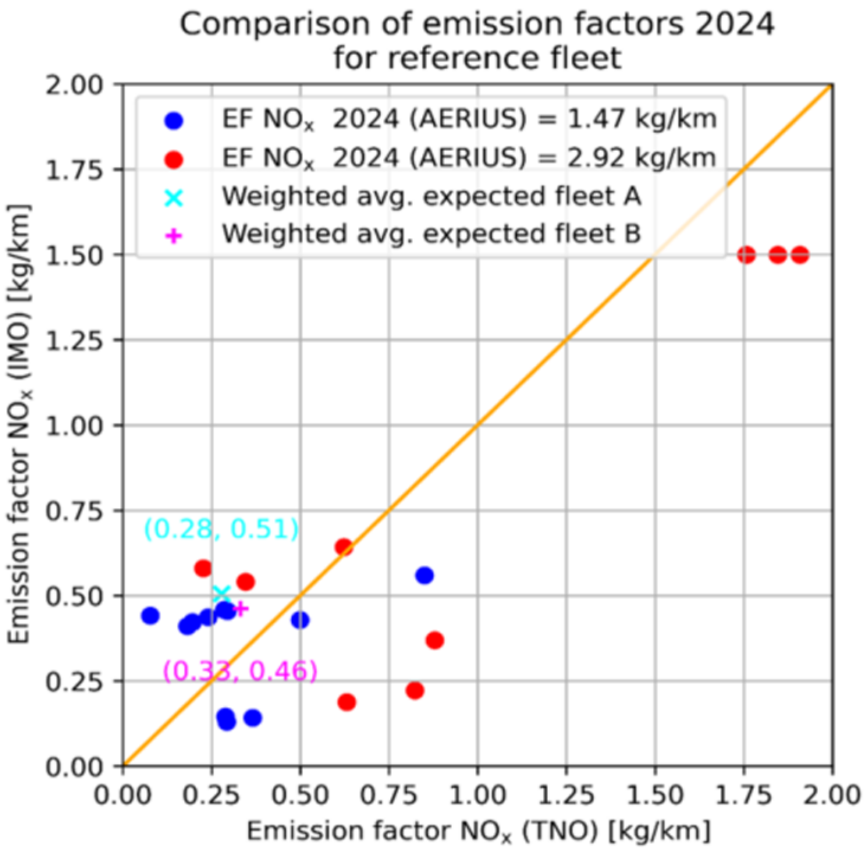

Figure 3.2: Scatter plot of emission factors obtained from calculation acc. to TNO and IMO

On the x-axis the final emission factor according to the TNO model is plotted for every vessel. On the y-axis the same is done for IMO. That yields twenty-one dots in two colours, which represent the emission factor used by AERIUS for the respective ship. The stated AERIUS factor already includes the manoeuvre factor for a trip of 8.5 km. Since the numbers used in AERIUS apply to GT-bins of vessels and the reference fleet only contains ships of two size-bins, there are only two different AERIUS factors. The three vessels in the right upper corner are Tier II-vessels with diesel engines running solely on fuel oil. That explains why their emission factors are higher than the ones of the rest of the reference fleet. These three ships are, however, not expected to visit jetty 4. The remaining reference fleet has emission factors of less than 1.0 kg/km (TNO) and less than 0.75 kg/km (IMO), respectively. There is significant scatter which means that the results of TNO and IMO models do not perfectly agree. This can also be seen in Figure 3.1 hierboven. On average, however, there is sufficient agreement to state that the emission factors of the expected fleet are significantly lower than what is assumed by AERIUS.

In addition to the dots, a cyan and a magenta cross in Figure 3.2 mark the position of the weighted average of the emission factors of the expected fleets. They are at 0.28 kg/km and 0.51 kg/km for scenario "A" and at 0.33 kg/km and 0.46 kg/km for scenario "B". (Refer to Table A.2 for the scenarios.)

To predict future emissions, AERIUS includes a forecast of emission factors. The numbers per year until 2040 can be found in [12]. Table 3.1 gives an overview of how the calculated emission factors of the reference fleet compare to the AERIUS numbers of three reference years. Again, the AERIUS factors already include the manoeuvre factors for a trip of 8.5 km. Since the reference fleets remain unchanged, the emission factors stay the same over the whole period whilst the AERIUS numbers of the two applicable fleet bins decrease. The distance specific NO_x emissions are expected to be seven percent lower in 2026 compared to 2024. The decrease in 2030 is about twenty percent compared to 2024. The calculated emission factors of the reference fleets are still significantly lower than the predicted fleet average in the reference years.

Table 3.1: Calculated emissions factors for expected fleet at jetty 4

Year / Emission factor [kg/km]	TNO	IMO	AERIUS (5000–9999 GT)	AERIUS (10000–29999 GT)
2024	A: 0.28 B: 0.33	A: 0.51 B: 0.46	1.47	2.92
2026			1.38	2.74
2030			1.16	2.32

4 Conclusion

Applying the bottom-up approach on which the Dutch emission inventory and the AERIUS model are based on to the expected fleets at jetty 4, yielded significantly lower distance-specific NO_x emissions then what is assumed in the default fleet in AERIUS. This is on one hand caused by the lower brake-specific NO_x emissions of engines running on LNG (cf. for example [27]). On the other hand, the reference and expected fleets at jetty 4 are significantly newer than the average fleet in Dutch waters and therefore meet higher environmental and emission standards. Furthermore, the sailing speed – an important driver of engine load and NO_x emissions – is lower compared to the average operation of seagoing vessels but engine loads are still high enough to yield low brake-specific NO_x emissions. Altogether, this leads to a NO_x emission factor of 0.28 kg/km and 0.33 kg/km, for reference fleets "A" and "B" respectively, which can be applied to the vessel movements related to jetty 4 in AERIUS.

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Signature

TNO › Mobility & Built Environment › Den Haag, 26 September 2024

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Appendix A
Vessel data

A.1 Input data used for calculation

The basic input data used for the calculation is summarized in Table A.1 hieronder.
The selection of vessels has been provided by Gate terminal. Unless stated otherwise, the data has been obtained from Clarksons' World Fleet Register (WFR) [26]. The lowest three vessels in the table are still under construction and no information could be retrieved from the WFR. The information on these vessels has been collected and shared by Gate terminal. Where possible, it has been verified with publicly available data, e.g., [28]. Information on service speed is crucial for both, the TNO and the IMO model. If this data was missing in WFR, it has been calculated by regression of data of the rest of the fleet by using equation (3) on [25, p. 34], cf. section A.2.

Table A.1: Basic input data of reference fleet

IMO Number	Name	GT	Capacity [m^3]	Main engine type	Fuel Types	Service speed [kn]	Power [kW]	Trans-mission type
9938767	Alice Cosulich	8847	8471	LPDF	LNG, VLS IFO	14.3[4]	4680	Electric
9868974	Avenir Ascension	8366	7500	LPDF	LNG, VLS MGO	12.8[4]	3000	Electric
9868962	Avenir Aspiration	8366	7500	LPDF	LNG, VLS MGO	12.8[4]	3000	Electric
9625140	Coral Anthelia	6441	6500	LPDF	LNG, VLS IFO	15.5	5400	Mechanical
9783124	Coral Energice	17020	18000	LPDF	LNG, VLS MDO	15.5	14400	Mechanical
9617698	Coral Energy	13501	15600	LPDF	LNG, VLS IFO	15.8	7800	Mechanical
9378280	Coral Favia	10105	10030	Diesel	VLS IFO	16.0	7000	Mechanical
9378278	Coral Fraseri	10105	10030	Diesel	VLS IFO	16.0	7000	Mechanical
9378292	Coral Fungia	10105	10030	Diesel	VLS IFO	16.0	7000	Mechanical
9404584	Coral Methane	7833	7500	LBSI	LNG	15.5	12900	Electric
9769128	Coralius	6015	5737	LPDF	LNG, VLS MDO	13.5	3000	Mechanical
9888182	Dmitry Mendeleev	6690	5800	LPDF	LNG, VLS IFO	12.8[4]	3000	Mechanical

IMO Number	Name	GT	Capacity [m³]	Main engine type	Fuel Types	Service speed [kn]	Power [kW]	Trans-mission type
9850680	Gas Agility	17645	18600	LPDF	LNG, VLS MDO	14.9[4]	5920	Electric
9750024	Green Zeebrugge	7403	5100	LPDF	LNG, VLS MGO	13.1	3330	Mechanical
9901362	K. Lotus	18723	18137	LPDF	LNG, VLS IFO	14.0	8640	Electric
9819882	Kairos	8070	7500	LPDF	LNG, VLS IFO	13.5	4752	Electric
9765079	New Frontier 1	9816	6469	LPDF	LNG, VLS MGO	13.0	4440	Electric
9870472	Optimus	6357	6000	LPDF	LNG, VLS MDO	13.4	2960	Mechanical
9977763[5]	Energy Stockholm	8597	8000	LPDF	LNG, VLS MDO	11.0	2520	Electric
n/a[5]	Orderbook 1	10478	12500	LPDF	LNG, VLS MDO	13.6		unknown
n/a[5]	Orderbook 2	14472	20000	LPDF	LNG, VLS MDO	15.5	5800	unknown

The expected slots per year are given in Table A.2 hieronder. Based on business data, only five out of 21 vessels of the reference fleet are expected to visit jetty 4 frequently.

Table A.2: Expected slots per year

IMO number	Scenario A		Scenario B	
	Slots p.a.	Weighting factor w_i	Slots p.a.	Weighting factor w_i
9938767	30	0.1	30	0.1
9404584	0	0	15	0.05
9850680	0	0	45	0.15
9750024	0	0	15	0.05
9901362	30	0.1	30	0.1
9819882	0	0	15	0.05
9870472	0	0	15	0.05
9977763	60	0.2	60	0.2
Orderbook 1	150	0.5	45	0.15
Orderbook 2	30	0.1	30	0.1

[4] Service speed obtained by regression of WFR data.
[5] Data of these vessels have been provided by Gate terminal.

Table A.3: Speed pattern of vessels approaching/leaving jetty 4

Route to jetty 4	Part 1	Part 2	Part 3	Total dist. / Average speed
Distance [km]	4.0	2.0	2.5	8.5
Speed [kn]	10.0	8.8	4.5	7.2

A.2 Regression of Service Speed

The service speed of some vessels could not be retrieved from WFR and had therefore to be estimated based on other parameters of the ship. For that purpose, the regression stated in equation (3) on [25, p. 34] was used:

Equation A.1: Regression of service speed

$$\text{Speed} = b_1 + b_2 \cdot \text{LOA} + b_3 \cdot \text{Power}_{\text{ME}} + b_4 \cdot \text{Dwt}$$

In Equation A.1, LOA refers to the Length-Over-All, Power_{ME} is the installed power of Main Engines, and Dwt is the Deadweight tonnage. The fitted service speed is compared to the values stated in WFR in Figure A.1 hieronder. It shows good agreement with a Standard Error of the Estimate of 0.67 knots. It is therefore assumed that the calculated service speeds will reasonably well represent the actual service speeds of the vessels.

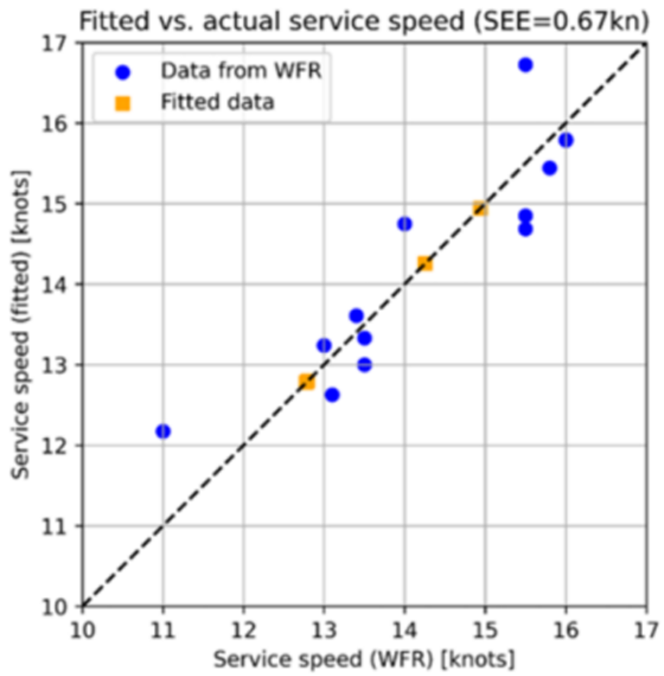

Figure A.1: Fitted Service speed vs. data from Clarksons' World Fleet Register

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