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Air emissions from shipping in the ASEAN region

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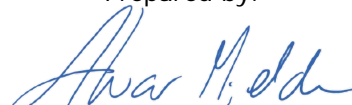
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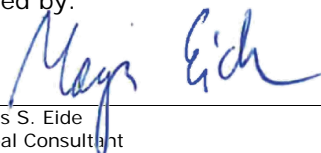
- Prepare a detailed overview of maritime traffic and the associated emissions for the ASEAN region today (baseline)
- Use the baseline estimates for further analysis of abatement measures to reduce the emission footprints, and
- Discuss policy instruments relevant for reducing emissions in the ASEAN region

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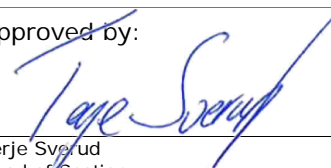
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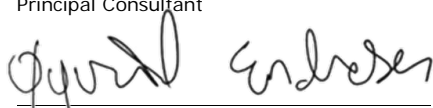


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1 EXECUTIVE SUMMARY

Southeast Asia is one of the most densely trafficked shipping areas in the world, with some of the major international sea routes for large cargo ships. Domestic and regional traffic has also increased, following the economic growth of the countries in the ASEAN (Association of Southeast Asian Nations). There is a need for better understanding of both emissions and impacts resulting from shipping activity in the ASEAN region. Geographically gridded inventories of emissions to air from shipping are fundamental as input to evaluate impacts on the environment, human health and climate, and to effectively assess what options are available to mitigate the impacts.

This report has been prepared for the Asia Europe Meeting (ASEM)-Conference “Green Shipping. Blue Business” in Singapore 26-27 April 2018.

What we did

This paper models shipping air emissions in the ASEAN region, and assess what options are available to mitigate the impacts. The objectives are three-fold;

- Prepare a detailed overview of maritime traffic and the associated emissions for the ASEAN region today (baseline), using AIS ship movement data
- Use the baseline estimates as basis for analysis of abatement measures to reduce the emission footprints, and
- Discuss policy instruments relevant for reducing emissions in the ASEAN region.

This three-phased approach is inspired by the document “Charting a course for green coastal shipping” published by the Green Coastal Shipping Program (2016) in Norway – a collaborative project between government authorities and the private sector with the objective of driving a green transformation of the Norwegian maritime sector.

What we found

Baseline for maritime traffic, fuel consumption and the associated emissions to air

The AIS-based modelling shows that a total of 29 630 oceangoing ships had operations in, or transits through, the ASEAN region, consuming about 35.1 Mton¹ of oil equivalents in 2017. The numbers are based on analysis of ships having AIS-transponders, covering domestic, international and transit sailings in the area. The key findings from fuel consumption modelling are:

- Bulk carriers, container vessels and oil tankers together accounts for more than 73% of the total fuel consumption in the region.
- Larger ships, above 10 000 gross tonnage, accounts for more than 85% of the total fuel consumption in the region.
- Depending on ship type, the time spent at berth/stationary/anchorage for cargo ships range from 40% to 60% of the vessels’ total operating time in the area.
- Fuel is consumed in cruising mode (82%), manoeuvring mode (1%) and berth/stationary/anchorage mode (17%).

¹ 1 Mton = 1 000 000 tonnes

Ship emissions in the ASEAN region are calculated by multiplying the AIS-based fuel consumption by emission factors. The AIS based tracking also allow for calculating sailed distance for individual ships and aggregated.

Table 1-1 present an overview of emissions by ship types for the ASEAN region. Key findings from the AIS -based emission modelling are:

- CO₂ emissions are 112 million tonnes, representing about 14% of the global ship emissions.
- Emissions of NO_x and SO_x are 2 320 and 1 730 Kton², respectively.
- Emissions of PM₁₀ and PM_{2.5} are 214 and 194 Kton, respectively.

Table 1-1 ASEAN ship emissions for 2017

Ship type	CO ₂ [Kton]	NO _x [Kton]	SO _x [Kton]	PM ₁₀ [Kton]	PM _{2.5} [Kton]
Oil tankers	19 490	340	308	37.0	33.4
Chemical/prod. Tankers	6 510	120	105	12.6	11.4
Gas carriers	9 360	200	151	18.1	16.4
Bulk carriers	33 750	790	545	65.4	59.1
General cargo vessels	4 420	80	71	8.6	7.8
Container vessels	29 030	630	469	56.4	50.9
Ro-Ro vessels	2 150	50	34	4.1	3.7
Reefers	510	10	8	1.0	0.9
Passenger vessels	2 800	50	36	4.4	4.0
Offshore vessels	2 160	30	1	4.1	3.7
Other vessels incl. Fishing	1 750	20	1	2.9	2.7
Total	111 930	2 320	1 729	214.6	194.0

Figure 1-1 shows the geographical distribution of modelled ship fuel consumption for the entire ASEAN region. The fuel consumption and associated emissions to air varies within the region, with hot-spots along the main international sea lanes, largest ports and busiest straits and channels (i.e. red color).

² 1 Kton = 1 000 tonnes

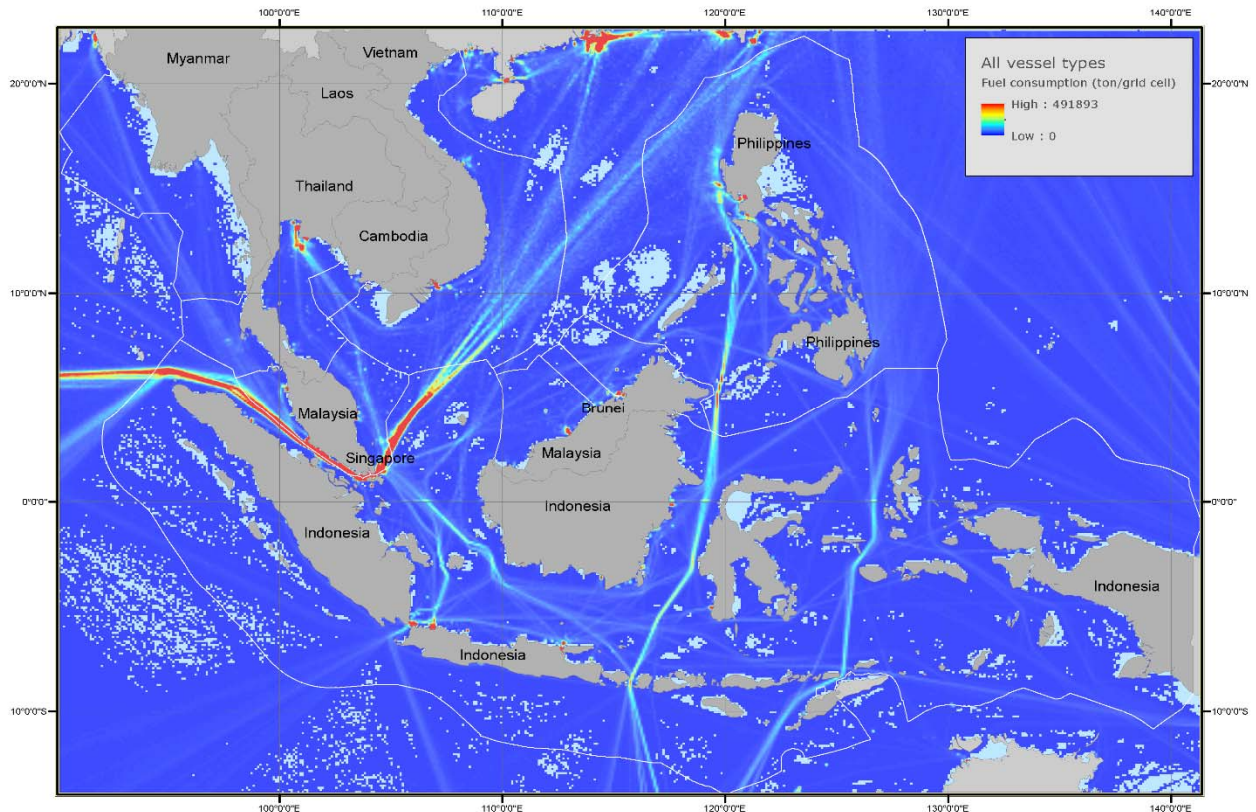



Figure 1-1: Shipping traffic 2017 tracked by fuel use (Source: DNV GL).

Analysis of abatement measures to reduce air emissions

A high-level review highlights the current global uptake of low and zero emission technologies worldwide. LNG powered vessels have already been introduced (currently 121 ships in operation and 127 confirmed newbuilds), biofuels and methanol are available in certain ports, and full electrical/hybrid ships are emerging in the short sea segment for offshore and passenger ships/ferries. Shore-side electricity is also emerging in certain ports, is the provision of electrical power to ships while at berth. An important development is the electrification of the Norwegian domestic ferry sector, with phasing in of about 60 battery electric ferries over the next few years.

The study points to promising operational and technical measures, alternative fuels, and exhaust gas treatment systems. Zero emissions alternatives are full-electric ships (currently applied in the ferry segment) and hydrogen fuel cell powered ships (first commercial application planned in 2021). Compared to the short sea segment, deep sea vessels have fewer options for zero emission solutions. Low emission solutions can be achieved by applying a wide number of solutions, such as alternative fuels and energy carriers (e.g. LNG, biofuels, methanol, hybridization with batteries, etc.), technical and operational measures (e.g. speed reduction, air lubrication, improved hull and propulsion technology, etc.), and exhaust gas after treatment (e.g. scrubber, SCR, filters, etc.).

Two example cases for application of reduction of air emission in the ASEAN region are presented; slow steaming for large container ships and electric operation of small passenger ships.



Deep sea case - slow steaming for large container ships: The 460 largest container vessels (above 100 000 GT) consumed approximately 2.1 Mton of fuel, representing 6% of the totals for the ASEAN region. This case assesses the effect of enforcing a speed limit for these ships. AIS-based analyses have been used to identify current sailing speeds and operating patterns for this fleet, and to calculate fuel consumption and associated emissions. The method is based on unchanged total sailing distance, but where fuel consumption (per nautical mile) at sailing speeds above the speed limit is adjusted down to consumption (per nautical mile) at the set speed limit. The modelling results for the introduced speed limits, shows:

- 6% reduction in reduction in air emissions, when applying a speed limit of 18 knots.
- 23% reduction in reduction in air emissions, when applying a speed limit of 15 knots.

The overall emission reductions achieved by introducing local speed restrictions may be cancelled or even negative if sailing time lost in the regulated areas are made up for by increased speed in other areas. However, the ASEAN region having high density traffic areas close to shore and in populated areas, would experience significant reduction effects on important local pollutants like NO_x, SO_x and PM if speed is reduced.

This case indicates that speed reduction could be an effective measure for emission reductions in the ASEAN region. Furthermore, it demonstrates a methodology which could be extended to other ship segments to assess the full potential for emission reduction through speed reduction in the ASEAN region.

Short sea case - electric operation of small passenger ships: A high level feasibility study was carried out for all passenger ships smaller than 1000 GT with registered port calls in the ASEAN region during a month of operation. The distance and fuel consumption between port calls was calculated for each voyage. A battery with an energy capacity of 1000 kWh can simplified be estimated to cover a distance up to 25 km (depending on the energy need of the ship). This covers the majority of the voyages in this segment.

For longer voyages, hybridisation with a high degree of charged electrical power from land may provide an option for very high emission reductions, with significantly reduced cost compared to full-electrification. To illustrate this a specific distance operated by smaller passenger ships (< 1000 GT) in the Philippines was investigated.

The high-level analysis indicates that electrification of smaller passenger ships is technically feasible – in particular in case of hybridisation with high degree of electrification is considered. Passenger vessels below 1000 GT account for 0.65 % of total ASEAN fuel consumption and emissions. This corresponds to 728 kton CO₂, 15 kton NO_x and 11 kton SO_x, which could be eliminated by full electrification.

It should be noted that the time spent in port is crucial for design of the energy transfer system, shore to ship, while battery banks onshore can lower the power requirement from the shore power grid. The overall emission reduction potentials, by using electric driven ships, are closely linked to the energy sources used by the onshore power grid.

The methodology demonstrated in this case could be further detailed to include economic factors and shore-side infrastructure. The analysis could also be extended to other ship segments to assess the full potential for emission reduction through electrification/hybridisation in the ASEAN region.

Policy instruments relevant for reducing emissions

This study outlines options available to policymakers and industry to further provide incentives for emission reductions from ships operating in the region. The options include measures from three categories:

- **Regulatory measures** (rules and regulations); Measures in this category directly impose demands on behavior or technology. Examples of legal instruments may be requirements in the form of laws, regulations or standards;
 - Among the latest international developments is that, MEPC 72 adopted the “Initial IMO Strategy on reduction of GHG emissions from ships”, (resolution MEPC.304(72)). This is IMO’s vision to phase out GHG emission as soon as possible within the end of this century. The aim is also to reduce total emissions from shipping by 50% in 2050 compared to 2008. A carriage ban on non-compliant fuel was approved, and is expected to enter into force in March 2020.
- **Economic measures** (taxes, subsidies, quotas, etc.); Economic instruments are based on incentives to change environmentally harmful behavior by making environmentally harmful activity more expensive or environmentally friendly activity cheaper. This is done by taxing unwanted behavior in the form of fees, or by subsidizing desired behavior or making allowances in a quota market. Incentive schemes such as the Norwegian NOx-fund arrangement can also be considered, where paid tax is distributed back to the industry as direct investment support for emission reducing technologies.
- **Other measures, including research and development;** Measures that do not involve economic or legal measures embrace a wide range of opportunities, from research and development, to targeted procurement policies (favouring low emission solutions) at government agencies.


Note that the options listed are not intended to be exhaustive. Rather, the intention is to point to relevant examples which could serve as inspiration and guidance for future work.

What we recommend

This study has shown an AIS-based emission modelling approach, which geographically allocates the emissions. Results from the modelling in the ASEAN region may be presented on different time scales (e.g. hourly, daily, monthly, yearly), for different ship types and size categories, and operating modes. These data can be integrated with Geographic Information System (GIS) software to ease analysis, and take advantage of the geospatial processing functionality. A reliable and up-to-date ship emission inventory is essential for getting overview of the trends and challenges, and for assessing the effect of different emission control options. It is therefore recommended to establish an environmental accounting model for continuous monitoring of ship traffic, air emissions and impacts in the region. The model could provide stakeholders with updated status for the most important air emission components, both local pollutants and GHG emissions.

Furthermore, it is recommended that the AIS-based emission inventory is further detailed to categorize emissions as domestic, international or transit. This could help guide ASEAN members in making targeted policy choices to fulfill national obligations relating to domestic emissions.

This study has also provided a high-level overview of the emission reduction technologies and fuels available. It is recommended that a detailed study is undertaken to simulate the possible uptake of these



emission reduction options in ASEAN waters, in order to quantify the emission reduction potentials and associated costs.

Finally, this study has provided an overview of policy options available for stakeholders to stimulate phasing in of new and alternative emission reducing technologies and fuels. It is recommended to initiate studies that identify barriers in way of achieving the policy targets, in order to tailor a package of policy measures which could lead to sustainable emission levels in specific areas or for the region.

2 INTRODUCTION

Southeast Asia is one of the most densely trafficked shipping areas in the world, with some of the major international sea routes for large cargo ships (e.g. Tournadre, 2014; Johansson et al, 2017; DNV GL, 2017). Asia is the main importing and exporting region in the world, accounting for 61% of unloaded cargo volume and 40% of loaded cargo volume in 2016, and has experienced heavy growth (UNCTAD, 2016). In 2016, 60% of the 250 Mtoe³ fuel consumed by global shipping was consumed in Indian and Pacific waters (DNV GL, 2017). As illustrated in Figure 2-1, the Straits of Malacca is the major passageway between the Pacific and Indian Oceans for the large cargo ships. The number of transits has increased by 50% between 2000 and 2016, and is dominated by container ships followed by oil tankers and bulk ships.⁴ Recent estimates indicate that 21% of global trade passed through the South China Sea in 2016, with China heavily influencing as over 64% of China's maritime trade transited the waterway.⁵ According to OECD (2018a), Southeast Asia had an average economic growth of 5.1% between 2011 and 2015. National and regional traffic has also increased, followed the economic growth of the ten countries in ASEAN (Association of Southeast Asian Nations). The region's seaborne exports to non-ASEAN countries accounts for 74%.⁶

There is a need for better understanding of both emissions and impacts resulting from the shipping activities in the ASEAN region. Geographically resolved ship emissions inventories are a fundamental input to evaluate impacts on the environment, human health and climate – and to effectively assess what options are available to mitigate these impacts (e.g. Endresen et al, 2003; Corbett et al, 2008; OECD, 2010; Liu et al, 2016; Li et al, 2017). The AIS (Automatic Identification System) ship movement data opens for expedient and accurate emission accounting.

This paper describes a framework for accounting of shipping emission in the ASEAN region, building on recent DNV GL work, with AIS ship tracking data from satellites as the cornerstone. Regional and global ship emission inventories has been developed, based on fleet and AIS ship tracking data, regionally (e.g. Endresen et al, 2007; Mjelde et al, 2014; Pitana et al, 2010; Jalkanen et al, 2009; Winther et al, 2014, 2017; DNV GL 2015b, 2016c; Liu et al, 2016; Li et al, 2017) and globally (e.g. Buhaug et al, 2009; Smith et al, 2014; Johansson et al, 2017; ICCT 2017a,b; DNV GL, 2017; Li et al, 2017). The objective in this project is three-fold:

- Prepare a detailed overview of maritime traffic and the associated air emissions for the ASEAN region (baseline).
- Use the baseline estimates for fuel consumption and air emissions as basis for analysis of abatement measures to reduce the future emission footprints.
- Discuss policy instruments relevant for reducing air emissions in the ASEAN region.

This three-phased approach is inspired by the document "Charting a course for green coastal shipping" published by the Green Coastal Shipping Program (2016) in Norway, which is a collaborative project between the government, authorities and the private sector with the objective of driving a green transformation of the Norwegian maritime sector.⁷

In this study, AIS-based modelling is carried out for 2017, and the emission components covered are CO₂, NO_x, SO_x and particulate matters (PM₁₀ and PM_{2.5}). The emission inventory is aggregated for 11 ship types and 7 ship size segments. The results are geographically distributed and presented on maps for selected ships types. A high-level discussion of possible low and zero emission technologies is given in Section 4.

³ Million tonnes of oil equivalent

⁴ <http://www.seatrade-maritime.com/news/asia/malacca-and-s-pore-strait-traffic-hits-new-high-in-2016-vlccs-fastest-growing-segment.html>

⁵ <https://chinapower.csis.org/much-trade-transits-south-china-sea/>

⁶ http://asean.org/storage/2016/11/Table18_as-of-6-dec-2016.pdf

⁷ <https://www.dnvgl.com/news/developing-a-roadmap-for-green-coastal-shipping-75090>

Ways to reduced emissions for the ASEAN region is demonstrated in two case studies; slow steaming for deep sea segment and electrification for short sea shipping, section 6 and 7. The report also presents a high-level discussion of policy measures for reduction of ship emissions in the ASEAN region.

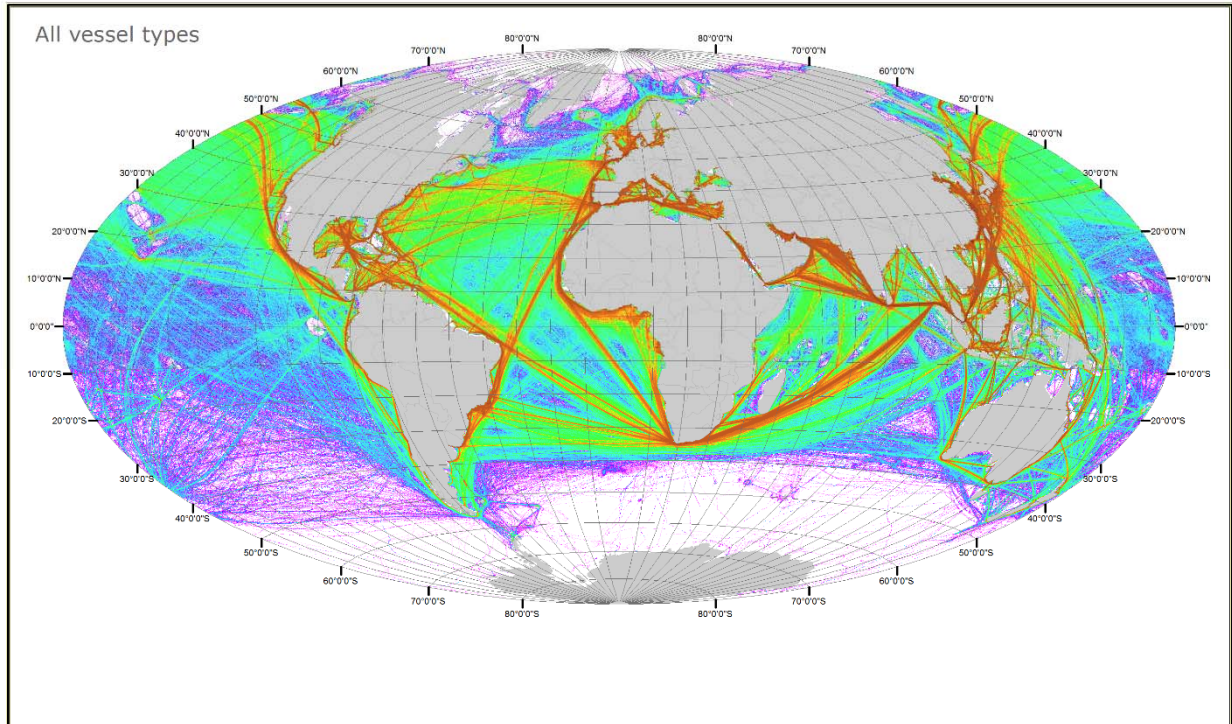


Figure 2-1 Worldwide ship traffic for 2017. The distribution is presented on a global grid of 0.1 by 0.1 degree latitude and longitude (Source: DNV GL, 2017).

3 ASEAN FUEL CONSUMPTION AND AIR EMISSION INVENTORY

ASEAN was established in August 1967 with the purpose of accelerating the economic growth, social progress, and cultural development in the region, and promoting regional peace and stability.⁸ ASEAN was established by the five original member countries: Indonesia, Malaysia, Philippines, Singapore, and Thailand. In addition, five countries have joined in; Brunei, Vietnam, Laos, Myanmar and Cambodia.

This section presents the estimated ship fuel consumption and emissions for the ASEAN region for the base year 2017. The analyses utilize DNV GLs AIS-based software tool for quantification of maritime emissions, as described in Appendix A. It should be noted that this work does not separate between domestic and international traffic, nor traffic only passing through the ASEAN area (transit).

3.1 Geographical area covered

The inventory results are dependent on boundary limits set in the analysis. Figure 3-1 shows the geographical area covered by the fuel and emission modelling, i.e. between latitude 14 degree south and 22.5 degree north, and between longitude 90 degree east and 141.5 degree east. This area embrace all member countries in the ASEAN region and some open sea areas outside or between the respective country economic zones. The figure shows the geographical distribution of modelled ship fuel consumption for the entire ASEAN region (described in the next section).

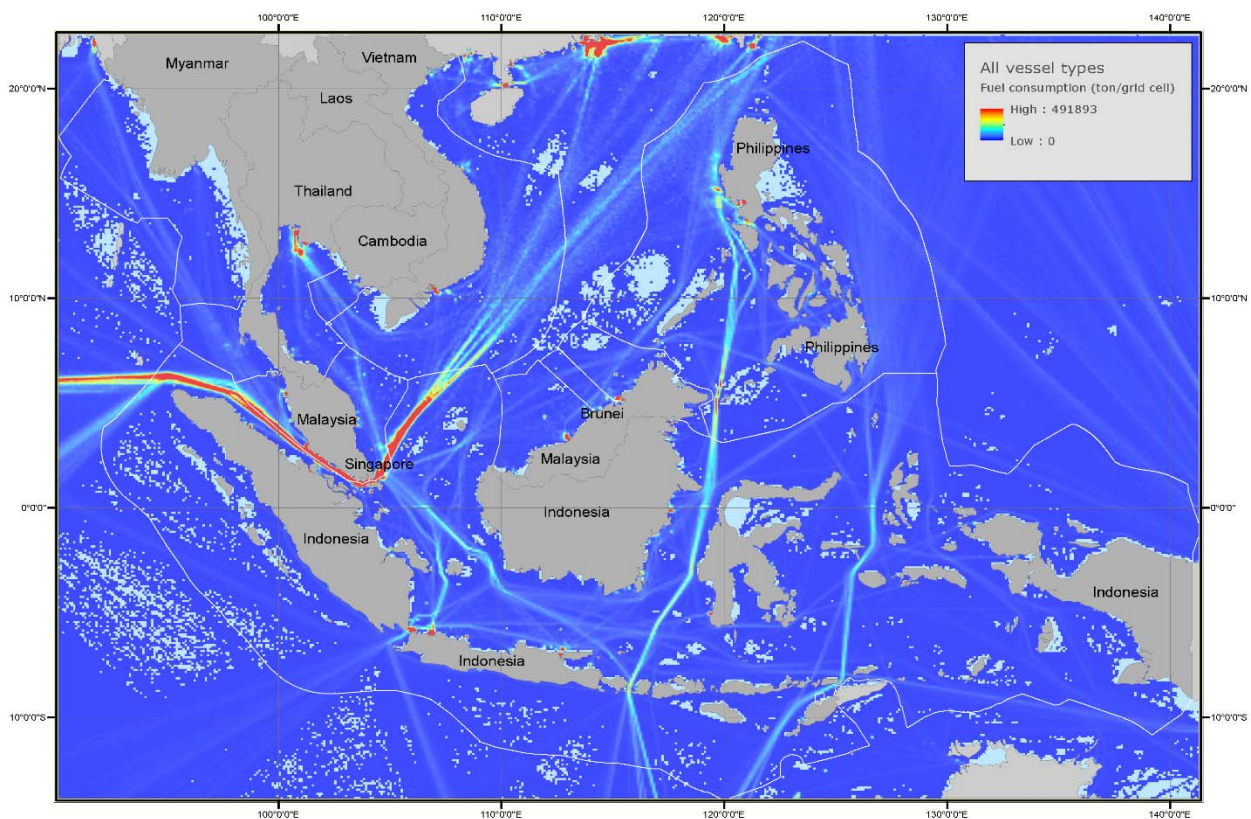


Figure 3-1 The geographical area covered by this analysis, including all vessels traffic 2017 by location and fuel use (Source: DNV GL).

⁸ Association of Southeast Asian Nations (ASEAN): <http://www.nti.org/learn/treaties-and-regimes/association-southeast-asian-nations-asean/>

3.2 Inventory of ship fuel consumption

The AIS-based modelling indicates that a total of 29 630 oceangoing ships travelled in the ASEAN area, consuming about 35.1 million tonnes of oil equivalents (Mtoe) in 2017. Table 3-1 shows the distribution of activity on different ship types. The numbers are based on analysis of ships having AIS-transponders, covering domestic, international and transit sailings in the area.

Table 3-1 ASEAN number of vessels, sailed distances and fuel consumption in 2017

Ship type	# vessels	Sailed distance [KNM]	Fuel consumption [Kton]
Oil tankers	3750	36 410	6 110
Chemical / prod. tankers	2270	25 800	2 040
Gas carriers	1130	18 920	2 930
Bulk carriers	8730	95 720	10 560
General cargo vessels	3460	28 950	1 390
Container vessels	3290	62 690	9 090
Ro Ro vessels	920	9 180	670
Reefers	300	2 580	160
Passenger vessels	920	15 450	880
Offshore vessels	1580	5 430	690
Other vessels inkl. Fishing	3280	10 280	580
Total	29 630	311 410	35 100

The AIS-based modelling offers great potential for performing in-depth studies on specific ship segments. Table 3-2 presents an overview of share of fuel consumed by 11 ship types and 7 size segments. Bulk carriers, container vessels and oil tankers together accounts for more than 73% of the total fuel oil consumption. The larger ships, above 10 000 gross tonnage accounts for more than 85% of the total fuel consumption. The fuel consumption in the ASEAN region amounts to approximately 14% of the global maritime fuel consumption. More than half of the worlds cargo carrying ships greater than 100 GT visited the ASEAN region in 2017, by number.

Table 3-2 ASEAN share of fuel consumption by ship type and size category in 2017

Ship type	<1000 GT *	1000 - 4999 GT	5000 - 9999 GT	10000- 24999 GT	25000- 49999 GT	50000- 99999 GT	≥100000 GT	Totals
Oil tankers	0.53 %	2.35 %	0.84 %	0.94 %	2.03 %	4.17 %	6.55 %	17.4 %
Chemical / prod. tankers	0.03 %	0.38 %	1.71 %	1.73 %	1.96 %	0.01 %	0.00 %	5.8 %
Gas carriers	0.04 %	0.44 %	0.20 %	0.40 %	1.25 %	1.65 %	4.37 %	8.3 %
Bulk carriers	0.01 %	0.09 %	0.22 %	2.49 %	11.62 %	10.15 %	5.50 %	30.1 %
General cargo vessels	0.03 %	0.65 %	1.68 %	1.15 %	0.43 %	0.02 %	0.00 %	4.0 %
Container vessels	0.00 %	0.13 %	1.35 %	5.22 %	6.04 %	7.08 %	6.08 %	25.9 %
Ro Ro vessels	0.03 %	0.07 %	0.11 %	0.09 %	0.55 %	1.06 %	0.00 %	1.9 %
Reefers	0.00 %	0.11 %	0.26 %	0.08 %	0.00 %	0.00 %	0.00 %	0.5 %
Passenger vessels	0.65 %	0.21 %	0.26 %	0.73 %	0.14 %	0.28 %	0.24 %	2.5 %
Offshore vessels	0.13 %	1.10 %	0.25 %	0.08 %	0.10 %	0.13 %	0.18 %	2.0 %
Other vessels inkl. fishing	0.39 %	0.29 %	0.30 %	0.41 %	0.19 %	0.04 %	0.02 %	1.6 %
Total	1.8 %	5.8 %	7.2 %	13.3 %	24.3 %	24.6 %	22.9 %	100%

AIS-based modelling has also been made to calculate fuel consumption by main operating modes. The time spent by each ship in the ASEAN region and associated fuel consumption are split in three operation modes; berth/stationary/anchorage, manoeuvring and cruising. The split is based on the AIS calculated speed over ground for each vessel and summarised for all vessels at berth/stationary/anchorage (0 knot), manoeuvring (1-5 knots) and cruising mode (above 5 knots).

Figure 3-2 shows how the time spent in each mode varies for each major ship type. The share of time spent in port/at anchor etc. for cargo ships in the ASEAN region range between 40% to 60% depending on ship type. The corresponding numbers for non-cargo ships and passenger ships range between 60% and 80%. This reflects large variations in trading patterns, services, turnaround time and operational efficiency. Bulk and container ships are the ones having typically the lowest share of time (typically 40%) spent at berth/stationary/anchor and 4-7% in manoeuvring. Oil tankers have the highest time spent in port/at anchor etc. It should be noted that the Singapore area is a major international hub for ships, hence the share of time spent at berth/stationary/anchor can typically be expected to be high.

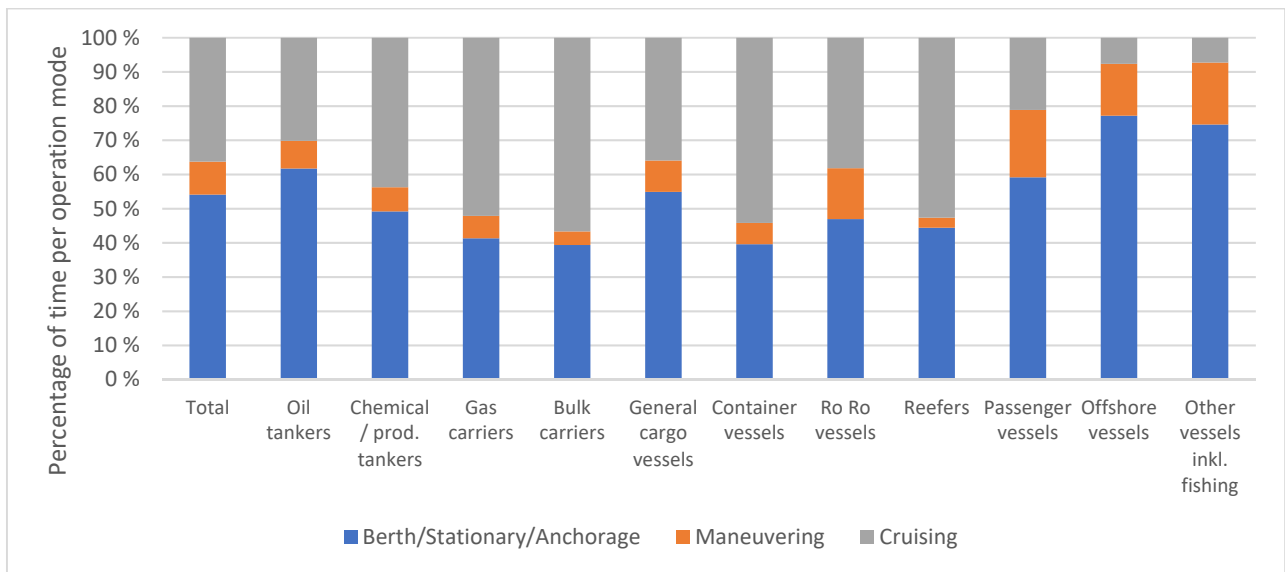


Figure 3-2 Share of time in each operation mode for major ship types (Source: DNV GL).

The time in the different operation modes is not proportional to fuel consumption. Figure 3-3 shows how the fuel usage by operation mode varies for each major ship type. The cruising mode dominates for the cargo ships, as between 65% to 95% of total fuel is used in this mode. The corresponding numbers for non-cargo ships is significantly lower, reflecting time a low speed operations. The share of fuel consumption in the three operation modes (berth/stationary/anchorage, manoeuvring and cruising) are overall approximately 17%, 1% and 82% respectively (see total, Figure 3-3).

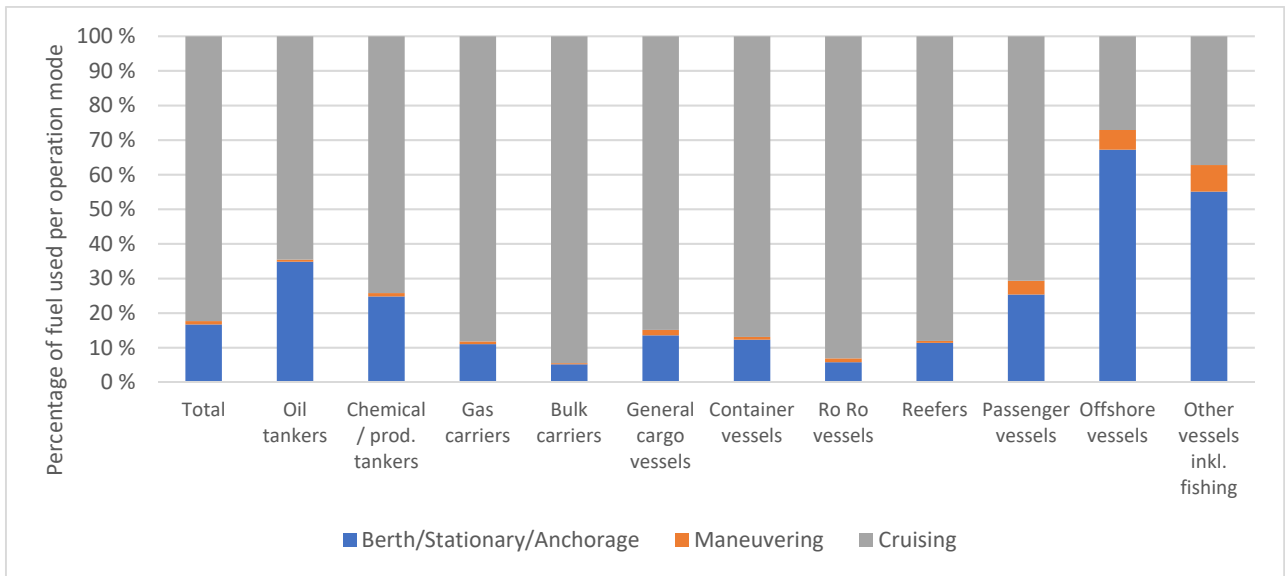


Figure 3-3 Share of fuel used by operation mode for major ship types. The distribution is based on fuel used for each ship type, as reported in Table 4-1 (Source: DNV GL).

The share fuel used in the different operation modes depends strongly on ship size. Figure 3-4 shows the gradually decrease in berth/stationary/anchoring consumption moving from smallest size categories to the largest vessels typically operating in long haul trades. The smallest size categories have around half of the fuel consumption in berth/stationary/anchoring mode, while the largest only around 5%. The three smallest size categories account for 15% of the overall emissions, but operates often close to shore and major shipping ports, surrounded by large populations. Reducing emission from the small ship segments could therefore give important contributions on improving local air quality.

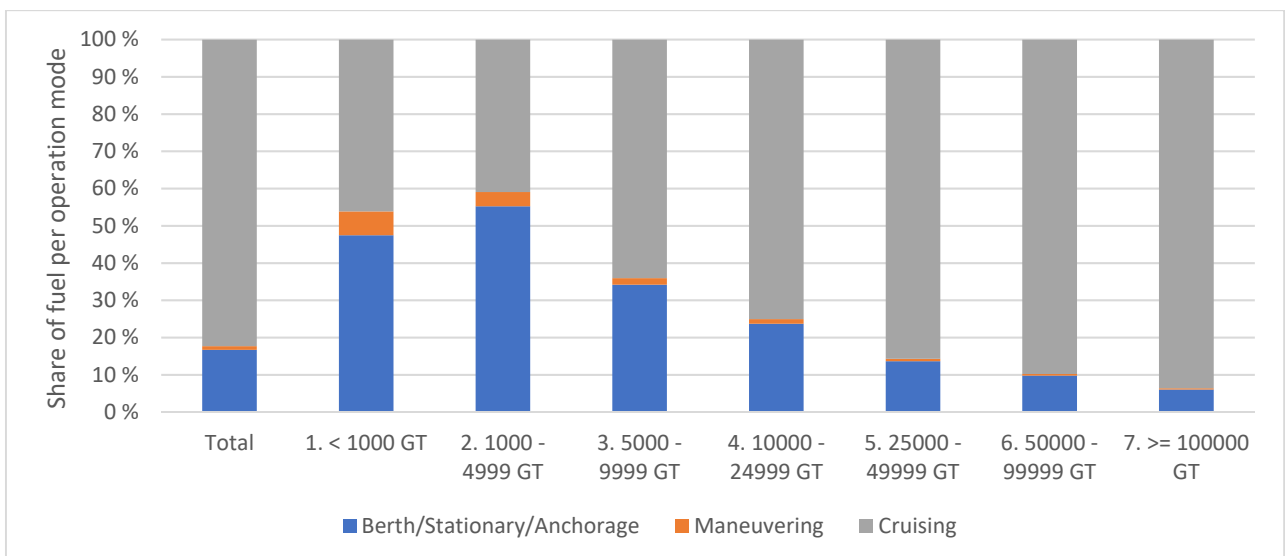


Figure 3-4 Share of fuel used by operation mode for different ship size segments. The distribution is based on fuel used for each size category, as reported in Table 4-1 (Source: DNV GL).

3.3 Inventory of ship emissions

Ship emissions in ASEAN region are calculated by multiplying the AIS-based fuel consumption by emission factors, as explained in Appendix A. The AIS based tracking also allow for calculating sailed distance for individual ships and aggregated. Table 3-3 present the estimated emissions by ship types for the ASEAN region. The estimate of CO₂ emissions is 112 Mton for the ASEAN region, while the emission of NO_x, SO_x, PM₁₀ and PM_{2.5} are 2 320, 1 730, 214 and 194 Kton respectively.

Table 3-3 ASEAN ship emissions for 2017

Ship type	CO2 [Kton]	NOx [Kton]	SOx [Kton]	PM10 [Kton]	PM2.5 [Kton]
Oil tankers	19 490	340	308	37.0	33.4
Chemical/prod. tankers	6 510	120	105	12.6	11.4
Gas carriers	9 360	200	151	18.1	16.4
Bulk carriers	33 750	790	545	65.4	59.1
General cargo vessels	4 420	80	71	8.6	7.8
Container vessels	29 030	630	469	56.4	50.9
Ro-Ro vessels	2 150	50	34	4.1	3.7
Reefers	510	10	8	1.0	0.9
Passenger vessels	2 800	50	36	4.4	4.0
Offshore vessels	2 160	30	1	4.1	3.7
Other vessels incl. Fishing	1 750	20	1	2.9	2.7
Total	111 930	2 320	1 729	214.6	194.0

Geographically resolved ship emission inventories are a fundamental input to evaluate impacts of pollution on the environment and human health. In Figure 3-5, ships' fuel consumption is charted to reflect trading patterns and routes in 2017. The distribution is presented on a grid of 0.1 by 0.1 degree latitude and longitude. Our results shows the dominant transport routes to/from southeast Asia (e.g. Malacca Strait, Strait of Sunda, Lombok Strait, Makassar Strait), with the busiest ports being Singapore and Hong Kong. The distribution of main cargo ship types shows large variation in traffic patterns and patchiness, reflecting differences in transport of oils, imports of raw materials for manufacturing industry, and trade in manufactured products. Compared with container ships and oil tankers, bulk vessels have a more diverse trading pattern with high number of transits also in the Lombok Strait and Makassar Strait.

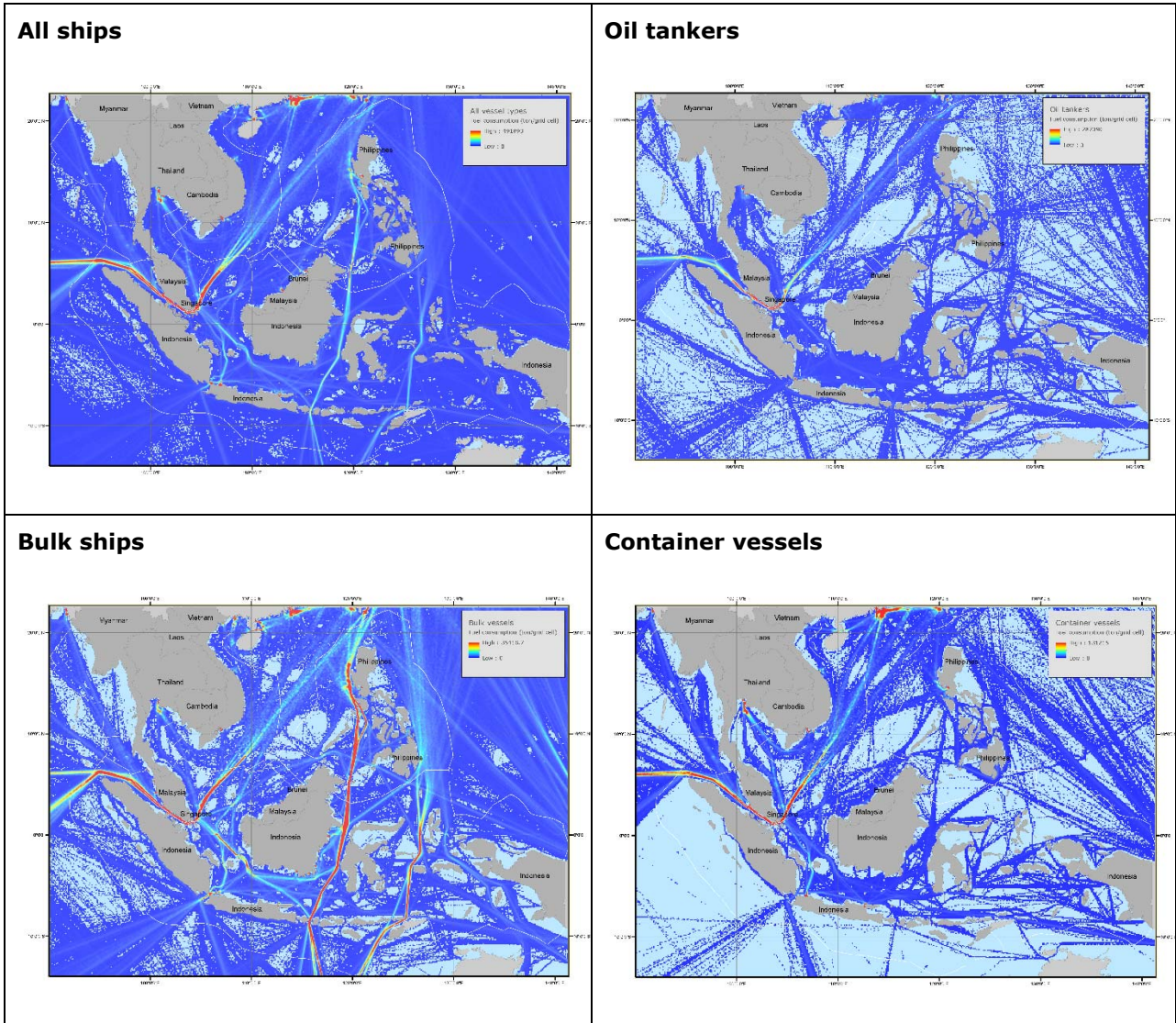


Figure 3-5 Shipping traffic 2017 by location and fuel use. Upper left All vessels, upper right Oil tankers, lower left Bulk ships, and lower right Container vessels (Source: DNV GL).

4 LOW- AND ZERO EMISSION TECHNOLOGIES FOR SHIPS

Exhaust emissions from a marine diesel engine, the typical power unit in the world fleet, largely comprise of CO₂, NO_x and SO_x, but also smaller quantities of CO and PM. There are several mitigation measures available for ships, where some influence specific exhaust gas components (such as scrubbers for SO_x), while others influence several or all emission components (such as electrification). The emissions of CO₂, NO_x and SO_x are subjected to international regulations.

While some solutions allow for zero emissions from ships, others are categorized as low emission solutions. Two main options are available for achieving zero emissions:

- Battery-electric, charged from shore
- Hydrogen for use in marine fuel cells

Moving towards true zero emission shipping, both hydrogen and electricity must be produced with zero emission, e.g. from renewable energy sources or having carbon capture and storage (CCS) in place.

Low emission solutions can be achieved by applying a wide number of solutions. The measures can be compiled in main groups such as:

- Alternative fuels and energy carriers (e.g. LNG, biofuels, methanol, hybridisation with batteries and hydrogen, etc.)
- Technical and operational measures (e.g. hull efficiency, propulsion/machinery efficiency (including hybridization), voyage execution, logistics, etc)
- Exhaust gas after treatment (e.g. selective catalytic reduction (SCR), scrubbers, particle filters, etc.)

These categories are discussed below, as well as barriers for uptake.


4.1 Alternative fuels

A wide range of alternative fuels can contribute to low and zero emission ships – although applicability, cost and availability currently restrict their use. The direct emission from the ship (tank to propeller) for selected fuels/energy carriers varies, as indicated in Figure 4-1. For example, using LNG as marine fuel significantly reduces SO_x and PM emissions, having an approximately 10% reduction in greenhouse gas (GHG) emissions and diminishes emissions of NO_x by 85-90% in the case of low-pressure engines. Only electrification and hydrogen give zero tank-to-propeller emissions. When considering alternative marine fuels, life cycle emissions should also be assessed, as large variation is reported for different fuels in different regions (e.g. Bengtsson et al, 2011, 2012; Chryssakis et al, 2013; DNV GL, 2014; Gilbert et al, 2018).

LNG powered vessels have already been introduced (currently 121 ships in operation and 127 confirmed newbuilds), biofuels and methanol^{9,10} are available in certain ports, and full electrical/hybrid ships are emerging in the short sea, offshore and passenger segments. The recently introduced two-stroke dual fuel engines has increased significantly the fuel flexibility, as they use fuels such as methanol, ethanol and LPG (or LNG/NG, Ethan), in addition to HFO/MGO. Marine fuel cells are also emerging, providing a higher

⁹ Stena Germanica bunkering in Gothenburg is the only example of methanol bunkering to a ship being carried out presently, http://www.bunkerindex.com/news/article.php?article_id=18047

¹⁰ Seven 50,000 dead weight tonne vessels are built with the first-of-its kind MAN B&W ME-LGI 2-stroke dual fuel engine that can run on methanol, fuel oil, marine diesel oil, or gas oil. <https://www.methanex.com/about-methanol/methanol-marine-fuel#sthash.oW84bYpp.dpuf>



efficiency and thereby lower fuel consumption and associated emissions compared to combustion engines. Shore-side electricity is also emerging in certain ports, ¹¹ also referred to as cold ironing and shore power. This allows for the ship's on-board generators to be shut down, reducing its corresponding emissions in port.

Based on current technology, a distinction between short-sea and deep-sea shipping should be made with regards to applicability of various fuels, as deep-sea vessels have fewer options compared to the short-sea segment:

- **Short-sea shipping** includes vessels typically operating in limited geographical areas, in relatively short routes, with frequent port calls. Energy demand, sailing schedule and bunkering pattern for such vessels may be suitable for testing new fuels, such as LNG, methanol and biofuels. Some segments have an operating profile suitable for the use of batteries as fully battery powered or in hybrid propulsion configurations. For instance, the Norwegian ferry sector is currently being electrified, with phasing in of about 60 battery electric ferries over the next few years. The use of hydrogen is also technically feasible, and Norway has an ongoing development project, with ambitions of putting in service a new ferry on hydrogen in 2021.¹²
- **Deep-sea shipping** includes mostly large ocean-going vessels covering long routes and often without a regular schedule (except for container vessels). These vessels require fuel that is globally available, while energy density is important to ensure maximization of space available for cargo transport over long distances. For such vessels, LNG is emerging as a viable low emission option as bunkering infrastructure becomes globally available. Biofuels can also be used, if they can be available in the quantities required and at a quality that will not create fuel compatibility problems. Based on current technological developments, electricity cannot be used in large scale for these vessels in the foreseeable future (Sandia report, 2017), although hybrid solutions can be of interest also for deep-sea shipping. Nuclear propulsion is technically feasible for large vessels, but political, societal and regulatory barriers can hinder its use. Various sail arrangements (e.g. sail, kite, fixed wing, Flettner rotors) have been tested out on merchant vessels over the years (DNV, 2010a), potentially reducing fuel consumption. A new Delft study estimated significant saving potentials applying wind powering on large tank and bulk ships (Delft, 2017).

The potential for alternative marine fuels will depend on factors related to meeting emission requirements, physical and chemical characteristics, availability, cost, safety, and local and global environmental footprint (e.g. DNV GL, 2014a, 2015a, 2017a). Recently, promising alternative fuels have been ranked using multi criteria methods (e.g. Deniz, 2016, Månsson, 2017; Hansson et al, 2017). Such methods are expected to give an additional support to ship owners and policy makers.

There is no “silver bullet” solution, and in most cases selection will be based on a compromise between benefits and drawbacks of various fuel options (DNV GL, 2015a). The final decision will vary for different ship types/sizes, operations, and strategic directions of each ship owner. In all cases, the cost associated with machinery, as well as the expected fuel prices, will play the dominant role. Safety will also be a primary concern and can also be translated into monetary terms once a design has been established and the necessary safety measures identified.

¹¹ <http://coastalconservationleague.org/wp-content/uploads/2010/01/EERA-Charleston-Shoreside-Power-Report-.pdf>
<https://www.zero.no/wp-content/uploads/2016/05/landstrom-i-norge.pdf>
<http://cruising.org/docs/default-source/research/environment-research-2017.pdf>

¹² Breaking new ground in hydrogen ferry project:
<https://www.sjofartsdir.no/en/news/news-from-the-nma/breaking-new-ground-in-hydrogen-ferry-project/>

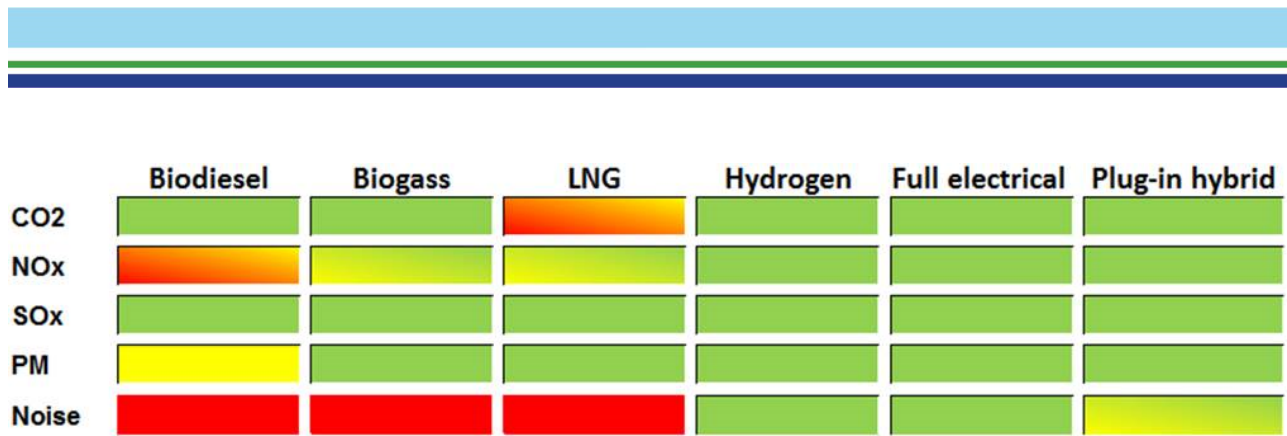


Figure 4-1 Indicative reduction potential for key emission components using selected low and zero emission fuels and technologies (*Tank-to-Propeller* emissions). Green indicates high potential. Red indicates low potential.

4.2 Technical and operational measures

A variety of technical and operational measures are available for reducing shipping's fuel consumption and emissions. The mitigation measures range from easily achievable operational measures to capital intensive technical solutions.

Technical measures are improving the energy efficiency of the ship. They are typically divided into measures for reducing propulsion energy demand (e.g. hull and propeller efficiency), improving energy production (e.g. waste heat recovery and machinery system optimization) and measures reducing the energy use of other on-board consumers (e.g. cargo handling systems, deck machinery, etc.).

Operational measures relate to how ships, integrated with maritime transport systems, can be operated more energy efficient (e.g. speed reduction, ship-port interface, weather routing, etc). A promising operational measure, with large saving potentials, are reduced speed of ships (e.g. Corbett et al, 2009; Zanne et al 2013; Lindstad et al., 2015; Eide et al 2017; Yin et al, 2017; CE Delft, 2012; 2017;). Speed reduction can be achieved by improving port and cargo operations in such a way that slow steaming can be accepted, or by explicitly changing the time tables and schedules. Part of the speed reduction can be absorbed in the current transport systems through reduced time in port and improved coordination and synchronisation between ship and port to avoid waiting in port, and use the extra time to slow steam (Longva, 2011; Andersson, 2017). There is a significant potential to improve efficiencies throughout the transport networks aligning the transport demand with size, operations and functionality of ships and with land-based infrastructure and logistics systems. The industry and related stakeholders must work together to realise on this potential. Increasing the transport system efficiency is a more complex matter that includes modal shifts and integration of value chains.

A recent literature review, covering 60 studies, provide quantitative estimates of CO₂ emission reduction potentials for different measures (Bouman et al, 2017). The reduction potential for each measure strongly depends on factors such as ship type, size, operational profile, technical conditions/status and ageing (e.g. DNV GL, 2016b; DNV GL, 2017c). Eide et al (2017) divided the measures per maturity level, indicating at which time the measures can be applied, rather than by functional area such as hull, machinery and operations:

- **Quick wins:** measures that are mature and in common use for existing ships and new builds (e.g. hull and propeller efficiency, voyage execution, etc.).
- **Up and coming:** measures that are tested and well known, but are still 3-5 years from being commonly applied (e.g. hybrids and use of shore power for propulsion).

- **Next generation:** measures that are being piloted today and are 5-10 years from becoming mature (e.g. wind power, air cavity lubrication, ballast free, etc.).
- **Black swans:** measure that are only at an idea stage. The impact and applicability of these measures are highly uncertain (e.g. wave powering¹³ of ships).

Medium and long-term projections for decarbonization in shipping has been reported by several studies (e.g. IMO, 2011; Eide et al 2011, 2013, 2017; Smith et al, 2016; OECD, 2018a). The results indicate cost-effective reduction potential for technical and operational measures (not including fuels) in the range of 20-30 %, and up to around 50-60 % if including the more expensive and novel technologies and solutions. An example of a Marginal Abatement Cost (MAC) curve for the world fleet in 2030 is presented in Figure 4-2. The MAC curves quantify theoretical reduction potentials, if a set of CO₂ reducing measures were to be implemented on the predefined ship categories.

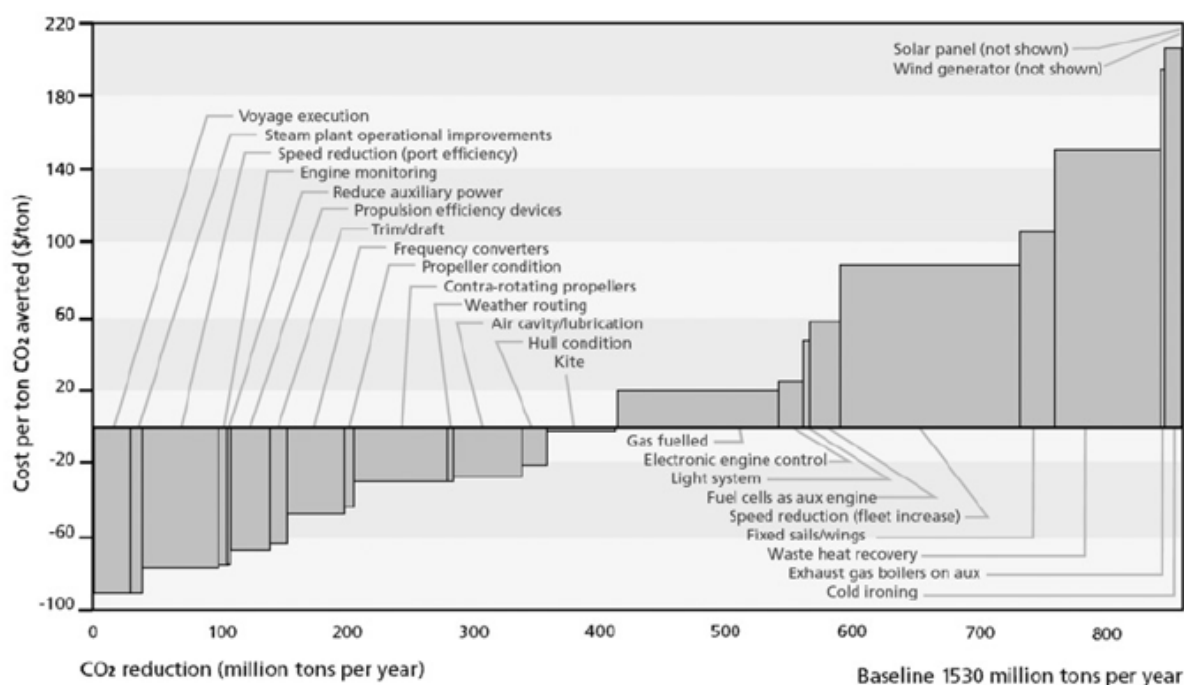



Figure 4-2 Average marginal abatement cost curve for the fleet in 2030 (Eide et al, 2011).

4.3 Exhaust gas treatment

To reduce emissions from marine engines, the measures can either be initiated before start of the combustion process, during the combustion or after as treatment of the exhaust gas. The most ideal reduction method depends on which component that is to be controlled.

For instance, SO_x can easily be controlled before the combustion process by removal of sulphur in the fuel, while NO_x can be controlled during the combustion process. After treatment is also an option for both components. Some of the reduction methods can have negative or positive effects on other exhaust gas

¹³ The history of wave-powered boats: <http://www.wavepropulsion.com/> and http://www.bluebird-electric.net/wave_powered_ships_marine_renewable_energy_research.htm



components. The measures using combustion modifications or after-treatment to reduce the emissions in general comes with a fuel penalty.

The amount of CO₂ and SO_x in the exhaust gas from an engine is directly proportional with the carbon and sulphur level in the fuel burned. Reduction of CO₂ and SO_x emissions can be achieved by an engine efficiency increase, or through a change to alternative fuels with lower carbon and sulphur contents (e.g. LNG). A short outline on relevant reduction measures are given below, and for more details consider e.g. DNV GL (2015b), Danish Environmental Protection Agency (2012), and Leinonen (2016).

4.3.1 SO_x reduction measures

Exhaust gas scrubbers is a well-known and a commonly used method for reducing the SO_x emissions from a ship. Worldwide, there are 297 scrubbers in operation at the end of 2017, and 134 in order.¹⁴ Cruise ships have the highest uptake of scrubbers. By 2020, different projections report between 3,200 to 4,400 scrubbers in service,¹⁵ although these estimates seem optimistic given the current number of installations.

In a scrubber, the exhaust gas from main- and auxiliary engines and boilers are cleaned by using sea water or chemically treated fresh water as a scrubbing agent. Additionally, there exist other scrubber technologies applying dry substances such as limestone. By using the exhaust gas scrubber technology, the ship can continue using high sulphur fuels, which is well-known and typically comes at an attractive price. In sulphur regulated areas, scrubbers are an attractive solution avoiding use of costly low sulphur heavy fuels or distillates.

Wet scrubbers are divided between open loop and close loop systems or as a hybrid system which allows for running in closed loop mode for a given time. In an open loop system sulphur is released to the sea in the scrubber waste water. There are local regulations prohibiting discharges of waste water from scrubbers (open loop systems). The use of scrubbers comes typically with a fuel penalty of up to 2%, costs for chemicals and extra maintenance.

4.3.2 NO_x reduction measures

Several methods which separately or combined reduce the NO_x emission from marine engines are available (DNV GL, 2015b). The methods are mostly based on changing the combustion temperature or by performing after treatment of the exhaust gas. Selective catalytic reduction (SCR) is the most commonly used method for removal of NO_x in the exhaust gas. The SCR method use a catalyst and a reductant, typically urea or NH₃ (ammonia), to chemically reduce NO_x to nitrogen gas (N₂) and water vapour (H₂O).

The total number of SCR installations in the world fleet prior 2013 was 519 (Makoveyenko, 2015). Over half of the ships with SCR installations are cargo ships. Data from the NO_x fund¹⁶ shows that ships operating in Norwegian waters dominates, accounting for more than 30% of the SCR installations worldwide. Applying this relationship and recent NO_x fund data (2014-2017), the SCR installations today is estimated to be around 670.¹⁷


Another emerging NO_x reduction measure is exhaust gas re-circulation (EGR), which can reduce the NO_x emission significantly. EGR involves circulating a controllable proportion of the engine's exhaust back into

¹⁴ LNGi: <https://www.dnvgl.com/maritime/mydnvgl-service-overview/lng-intelligence-lngi/index.html>

¹⁵ <https://www.bunkerspot.com/global/43344-global-2020-scrubbing-will-the-lowest-cost-route-to-compliance-says-consultant>

¹⁶ The NO_x Fund gives support to NO_x reducing measures: <https://www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/>

¹⁷ The NO_x Fund gives support to NO_x reducing measures: <https://www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/>



the intake air, which reduce the formation of NO_x in the combustion process. The EGR system reduces available oxygen in the cylinder and it is observed the production of particulates may increase.

Addition of water to the combustion process will also reduce the formation of NO_x in the combustion process. There are several ways of adding water to the combustion process, like fuel-water emulsions, humid air systems or direct water injections.

LNG as alternative fuel reduce the NO_x emissions significantly.

4.3.3 PM reduction measures

The formation of particulate matters (PM) are closely linked to fuel type and quality, the sulphur content and the operational load of the engine (ICCT, 2017a). Technical measures which reduces particulate emissions are few. However, it is known that the alternative fuels, like LNG and low sulphur fuels, reduce the PM emissions significantly.

For road engines, a series of filter solutions have been developed, providing more than 90% reduction in PM emissions. These filters may also be tuned to reduce around 90% of CO and Hydrocarbon (HC) emission from diesel engines. For maritime engines, such filters have not proven to be practicable due to the large amount of ash emission from the fuel and lubrication oil, and the consequent clogging of the filters. However, the development is on-going and tests have indicated reduction potentials in the region of 60-90% (Jacobs, 2014)¹⁸. This is counterbalanced by a small penalty on energy consumption due to increased back-pressure from the filters. There are also other challenges reported such as space requirements and cleaning/maintenance needs (Danish Environmental Protection Agency 2012; Leinonen, 2016). An overview of use of diesel filters in the maritime sector has recently been reported.¹⁹ Measures initiated primarily to reduce SO_x typically also reduce PM emissions.

4.4 Barriers to overcome

There are multiple challenges with introducing novel technologies. This can be safety requirements, space and weight limitations, system integration and alternative operational practices, limited knowledge and experience with the solution, no verification methods or test facilities available, limited funding to carry out demonstration projects, limited financial capacity to handle increased investment costs or building new ships, lack of supporting policy instruments and legal and regulatory issues.

The barriers for uptake of reduction technologies in shipping have been investigated by several studies (e.g. DNV 2012; DNV GL, 2016d; DNV GL, 2017c; Acciaro et al 2013; Rehmatulla et al 2015; Rehmatulla & Smith 2015). Findings indicate the importance of financial and technical barriers, but also managerial practices and legal constraints. Each reduction technology will have very specific challenges and barriers to be realised and considered as viable alternative for a significant part of the world fleet. Action to be taken to overcome these barriers, are suggested by Eide et al (2017).

¹⁸ https://en.nabu.de/imperia/md/content/nabude/verkehr/1602-info_heincke_measurements_en.pdf

¹⁹ <http://www.theicct.org/sites/default/files/12-Diesel%20Particulate%20Filters%20for%20PM%20Control%20from%20Marine%20Engines%20-%20Mike%20Geller%2C%20MECA.pdf>

5 DEEP SEA CASE - SPEED LIMIT IN ASEAN REGION

One of the options available to reduce emissions from shipping is reduced speed – as outlined in Section 4. The amount of fuel a ship uses for propulsion is proportional to the energy required to overcome the resistance the ship meets as it travels through the water at a given speed. Fuel savings from reduced speed have been documented in practice (e.g. Zanne et al 2013) and through theoretical studies (e.g. Eide et al 2017; Lindstad et al., 2015; Corbett et al, 2009; Yin et al, 2017; Traut et al, 2013). Legal, technical and environmental aspects of introducing speed limits at sea have also been considered (e.g. CE Delft, 2012). This section presents a case study for slow steaming for large container ships in the ASEAN region. The effect of speed reduction on fuel consumption and emissions for the 460 largest container vessels (above 100 000 GT) in the ASEAN region is estimated.

5.1 AIS-modelling of speed reduction

AIS-based analyses have been used to identify current sailing speeds and operating patterns for the assessed fleet, and to calculate fuel consumption and associated emissions. The AIS analyses are used to establish the baseline for current fuel consumption and emissions to air.

The analysis of emission reduction from speed limitation has been performed for all selected vessels in the area, where various maximum allowed speeds are entered into the model. All observed speeds of a single ship exceeding the specified limit within the analysis area adjusted down to the specified limit. The model then calculates the amount of fuel savings, as well as the associated emission reductions, using the “Cubic Rule” method. Change in specific fuel consumption at modified engine load is also considered. The method is based on unchanged total sailing distance, but where fuel consumption (per nautical mile) at sailing speeds above the speed limit is adjusted down to consumption (per nautical mile) at the set speed limit. Figure 5-1 shows the calculation principle used, where each ship sailing above the speed limit is assigned a speed within the assigned speed limit.

The methodology has been developed in a recent project for the Norwegian Maritime Authority (DNV GL 2018).

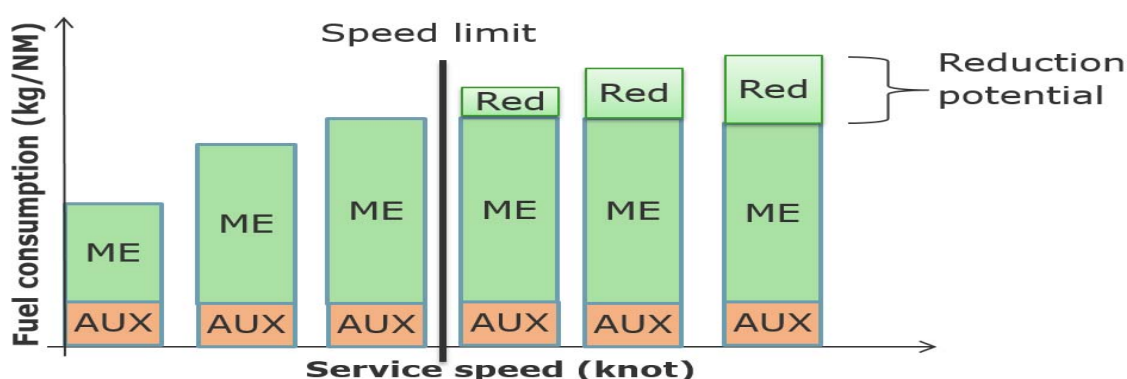


Figure 5-1 Principle for estimating emission reduction potentials introducing speed limits (DNV GL, 2018)

5.2 Modelling results

This study encompasses all container vessels larger than 100 000 GT, observed in the ASEAN region from January to December 2017. The amount of fuel consumed for this container segment is approximately 2.1 Mton, representing 6 % of the totals for the ASEAN region. Figure 5-2 presents the average speed profile for the vessels observed in this ship segment. As the average design speed is 23 knots, the AIS based results shows that slow steaming already occurs for the large container vessels operating within ASEAN region.

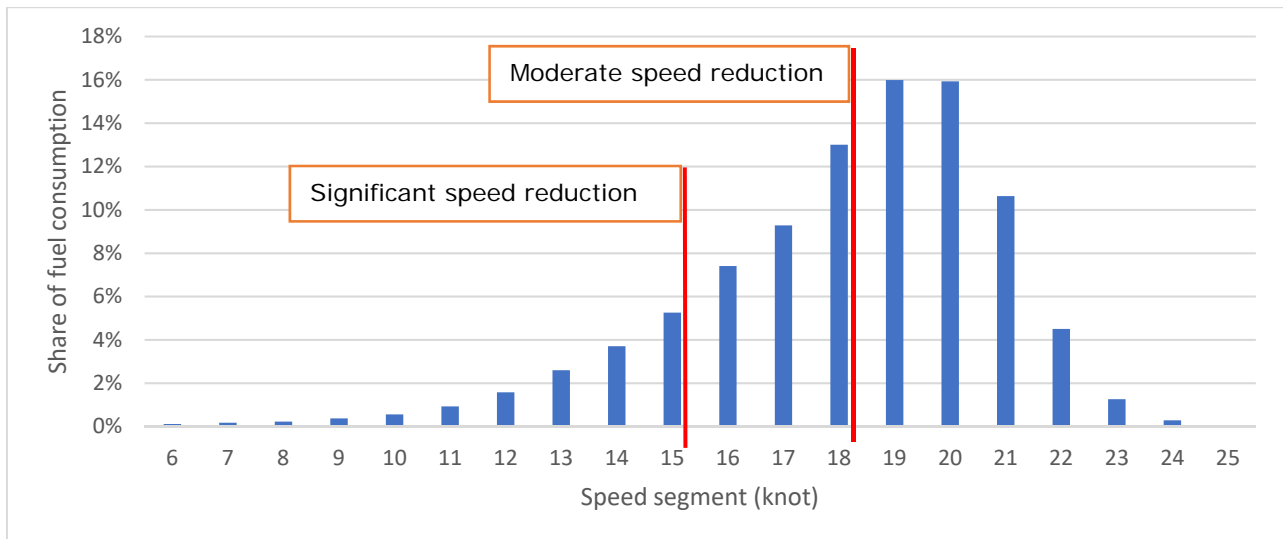


Figure 5-2 Average fuel and speed profile for all container vessels above 100 000 gross tonnage, cruise mode in the ASEAN region (Source: DNV GL).

An analysis of fuel consumption (tonnes/nm) has been performed at different sailing speeds. The effect of speed reduction is calculated for each individual vessel, as there are large operating variations between the ships. As an illustration, Figure 5-3 shows the average fuel consumption/nautical mile for all container vessels above 100 000 GT. The figure shows that there is typically a lower threshold of 6-8 knots where reduced speed no longer gives reduced fuel consumption/nautical miles. If the speed is reduced too much, consumption and emissions will increase.

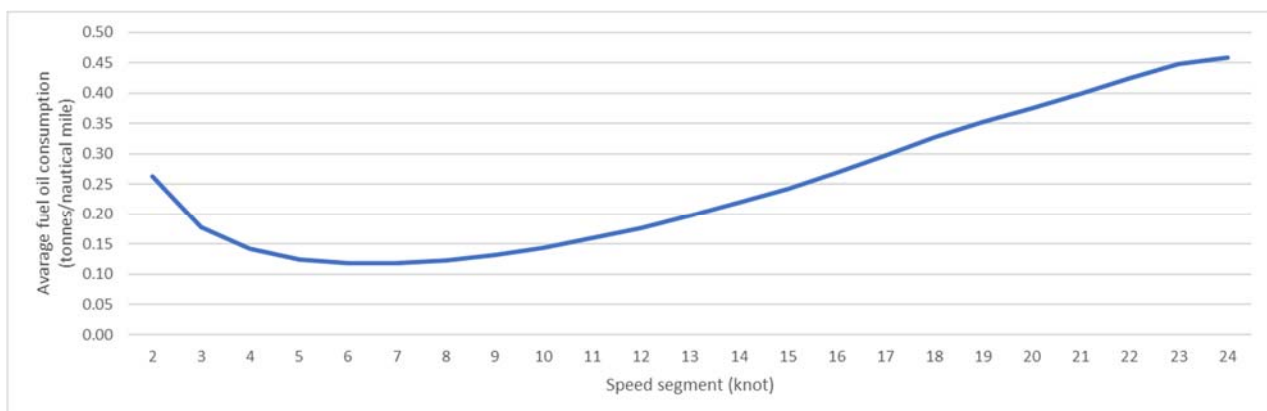



Figure 5-3 Average fuel consumption per nautical mile for container vessels above 100 000 gross tonnage (Source: DNV GL).



For estimating the effect of reduced fuel consumption and emissions, a moderate speed reduction of 18 knots and a significant speed limit of 15 knots are used for the entire ASEAN region. Both speed limits are significantly above the threshold level where reduced speed no longer will give a reduction in the fuel consumption. The effect of speed reduction is calculated for all 460 container vessels observed in the selected size segment.

The modelling results shows that setting the moderate speed limit at 18 knots gives a potential 6 % reduction in fuel consumption and emissions. If the speed limit is lowered significantly, to 15 knots, the fuel and emission reductions is approximately 23%. The fuel and emission reductions observed in this regional study is in line with global estimates reported by OECD (2018b).

The emission reductions achieved by introducing local speed restrictions may be cancelled or even negative if sailing time lost in the regulated areas are made up for by increased speed in other areas. However, the ASEAN region having high density traffic areas close to shore and in populated areas, would experience significant reduction effects on important local pollutants like NO_x, SO_x and PM if speed is reduced. Ways of introducing lower speed as an emission reduction measure are discussed in OECD (2018b) and CE Delft (2017).

Maritime engines are typically designed for a certain specific load and speed range at which the total efficiency is optimised. In case of introducing a significant speed reduction, it is likely that technical adjustments on the propulsion engines are required to maintain safe and efficient long term operation of the vessels. Derating of engines could be the best solution if a vessel is scheduled for long term reduction of operation speeds (e.g. Wartsila 2010).

This case analysis indicates that speed reduction could be an effective measure for emission reductions in the ASEAN region. Furthermore, it demonstrates a methodology which could be extended to other ship segments to assess the full potential for emission reduction through speed reduction in the ASEAN region.

6 SHORT SEA CASE - ELECTRIFICATION OF PASSENGER SHIPS IN THE ASEAN REGION

As stated in Section 4, electrification is one of the few options available for zero-emission shipping. This section presents a high level feasibility study for electrification (fully or partly in hybrid solutions) of passenger ships smaller than 1000 GT with registered port calls in the ASEAN region.

On a *full-electric* ship, all the power, for both propulsion and auxiliaries, comes from batteries which are charged from an on-shore connection to the electric grid while the ship is at berth. A *hybrid-electric* solution can also charge its batteries from shore, but has also conventional machinery to cover smaller or larger parts of the operation (as well as charging the batteries on Voyage). A ship can operate on batteries alone for parts of the operation, for instance in port operation, during stand-by operations, etc. Hybrid solutions without battery charging from shore can also reduce fuel consumption and emissions, by increasing the effectiveness of the conventional machinery. Today, limited shore based infrastructure for charging is available, but progress is made in certain regions^{20,21} (e.g. Ecofys, 2015).

Installing battery systems (incl. replacement after typically 8-10 years) on board will increase investment costs, compared to traditional diesel engines. In addition, infrastructure investments on land is required to provide electricity. The electricity production from hydropower is reported to be price competitive (e.g. Hansson et al 2016, DNV GL 2015c) with MGO.

Smaller passenger ships/ferries are often ideal candidates for electrification, as they typically operate in limited geographical areas, in relatively short routes, with frequent port calls, suitable for charging of the batteries. Their local operation profile, as well as their energy demand, therefore make them suitable candidates for the use of batteries (fully battery powered or in hybrid propulsion configurations). For comparison, the Norwegian ferry sector is currently being electrified, with phasing in of about 60 battery electric ferries over the next few years. Even though most of the energy consumption on these ferries will be electricity charged from land, the concepts are typically hybrid solutions including diesel engines for back-up and limited parts of the operation.

6.1 AIS-based screening of potential for electrification

The potentials for electrification is assessed using a novel AIS-based screening methodology, that consider operational patterns and typical distances sailed and related fuel consumption between port calls.

Based on AIS data, the fuel consumed between each port call is calculated for each ship. The fuel consumption estimate corresponds to an energy requirement (kWh), which is used as an estimate for the battery capacity required for the ship to operate either fully electric or partly electric (ref. "plug-in" hybrid).

Since smaller passenger ships are the most prominent candidates for electrification, only passenger ships with tonnage below 1000 GT are assessed in this case analysis, using data for one month.

²⁰ First for Shore Power in India: <http://www.maritime-executive.com/editorials/first-for-shore-power-in-india>

²¹ Shore power, Norway: <http://www.tu.no/artikler/havner-vil-fa-hurtigruten-over-pa-landstrom/193818>
<http://www.mynewsdesk.com/no/enova-sf/pressreleases/140-millioner-til-landstroem-1689508>

6.2 Modelling results

The distance and fuel consumption between port calls is calculated for each voyage, and plotted in Figure 6-1. It is seen that the typical fuel consumption for a given distance can vary greatly, depending on the energy need of the ship (primarily determined by its weight and speed). A battery with an energy capacity of 1000 kWh can simplified be estimated to replace slightly below 0.2 tonne of conventional fuel. As indicated in Figure 6-1, this can typically cover a distance up to 25 km, depending on the energy need of the ship.

The figure shows that the majority of voyages can be covered using less than 1000 kWh of energy. Furthermore, it can be inferred from the figure that by doubling the battery capacity, virtually all voyages can be battery powered for this segment.

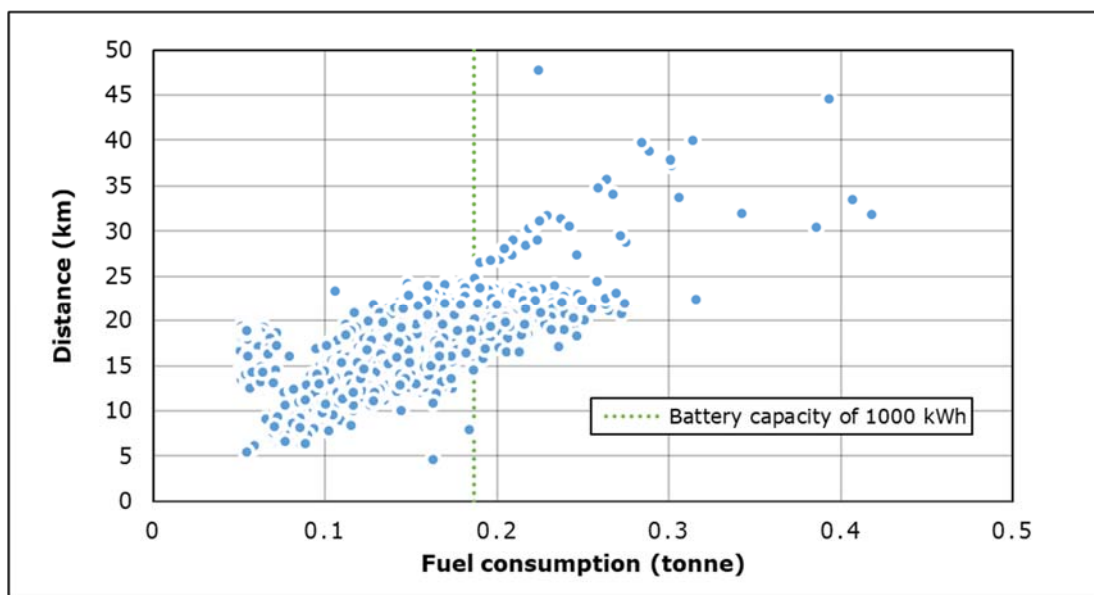


Figure 6-1 Fuel consumption (tonne) plotted against distance of voyage (km) for passenger vessels < 1000 GT operating in ASEAN region. The capacity of a 1000 kWh battery is indicated by the green line (Source: DNV GL).

For longer voyages, hybridisation with a high degree of charged electrical power from land may provide an option for very high emission reduction, with significantly reduced cost compared to full-electrification. To illustrate this a specific distance operated by smaller passenger ships (< 1000 GT) in the Philippines is investigated. The fuel consumption for each voyage of a year of operation is calculated based on AIS ship movement data.

Figure 6-2 shows how the fuel consumption per voyage is distributed among the voyages for a crossing distance of around 40 km. The figure shows that a battery must be dimensioned at around 2150 kWh to operate all voyages full-electric. A 1500 kWh battery may be sufficient for full-electric operation of half of the voyages. However, using a 1500 kWh battery in hybrid solution with a conventional fuel engine may be an option for such operation; this would lead to a hybridization factor (energy consumption covered by battery divided by total energy consumption) of around 70 % for the most energy requiring voyages.

This high-level analysis indicates that fully electrifying this ship segment is technically feasible – in particular if hybridisation with high share of electricity from shore is considered. From Section 3 we see that passenger vessels below 1000 GT account for 0.65 % of total ASEAN region fuel consumption and

emissions. This corresponds to 728 kton CO₂, 15 kton NO_x and 11 kton SO_x, which could be eliminated by electrification.

It should be noted that the time spent in port is crucial for dimensioning of the system transferring power to the ship and how the connection to the power grid is arranged. The charge effect (kW) between shore connection and the ship is reduced by 50% if the time spent in port is doubled. The use of battery banks onshore (as a buffer) can lower the power requirement from the shore power grid. The emission reduction potentials, by using electric driven ships, are closely linked to the energy sources used by the onshore power grid.

The AIS-based analyses can be extended to other ship segments, and could also provide the most promising high emission areas suitable for electrification. Such areas could overlap with existing and planned on-shore infrastructure capacities.

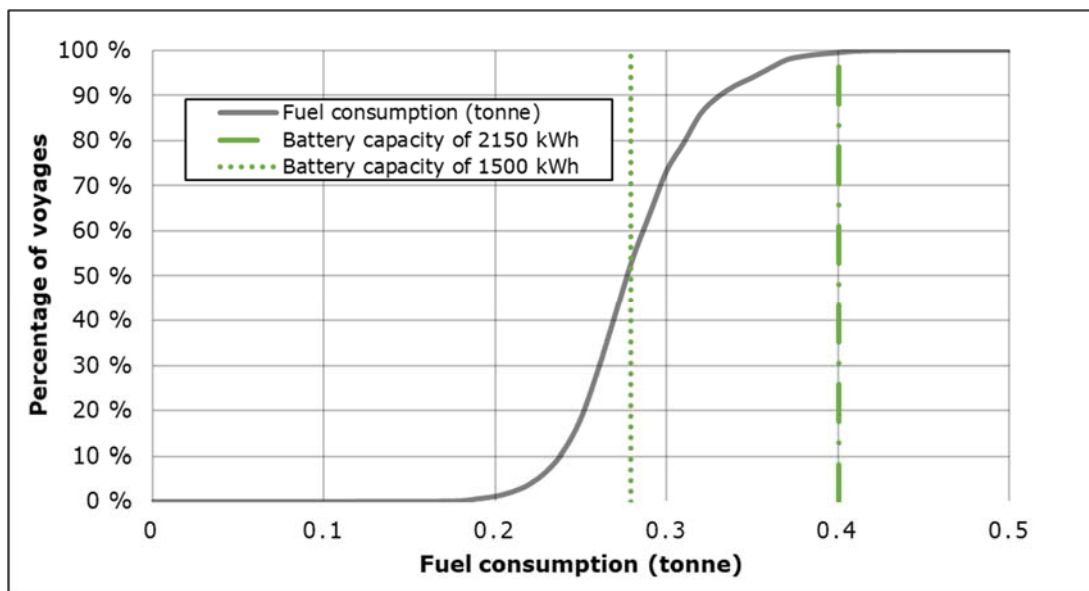


Figure 6-2 Accumulated percentage of voyages plotted against fuel consumption per voyage for a selected passenger ship < 1000 GT, operating a crossing distance around 40 km (Source: DNV GL).

7 POLICY MEASURES REDUCING SHIP EMISSIONS

There are several current policies and regulations impacting on future emissions from ships in the ASEAN region. Most importantly, the International Maritime Organization (IMO) has adopted a set of regulations for the prevention of air pollution by ships, outlined in Annex VI of the MARPOL Convention. Under the revised MARPOL Annex VI, the global sulphur cap will be reduced from current 3.50% to 0.50%, effective from 1 January 2020.²² MARPOL Annex VI also contains provisions for setting up special SOx Emission Control Areas (ECAs), characterized by more stringent controls on emissions as illustrated in Figure 7-1. In these areas, the sulphur cap is 0.1 %. Furthermore, three local sulphur control areas have been defined in China (Pearl River delta, Yangtze River delta and Bohai Bay) and gradual introduction of 0.5% sulphur fuel is planned from 2016 to 2019, starting with enforcement of low-sulphur fuel at berth in core ports from April 2016 (DNV GL, 2017a; NRDC, 2017). Ships have been inspected, and penalties issued to ships violating the rules.²³

Annex VI also sets limits on emissions of nitrogen oxides (NOx) from diesel engines.²⁴ Different levels (Tiers) of control apply based on the ship construction date, and within any Tier the actual limit value is determined from the engine's rated speed. ECAs is also established for NOx with more stringent requirements.

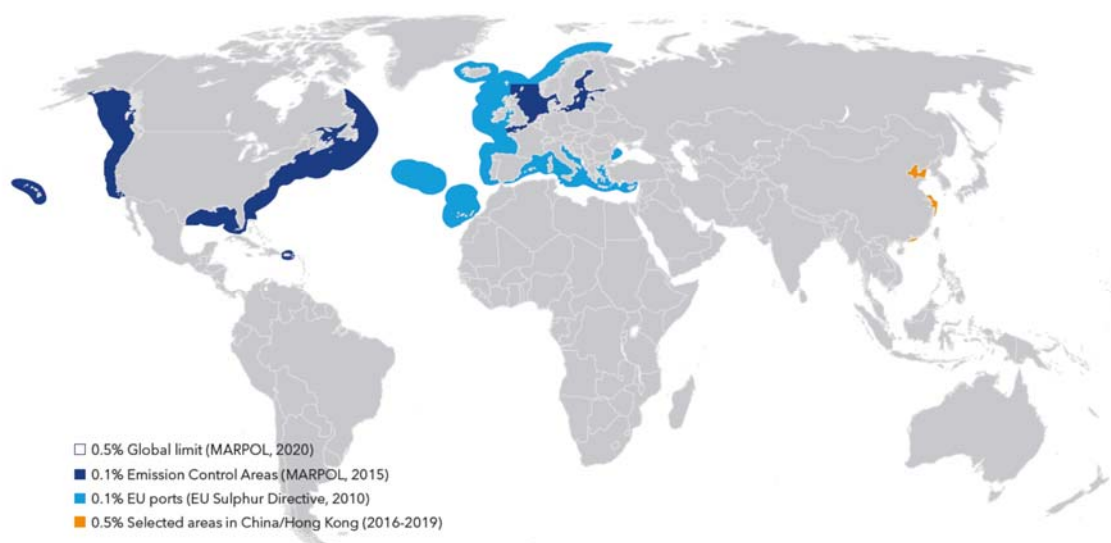



Figure 7-1 MARPOL ANNEX VI Sulfur emissions control areas, incl. local sulfur control areas in China (source: DNV GL 2017d).

MARPOL also include global policy instruments for reducing CO₂ emissions, with the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) currently as the only mandatory instruments. These instruments are supplemented by technical cooperation and technology transfer. However, the IMO has agreed on a Roadmap for developing a comprehensive IMO strategy on reduction of GHG emissions from ships. An agreement on the strategy for GHG emission reductions were

²² IMO, <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx>

²³ <http://www.climatechangenews.com/2017/04/20/chinas-plan-cut-shipping-emissions/>

²⁴ IMO, [http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-\(NOx\)----Regulation-13.aspx](http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-(NOx)----Regulation-13.aspx)



made at MEPC 72, with commitment to reduce GHG emissions and aiming to phase out GHG emissions as soon as possible within this century.

There are also existing market-based drivers for reducing GHG emissions in the maritime sector; mainly high fuel costs and market competition. High fuel prices combined with a competitive market due to an overcapacity in the world fleet have been a driver to improve ships' energy efficiency and reduce fuel costs. To date, however, the shipping industry has not capitalized on the full reduction potential, despite the development of "eco" ships. Other relevant market-based drivers are for example:

- Indexing system for green shipping, such as Rightship, Clean Cargo Working Group (CCWG), Clean Shipping Index (CSI), The Environmental Ship Index (ESI), Green Award.
- Push from charterers, banks, investors, and insurance companies to reduce CO₂ emissions.
- A premium for energy efficient ships in the charter market.

This section outlines an array of options available to ASAN region and its members to further provide incentives for emission reductions from ships in the region. The options include measures from three categories:

- Regulatory measures (rules and regulations);
- Economic measures (taxes, subsidies, quotas, etc.);
- Other measures, including research and development.

Note that the options listed are not exhaustive. Rather, the intention is to point to relevant examples which could serve as inspiration and guidance for future work. More information on economic measures and green schemes are available (e.g. NRDC, 2017; COGEA, 2017; OECD, 2014; OECD 2018b,c).

7.1 Regulatory measures

Measures in this category directly impose demands on behavior or technology. Examples of legal instruments may be requirements in the form of laws, regulations or standards. Agreements between authorities and individual companies are also included in this category.

Examples include;

- **Emission standards – like those covered by IMOs MARPOL convention.**
 - Among the latest international developments is that, MEPC 72 adopted the "Initial IMO Strategy on reduction of GHG emissions from ships" (resolution MEPC.304(72)). The vision unequivocally states that the ultimate goal is full decarbonization as soon as possible within this century. The specific goals are set as efficiency targets of at least 40% by 2030, pursuing efforts towards 70% by 2050, as well as reducing the total annual GHG emissions by at least 50% by 2050 compared to 2008. A carriage ban on non-compliant fuel was approved, and is expected to enter into force in March 2020.
 - I.e. parts of ASEAN may for instance apply for ECA status.
- **Mandatory** Requirements for the inclusion of biofuels in fuel sold: This may include requirements for the percentage of biodiesel in MGO and percentage of biogas in LNG. Though not yet applied to the maritime sector, this measure is used in the automotive fuel markets e.g. in Norway.

- **Requirements for technology or emissions in other public regulations:** There may also be demands for technology and emissions e.g. resource extraction permits on the continental shelf and in the aquaculture or fishing industries. **Could also include:**
 - Requirements on tug-boats, pilot vessels
 - Requirements on ferries
 - Requirements on coast-guard vessels

7.2 Economic measures

Economic instruments are based on incentives to change environmentally harmful behavior by making environmentally harmful activity more expensive or environmentally friendly activity cheaper. This is done by taxing unwanted behavior in the form of fees, or by subsidizing desired behavior or making allowances in a quota market.

Examples include;

- **Differentiated port fees:** Differentiated port infrastructure fees to promote environmentally friendly maritime transport activities and sustainable transportation have been applied in Norway, Sweden and Netherland. A new report claim that reduced fees potentially could reduce payback time for both LNG and power from shore (COGEA, 2017).
- **Vessel speed reduction:** Programme of Port of Long Beach and Port of Los Angeles, the Eco Action Programme and Blue Circle Award in Port of Vancouver (Winnes, 2015). Initiative for reducing emissions from vessels entering and leaving the harbour.²⁵
- **Voluntary fuel switch scheme:** Programs applied in various ports that provides incentives to ships to use low sulphur fuel (OECD, 2014). For example, the Fair Winds Charter (FWC) voluntary at-berth fuel switching program for ocean-going vessels calling at Hong Kong. Participating vessels switch to low-sulphur fuel (0.5% sulphur content or less) while at berth in Hong Kong.²⁶
- **Fees and taxes:** Fees on emission of CO₂ and NO_x for all fossil fuels will make environmentally friendly alternatives more attractive. Reduced fees for selected alternative fuels can provide further incentives

National policies are also in place to promote technology uptake and emission reduction. For example, Norway has implemented the following policies:

- **Enova²⁷:** A Norwegian state support body that contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply. Enova shall help national reduction in greenhouse gas emissions and develop new energy and climate technology, as well as push ideas to the market and ensure innovations increase in both scope and speed.
- **NOx fund²⁸:** The Business Sector's NOx Fund gives support to NOx reducing measures. Shipping and other industries are exempted from state NOx-tax, and instead pay a lower fee into the NOx-fund (owned by the business sector itself). In return, the Fund is strictly committed to achieve significant emission reductions. All funds are thus redistributed back to the associated enterprises to support NOx reducing measures. Enterprises apply for support to a variety of projects, and

²⁵Port of Los Angeles, <https://www.portoflosangeles.org/environment/progress/initiatives/vessel-speed-reduction-program/>
Port of Long Beach, <http://www.polb.com/environment/air/greenflag.asp>

²⁶Fair Winds Charter: <http://civic-exchange.org/fair-winds-charter/>

²⁷ ENOVA: <https://www.enova.no/about-enova>

²⁸NOx Fund: <https://www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/>

granted support will be paid once the relevant measure have been implemented and documented. Stimulates innovation and implementation of new technology, incl. CO₂ reduction. Other authorities show increasing interest in the NOx Fund model.

Relevant for ASEAN is the green shipping initiatives in Singapore, that includes seven programmes designed to provide incentives to adopt clean and green shipping practices.²⁹

7.3 Other measures

Measures that do not involve economic or legal measures embrace a wide range of opportunities, from research and development, to targeted procurement policies at government agencies.

Examples include:

- **Targeted research and development**
- **Targeted public procurement policies**, for instance such as in the Norwegian ferry sector, where zero emission solutions are favoured.
- **Information work to enlighten and inspire**
 - Ship-owners
 - Charterers
 - Government agencies
 - The general public
- **International cooperation on standards, including**
 - Global standards; IMO, ISO etc.
 - Regional standards; EU, ASEAN etc.
- **Green Coastal shipping program³⁰**: Is a joint program between government and industry to create the world's most effective and environmentally-friendly fleet of coastal vessels. The program was initiated by and is organised by DNV GL. The program is aiming to revolutionise the way coastal shipping operates, converting fleets to run partly or entirely on batteries, liquified natural gas (LNG) or other green fuels. The program has 34 members and carry out pilot projects focusing on uptake of environmentally-friendly fuels and energy efficient design.

²⁹ Green shipping initiatives: <https://www.mpa.gov.sg/web/portal/home/maritime-singapore/green-efforts/maritime-singapore-green-initiative>

³⁰ <https://www.dnvgl.com/maritime/research-and-development/futuristic-projects-transform-coastlines/index.html>
<https://www.dnvgl.com/news/developing-a-roadmap-for-green-coastal-shipping-75090>

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APPENDIX A

METHODOLOGY, AIS BASED MODELLING OF SHIP EMISSIONS

This section give an overview of the AIS-based software tool established by DNV GLs for modelling of fuel consumption, emission and abatement potentials for the shipping industry.

DNV GL has access to global data from the Automatic Identification System (AIS), for the period 2013 to date. The AIS data provide a detailed and high-resolution overview of all ship movements, where current sailing speeds, operating patterns, sailed distances (nautical miles) and time spent in areas are identifiable for each identified ship (those having the AIS system installed). The AIS transponder is mandatory for almost all ships above 300 gross tons, which automatically transmits a unique ship identity code, a precise position reference and the ship's heading and speed down to seconds' intervals. The AIS system is also used by many smaller vessels, and these ships will be included in the modelling.

The information from the AIS system is merged with technical databases for detailed information on the individual ships, such as installed power on main and auxiliary engines, machinery configurations, ship design speed, tonnage, etc. The two data sources together with several supporting data tables form the basis for the AIS-based environmental accounting system for ships, as outlined in

Figure A-1. The model is used to calculate engine load profile, fuel consumption, emissions and operational characteristics for main engines, auxiliary engines and boilers for each individual AIS registered ship position. The AIS-based modelling offers great potentials for performing in-depth studies and aggregation of results, e.g. in time periods, for geographical areas, specific ship types and size segments, etc.

The emission components covered in this study is CO₂, NO_x, Sox and particulate matters (PM₁₀ and PM_{2.5}) and the emission factors denote the amount of pollutant as function of the fuel consumption (kg pollutant per tonne of fuel). The following factors form the basis for the emissions calculations:

- Specific fuel consumption for main and auxiliary engines for different types and size categories of ships is based on the 2009 IMO GHG study (Buhaug et al, 2009), as used in *havbase.no*.
- Calculation of CO₂ is based on standard factors for Marine Distillate Fuel and HFO, as used in *havbase.no*.
- Calculation of NO_x emissions is based on standard factors for different types and size categories of ships based on EIAPP values (weighted values) for relevant machinery, as used in *havbase.no*.
- SO_x and particulate matter are based on emission factors for world average sulphur content in marine distillates and HFO, where distillates have 12.6 kg SO_x/ton fuel (0.63%S) and HFO 51.6 kg SO_x/ton fuel (2.58%S) (EMEP/EEA, 2016).
- PM₁₀ and PM_{2.5} differs for marine distillates and HFO. For marine distillates, the emissions factors are 1.5 and 1.4 kg/ton fuel respectively, while the corresponding emission factors for HFO are 6.2 and 5.6 kg/ton fuel (EMEP/EEA, 2016).

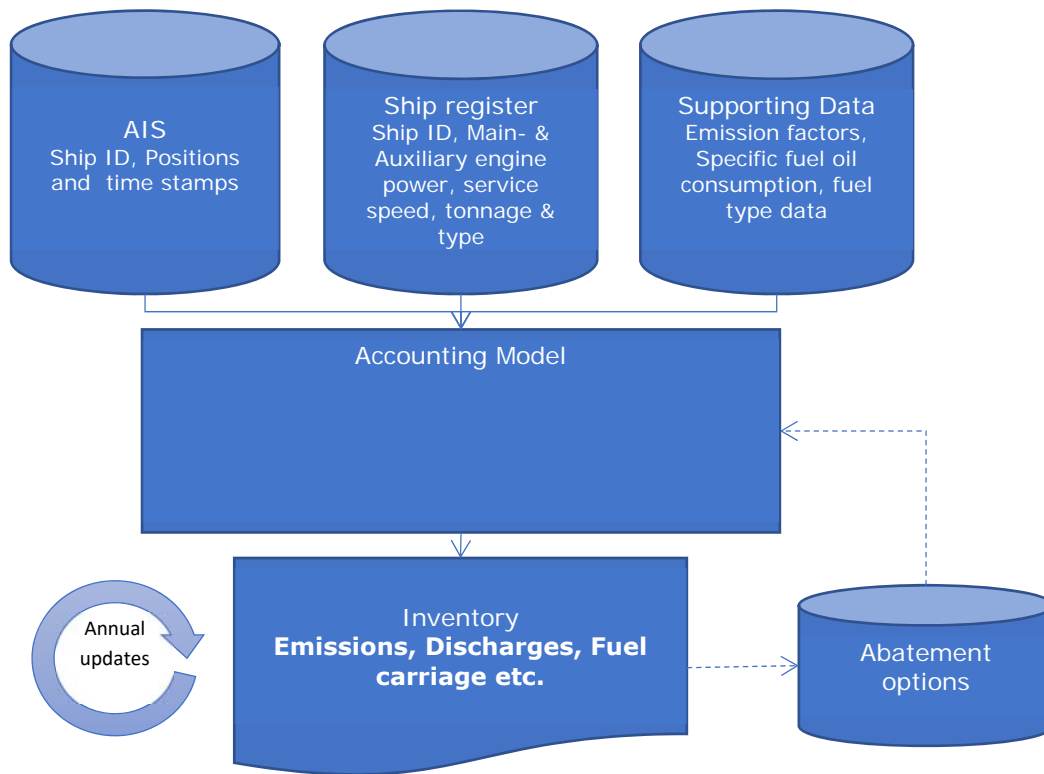


Figure A-1: Framework for AIS-based environmental accounting and abatement modelling (Mjelde et al, 2014; DNV GL, 2014b)

The AIS-based environmental accounting model has been established in cooperation with the Norwegian Coastal Administration (NCA), where results for Norwegian waters are typically aggregated for selected ship types and size segments and presented in the NCA owned web portal *havbase.no*.

Additionally, DNV GL incorporate information on abatement technologies for estimating effects of introducing alternative fuels and emission abatement technologies. DNV GL has its own CO₂ database for different ship types, covering costs and emission reduction potential for a large number of measures. DNV GL has recently also provided IMO with an interactive web tool for assessing and screening of CO₂ measures (IMO, MEPC 69/INF. 18).³¹ DNV GL has also an in-house alternative fuel portal, the LNGi portal³², which is a unique LNG intelligence portal established by DNV GL for supporting and accelerating the uptake of LNG as fuel. With the CO₂ abatement database and alternative fuel portal as input, it is possible to calculate mitigation potentials and marginal abatement cost (MAC) curves for ships. The use of alternative fuels is a particularly interesting measure, since they can contribute to substantial emissions reductions. The abatement module is using AIS-data for identifying ship performances and modelling of ship emissions and mitigation potentials (e.g. Eide et al, 2013; Mjelde et al, 2014; DNV GL, 2016a; DNV GL, 2017).

³¹ IMO: <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Computer-based-model-to-appraise-the-technical-and-operational-energy-efficiency-measures-for-ships.aspx>

³² LNGi: <https://www.dnvgl.com/maritime/mydnavgl-service-overview/lng-intelligence-lngi/index.html>



Uncertainties

When interpreting the results one should keep in mind that the inventories presented is based on AIS modelling for the ship types tracked. Uncertainty in total fuel consumption can be divided into:

- **Propulsion of the ship:** AIS-based fuel consumption modelling for propulsion machinery performed according to the "Cubic Rule" method utilizes knowledge of the ship's design speed and observed speed from the AIS system. This means that we can calculate relatively accurately the load on the main engine, and hence the ship's fuel consumption.
- **Onboard energy use:** Uncertainty in total fuel consumption will be linked to fuel consumption for auxiliary engines and boiler, where AIS cannot be used for other than indicating operating hours. Separate calculations are made for each individual ship at sea and in port, based on AIS data and assumed the operational practises of the auxiliary engines and boilers.

For ships analysed, the uncertainty is typically with a 5-10% margin of error compared to reported consumption (fleet based estimate).





About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our professionals are dedicated to helping our customers make the world safer, smarter and greener.