Reduction of Marine Emissions

Case Study of Norway and Port of Oslo

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Executive Summary

The objective of this study is to gather information from Norway, a leading jurisdiction in reducing greenhouse gas and air quality emissions from shipping, so ECCC can use the information to determine similarities and differences between Canada and Norway in drivers, initiatives, economics and technologies employed to reduce air emissions and to assess what policies, incentives and technologies can be replicated in Salish Sea.

Norway is the world's fifth largest maritime nation and a global key player in developing a sustainable shipping sector for the 21st century. It submitted a new ambitious target to reduce greenhouse gas emissions to the UN in February 2020. The strengthened target is to reduce emissions by at least 50% and towards 55% by 2030, compared to 1990 levels. The previously established climate target was to reduce emissions by at least 40% by 2030.

Norway has also set ambitious targets to reduce emissions from domestic maritime traffic and fisheries by half by 2030 and is stimulating low- and zero-emission solutions in all ship categories. These targets may be revised considering the new national climate target established in February 2020. The City of Oslo has set a much more ambitious emission reduction target than the national government. The City of Oslo and the Port of Oslo aim to reduce greenhouse gas emissions by 95% compared to 1990 levels and 85% compared to 2017 levels respectively by 2030.

The Norwegian government action plan on green shipping is focusing its policies to ensure that Norway meets international climate commitments and targets on emission reductions; create opportunities for growth and jobs; and develop environmental technology with export potential. The Port of Oslo's action plan includes 17 measures to ensure the port meets its climate targets. Among them, reducing emissions from foreign and local ferries, and making port operations including handling of goods and cargos emissions-free will reduce emissions by about two-thirds. Norway will also prepare an action plan for public transportation and a plan to use alternative fuels in the transportation sector.

Policies driving change in the Norwegian maritime sector are international climate commitments (e.g. the Paris Agreement) and Norwegian specific drivers, including (1) the Climate Change Act; (2) the need to reduce emissions from transportation, which is one of three largest sources of emissions; (3) the need to shift freight from road to sea; (4) the need to address Norway's largest direct source of microplastic from tyre wear; (5) the 2015 Maritime Strategy; (6) recognition that investments made today with a long

service life (e.g. new ferries) may be lock-in to an industry structure that makes it difficult to meet climate targets without strict environmental performance requirements; (7) aspiration to be a key player in developing a sustainable shipping sector for the 21st century; (8) desire to transform Norwegian ports to be emission-free by 2030; and (9) desire to play a leading role in IMO's work to reduce GHG emissions.

Norway uses both policy and economic instruments to reduce GHG emissions from shipping. Policy instruments are regulatory measures and requirements, and economic instruments are taxation and funding instruments.

Regulations related to marine air emissions include international, European Union and Norwegian regulations. International regulations include (1) MARPOL, (2) environmental rules for Emission Control Areas, (3) IMO Polar Code and (4) Law of the Sea. Norwegian regulations include (1) the Ship Safety and Security Act, (2) the Pollution Act, (3) the Regulations on Environmental Safety and Mobile Facilities (which include adoption of MARPOL regulations on sulphur content of marine fuel, NOx emissions and energy efficiency requirements; adoption of EU Monitoring, Reporting and Verification Regulations; adoption of EU Sulphur Directive; and special requirements on emission of SOx and NOx in the World Heritage fjords); (4) phase in low- and zero-emission solutions for shipping in World Heritage fjords by 2030; (5) adoption of EU implementing decision on frequency of sampling of marine fuels; and (6) adoption of EU trans-European transportation network. In addition, there are requirements for all new ferry tenders to include low- or zero-emission technology and procurement of carbon credits to supplement national measures to reduce global GHG through the Carbon Credit Procurement Program.

Taxation on emissions is one of the main instruments of Norway's climate policy. For shipping, the most relevant taxes are carbon tax, NOx tax and electricity tax. The standard carbon tax rate applies to shipping. In 2019, the normal tax rate was NOK 508 per tonne CO2-eq for mineral oil, NOK 508 per tonne CO2-eq for LNG, and NOK 507 per tonne CO2-eq for LPG. Carbon tax rate will be increased by 5% per year from 2020 to 2025. Diesel use for fishing in domestic water is subject to the carbon tax with a reduced rate (NOK 109 per tonne of CO2-eq) but exempted from other energy taxes. Through the Gothenburg Protocol, Norway is limiting NOx emissions to a maximum of 156,000 tonnes per year from 2010. In 2020, the NOx tax is NOK 22.69/kg of NOx emitted. It applies to all ships with a total installed propulsion capacity of over 750kW within Norwegian territorial waters irrespective of the nationality. A reduced electricity tax rate was introduced in 2017 for commercial shipping. In 2019, the reduced electricity tax rate is NOK 0.005 per kWh (the standard rate is NOK 0.1558 per kWh).

Norway provides a substantial amount of funding and different forms of initiatives to incentivize green shipping. One of Norwegian government's main funding agencies for climate and energy projects is Enova SF, part of the Ministry of Climate and Environment. It had over NOK 3 billion (CAD $410 million) in the 2019 budget. Of its 1,000 projects funded in 2018, many were related to green solutions for marine transportation. In addition, Innovation Norway, the Research Council of Norway and the European Union also have funding programs.

Other initiatives and funding are provided through Maritime Clusters and Test Facilities, private sector cooperation forums, the Norwegian Catapult, the Norwegian Export Credit Guarantee Agency and Export Credit Norway, NOx Fund, cooperation initiatives between the authorities and the business sector, ship registers, environmental requirements in public procurement processes, innovative procurement, innovative partnership, the national programme for supplier development, common approach to the cruise industry by Norwegian ports and the Green Barometer.

There are also voluntary initiatives, for example, Equinor included requirements to use battery-hybrid vessels and shore power and to implement energy efficiency measures when entering new long-term contracts. At the port level, there are incentives such as Environmental Ship Index, Green Award and Environmental Port Index.

There are good reasons for limiting air pollutants in current regulations. The rationale for improving fuel efficiency is to reduce all fuel induced air emissions. The rationale for reducing CO2 emission is to target main emission sources of ship operations. The rationale for limiting SOx emissions is because marine fuels have higher sulphur contents and are responsible for 20% of SOx emitted in Europe. The rationale for reducing NOx emissions is because domestic shipping and fishing account for 1/3 of the total emissions. The rationale for reducing VOC emissions is because the loading of crude oil onto tankers is the most important emission source in Europe.

Section 4.1 provides information on incentives and measures by vessel categories. A few important characteristics in Norway's policy that are critical to its success in accelerating a green transition in the maritime sector are highlighted below.

- Norway has smartly aligned the need to fulfill its climate commitments with its regional development (e.g. job growth) and industrial policies (e.g. development of green solutions with export potential), so the country can become a key player in developing a sustainable shipping sector for the 21st century.

- Action plans at national government and port level have detailed information on ship inventory, average age of vessels and total emissions by vessel type, enabling the authorities to make informed decisions. The Port of Oslo's action plan further detailed different GHG emissions (CO2, NOx, SOx, PM) by vessel type, emissions from ship operations (port/docking, manoeuvring, entry/exit) by vessel type, timeline and expected contributions to reduce GHG emissions by each measure.

- Foresight to see that stringent environmental regulations are required today to ensure that major capital investments with a long lifespan (e.g. new ships with lifespan of 25 years) will contribute to environmental targets.

- The Norwegian government's policies have been developed through close cooperation between the authorities and the industry.

- The policies cover the entire value chain from research to market regulations, in order to increase the demand for climate and environmental technologies.

- The use of innovation clusters to enhance competitiveness, drive innovation, accelerate technology development and create new business processes / value chains.

- The inclusion of environmental requirements in procurement processes by central government agencies and county authorities, combined with support from funding agencies such as Enova and the NOx Fund for new ferries, high-speed vessels and charging infrastructures has proven to be an effective way of promoting the development of zero- and low-emission technologies.

- Grants were provided by the Norwegian government to build up expertise in municipality and county authorities, so they could include environmental requirements in their procurement processes.

- The Norwegian government will consider the higher costs to provide ferry and high-speed passenger services with requirements to have zero- and low-emissions when revising the revenue system for the counties, thus providing incentives for counties to adopt green solutions.

- Effective use of innovative procurement, for example, using a hydrogen-electric ferry if the service requires too much energy than battery-electric solutions can provide and using it to gain operational experience with liquid hydrogen that can be used to scale up hydrogen solutions in other market segments such as high-speed vessels.

- A variety of pilot projects covering different technologies for different market segments. Appendix A provided a list of pilot projects in the Green Shipping Programme.

- Instruments like the carbon tax, a lower electricity tax rate for commercial vessels, grants for new green vessels and port charging infrastructures, and differential rates for port fees based on environmental grounds are making green solutions more competitive.

Appendix B provides a summary of policy recommendations to Norway by SINTEF, Lund University and Norwegian University of Science and Technology.

In terms of economics, a coarse comparison of bunker fuel prices shows that IFO 180, IFO 380 and MGO are all more expensive in the Port of Bergen, Norway than in the Port of Vancouver. The total electricity price paid by the Port of Bergen was about NOK 1.12 per kWh and over half of the rate paid is related to full grid tariff. In British Columbia, Canada, the electricity rate for large general service in 2020 is C$ 0.06 per kWh (or NOK 0.44 per kWh), which is 40% of the electricity rate for the Port of Bergen in 2018.

Several zero- and low-emission fuel solutions show promising potential. It appears from the action plans that the key technologies the Norwegian government and the Port of Oslo are focusing on are battery-electric, battery-hybrid, hydrogen, ammonia, LNG, biodiesel and biogas, onshore power and autonomous ships. Energy efficiency measures appeared to be lower priority or ignored. However, Norwegian research organization, SINTEF Ocean (formerly Marintek) is clear that there needs to be more research in energy efficient technologies (including hullforms and propulsion), increased focus on sustainable energy sources to reduce the use of carbon- and non-carbon-based fuels and development of wind assisted propulsion technologies, high-efficiency hullforms, weather-routing systems etc. That view was shared by the International Council on Clean Transportation and the European Parliament. Additionally, Equinor included requirements to implement energy efficiency measures in its long-term contracts with suppliers. There are also studies in this report that highlight the importance of energy efficiency measures in reducing GHG emissions. For example, Wang & Lutsey (2013) projected that by fully embracing the available technologies and best practices of the top 5% industry leaders of today, there is the potential to cut international shipping's CO2 emissions in half by 2040 even when business-as-usual freight movement doubles.

Most recent research conducted by SINTEF Ocean, the International Council on Clean Transportation and the Clean Ship Coalition reviewed that some LNG technologies will increase GHG emissions compared to conventional fuel, when accounting for methane emissions from production, processing, delivery and unburned methane (methane slip). In another study by Germany and Finland, it found significant black carbon emissions in new low sulphur fuels that increases proportionally with the aromatic content. These highlighted (1) a need to adopt shipping policies that can reduce broader GHG emissions instead of a single air pollutant only (e.g. CO2) and include the well-to-tank emissions of fuels; (2) a shortcoming in EEDI and SEEMP that focus only on CO2 emissions and ignored other more harmful emissions; and (3) a need to assess the Global Warming Potential using a 20-year timeframe instead of a 100-year timeframe because the warming impact of methane in 20-year timeframe is 85 times larger than CO2 and the warming impact of black carbon in 20-year timeframe is over 4000 times greater than CO2.

For Canada, it is important that policies related to the reduction of greenhouse gas emissions for shipping set ambitious SMART goals; use all available technologies and best practices to achieve emission targets cost effectively; support continuous research and development; develop strong innovation clusters to foster innovation and gain competitive advantage; create synergy with government, industry and academics collaborating on projects; the development of green technology to economic development, job growth and export opportunities; fund pilot projects to encourage entrepreneurship and risk taking; incorporate requirements of green solutions in public procurements; provide appropriate incentives for industry to embrace new green solutions; partner with industry to develop scale-up strategies for new green solutions; and continuously learn from the success of one market segment and replicate it in other market segments.

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1 Introduction

Environment and Climate Change Canada (ECCC) is interested in better understanding the drivers, initiatives, economics and technologies employed to reduce air emissions from shipping in leading jurisdictions and ports around the world. ECCC has chosen Norway and the Port of Oslo in this case study, to learn from their experience in reducing marine emissions. The objective is to gather relevant information for ECCC to determine similarities and differences in shipping between Canada and Norway, and assess what policies, incentives and technologies can be replicated in the Salish Sea.

The scope of this study includes the following:

1. Description of Norway and the Port of Oslo, including
    a. Geographic location
    b. Size of and throughput of the port
    c. Types and throughput of imports and exports (e.g., LNG, coal, grain, containers, oil, etc.)
    d. Unique information about the jurisdiction (e.g. usage of the area, and land or bridge restrictions on ship flow or movement)

2. Description of the goals, drivers, and motivations for policy changes and resulting changes in technology adoption and emission reductions
    a. Policies driving change (e.g. improvement in air quality, reduce GHG emissions, protection of marine mammals etc.)
    b. Government initiatives (e.g., regulatory vs voluntary)
    c. Targets and rationale for targets

3. Description of the economics for the changes being made or proposed
    a. Any incentives, rebates, or other drivers
    b. Relation and similarities to certificate programs such as Green Marine (This type of program would have an effect on emission reductions in the Salish Sea and therefore if there is a similar program in the other jurisdiction then it could also influence emissions.)
    c. Economics of the jurisdiction (e.g. electricity rate, fuel price, fuel availability etc.)
    d. Any information on technology used for emission reductions that NRC comes across in its research on the other topics

2 Norway and the Port of Oslo

2.1 Norway

Norway is a maritime nation located in Northern Europe on the northern and western parts of the Scandinavian Peninsula. Most of the country borders water. Norway has a long history in shipping and has developed advanced knowledge and skills. As marine transportation is becoming more energy efficient, Norway is leading development internationally to make shipping greener. The country's maritime industry is focused on development, testing and implementation of high-tech solutions.

The Norwegian fleet is modern and specialized in capital intensive industries, such as offshore and transportation. Norway is the world's fifth largest maritime nation measuring its fleet value, and the world's seventh largest maritime nation considering the number of vessels (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

In June 2017, the Storting (Norwegian Parliament) adopted a Climate Change Act (Lov om klimamål) which establishes by law Norway's emission reduction target for 2030 and 2050, see Box 1 (Norwegian Ministry of Climate and Environment 2018). In February 2020, Norway submitted a more ambitious emission reduction target for 2030 under the Paris agreement. Norway's new and strengthened target is to reduce emissions by at least 50%, and towards 55%, by 2030 compared to 1990 levels (Government of Norway, 2020). Norway's emissions levels between 1990 and 2017 are shown in Table 1 and Table 2 (Norwegian Environmental Agency, 2019). A comparison of emission reduction targets of selected countries is shown in Table 3 (Climate Change Authority, 2019). In the table, the Climate Change Authority used Norway's old emission reduction targets of at least 40% established in 2016, instead of the new target of at least 50% established in 2020.

Box 1: Norway's climate targets

1. Reduce emissions by 30% by 2020 compared to 1990 levels
2. Reduce emissions by at least 50% and towards 55% (40% was established in 2016) by 2030 compared to 1990 levels (established in 2020)
3. Climate neutrality by 2030
4. Low-emission society by 2050

Table 1. Emissions of greenhouse gases in Norway during the period 1990-2017. Units: CO2 in Mtonnes (Mt), CH4 and N2O in ktonnes (kt) and other gases in ktonnes CO2 eq. (kt CO2 eq.)

Gas	CO_2	CH_4	N_2O	PFC	SF_6	HFC
Year	Mt	kt		kt CO_2 eq		
1990	35.3	232.0	13.7	3894.8	2098.5	0.04
1995	38.7	235.3	12.4	2314.0	579.8	92.0
2000	42.5	227.9	12.8	1518.5	891.4	383.3
2005	44.0	219.2	13.7	955.3	296.1	614.3
2008	45.4	213.1	10.5	896.0	59.8	806.1
2009	43.9	214.5	8.6	438.3	55.7	856.1
2010	46.2	215.2	8.3	238.4	68.6	1064.5
2011	45.5	208.9	8.3	262.6	54.3	1105.8
2012	45.0	207.3	8.4	200.5	53.5	1140.8
2013	44.9	208.4	8.3	181.0	56.3	1155.2
2014	44.9	212.0	8.3	178.9	50.1	1235.6
2015	45.3	207.6	8.4	146.4	69.8	1232.9
2016	44.5	203.7	8.2	186.2	63.6	1363.6
2017	43.7	200.9	8.0	131.0	58.8	1402.8

Source: Statistics Norway/Norwegian Environment Agency

Table 2. Emissions in million tonnes CO2 equivalents in 1990, 2016, 2017 and changes (%) between 1990-2017 and 2016-2017 (without Land use, land-use change, and forestry (LULUCF)).

Year	CO_2	CH_4	N_2O	PFCs	SF_6	HFCs	Total
1990	35.3	5.8	4.1	3.9	2.1	0.00004	51.2
2016	44.5	5.1	2.4	0.2	0.1	1.4	53.6
2017	43.7	5.0	2.4	0.1	0.1	1.4	52.7
Changes 1990-2017	23.7 %	-13.4 %	-41.5 %	-96.6 %	-97.2 %	3187970.5 %	2.9 %
Changes 2016-2017	-1.7 %	-1.4 %	-1.8 %	-29.7 %	-7.6 %	2.9 %	-1.7 %

Source: Statistics Norway/Norwegian Environment Agency

Table 3. Comparison of emissions reduction targets of selected countries

Country/region	Stated target	Change from 2005 in 2030
UK	50 per cent below 1990 levels by 2023-2027	-61 per cent
Switzerland	50 per cent below 1990 by 2030	-51 per cent
Germany	55 per cent below 1990 by 2030	-45 per cent
Norway	At least 40 per cent below 1990 by 2030	-44.5 per cent
US	26 to 28 per cent below 2005 by 2025	-35 to -39 per cent
EU	At least 40 per cent below 1990 by 2030	-34 per cent
Canada	30 per cent below 2005 levels by 2030	-30 per cent
New Zealand	30 per cent below 2005 levels by 2030	-30 per cent
Australia	26 to 28 per cent below 2005 levels by 2030	-26 to -28 per cent
Japan	26 per cent below 2013 levels by 2030	-25 per cent
China	Peak CO2 emissions around 2030 60-65 per cent reduction in carbon intensity by 2030 on 2005 level	+72 to +96 per cent
Republic of Korea	37 per cent below BAU by 2030	+1 to -5 per cent

Notes: Japan's efforts to reduce emissions were dealt a blow by the Fukushima disaster—closure of all its nuclear power plants increased its reliance on fossil fuels. Change, except for Norway, is CCA calculation. China committed to peak its emissions around 2030, and to reduce emissions intensity by 60-65 per cent on 2005 levels by 2030; the range shown is an indicative estimate based on projected growth in China's real GDP. Korea has committed to reduce its emissions by 37 per cent from business as usual levels by 2030; the range shown is an estimate based on its 2005 emissions including and excluding the land sector. The US figure is a linear extrapolation from its 2020 target through its 2025 target; the UK figure is a linear extrapolation from its 2020 target through the mid-point of its 2023-27 budget. Source: Authority observations on Australia's 2030 target (/publications/authority-observations-australias-2030-target).

The Norwegian government's ambition is to cut emissions from domestic maritime traffic and fisheries by half by 2030 (this may be revised considering Norway's new emissions reduction target established in February 2020) and is stimulating low and zero emission solutions in all vessel categories. Norway's Action Plan for Green Shipping (2019) presented a policy with focus on green shipping that will

1. Ensure that Norway can meet its international climate commitments and its targets for emission reductions in the transportation sector,
2. Support regional policy to create opportunities for growth and jobs along the coast, and
3. Promote industrial policy to develop environmental technology with export potential (Norwegian Ministry of Climate and Environment 2019a).

The focus on green shipping also contributes to global technological development that is necessary for the world to reach the goals of the Paris Agreement (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

To reduce marine emissions, Norway uses both policy and economic instruments. Policy instruments include regulatory measures and requirements, and economic instruments include taxation and funding instruments. The Norwegian government's policy has been developed through close cooperation between the authorities and the industry. It covers the entire value chain from research to market regulations, in order to increase the demand for climate and environmental technologies. Policy instruments, funding instruments and cooperation arrangements are relevant for all vessel categories. (Norwegian Ministry of Climate and Environment, 2019a and Norwegian Ministry of Trade, Industry and Fisheries, 2019)

Good examples of this public-private collaboration are the cooperation with the Green Shipping Programme and the environmental agreement between the Norwegian state and business organisations on measures to reduce NOx emissions (Norwegian Ministry of Climate and Environment, 2019a). Since 2015, the Green Shipping Programme has contributed to raising awareness and commitment to greener maritime traffic. The studies help develop zero- and low-emission solutions for Norwegian domestic maritime traffic (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

In addition to adopting international regulations, Norway has also adopted global initiatives and selected European Union (EU) initiative, as well as developed unique Norwegian initiatives. These regulations, taxes, incentives and initiatives will be discussed in detail later in this report.

Examples of international regulations include:

- The International Convention for the Prevention of Pollution from Ships (MARPOL)
- Energy Efficiency Design Index (EEDI)
- Ship Energy Efficiency Management Plan (SEEMP)
- IMO Polar Code
- Law of the Sea

Examples of global initiatives include:

- World Ports Sustainability Program (WPSP) Environmental Ship Index (ESI),
- Green Award etc.

Examples of European Union initiatives include:

- A maximum limit of 0.1% mass sulphur is applied to moored ships for more than 2 hours (EU Sulphur Directive).
- The sulphur content of fuels for passenger ships in scheduled service in Norway's exclusive economic area (EEA) is limited to 1.5% (EU Sulphur Directive).
- EU Emission Trading System (EU-ETS).
- EU Monitoring, Reporting and Verification of greenhouse gas emissions (EU-MRV).
- EU decision on frequency of sampling of marine fuels.

Examples of unique Norwegian initiatives include:

- Norway carbon tax.
- Norway NOx tax and NOx Fund.
- Special rules on emission of SOx and NOx in the World Heritage fjords.
- Prohibition against using heavy bunker oil in the waters around Svalbard (Specific legislation under Law of the Sea for Coastal states).
- Common approach to the cruise industry by Norwegian ports.
- Incentives for zero- and low-emission ships in the Norwegian ship registers.
- Environment Port Index (EPI) developed by a consortium of Norwegian cruise ports in collaboration with DNVGL.
- Innovative public procurement policy that demands zero- or low-emission technologies.

In addition to the above regulations, taxes, incentives and initiatives, Norway has other broad policies and economic instruments that cover the entire value chain. A few key examples are mentioned below and more will be discussed in detail in later sections.

Stricter environmental requirements create new market opportunities and demand for green solutions. An example of this is the UN International Maritime Organization's (IMO) ambition to cut emissions from international maritime traffic by half by 2050. Recognizing the growth potential in the global market for zero- and low- emission solutions in the next decades due to stricter environmental requirements, Norway's policy is to create opportunities for jobs, growth and export potential through the development of environment technology. Norwegian companies have developed many new solutions in maritime transport and exported them internationally. This puts Norway in a good position to capture new demands for green solutions (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

Norway is one of few high-cost countries that are still building vessels. The key for shipyards and suppliers to maintain a sustainable, competitive advantage is to be very high-tech and advanced. The Norwegian government aims to make the shipyards and suppliers more competitive. The Norwegian Export Credit Guarantee Agency (GIEK) has been able to provide lender guarantees for export related investments in Norway. Guarantees can be in the form of loans for capital investments. In 2018, GIEK and Export Credit Norway established a new three-year financing scheme for vessels. Loans and guarantees are available for purchasing vessels from Norwegian shipyards for use in Norway. This includes vessels such as fishing boats, ferries, fish carriers, speedboats and commercial shipping vessels (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

The Norwegian government also wanted to stimulate further green growth and competitive power, and facilitate increased export of green technologies in the maritime industry. One of the means being pursued is to secure better market access through trade agreements with emerging markets (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

Enova is part of the Ministry of Climate and Environment, and provides funding for investments in climate and energy projects in all sectors. It had over NOK 3 billion (C$ 400M approximately) in the 2019 budget. The primary objective of Enova is to contribute to reductions in greenhouse gas emissions, improved security of energy supply, and the development of technology that will bring about reductions in greenhouse gas emissions in the longer term (Norwegian Ministry of Climate and Environment, 2019a).

Norway's success in its implementation of a broad array of policy and economic instruments to reduce marine emissions is evident in the rapid adoption of green technologies and initiatives by the domestic fleet and ports, for example, electrification of ferries and installation of shore power and other zero-emission solutions when docked or handing freight.

Figure 1 shows the ships on the order book at the end of 2017. It included a significant proportion equipped with low- and zero-emission technology. Among the 277 ships being built for operation in Norwegian waters, 187 were classified as conventional, 70 were to be equipped with batteries, 13 were LNG-fuelled and 7 were battery-LNG hybrids. These figures include retrofitting of batteries in LNG-fuelled ships. LNG and battery-propelled vessels accounted for almost half of the ships on order (Norwegian Ministry of Climate and Environment, 2019a).

By 2021, there will be about 70 electrical or hybrid ferries in service along the coast, representing more than one-third of the country's car ferries and the fastest market segment in implementing green technologies. Green technologies are also being developed for different vessel types in other market segments, but the implementation of new technologies is at a slower pace compared to the ferry segment (Norwegian Ministry of Trade, Industry and Fisheries, 2019).

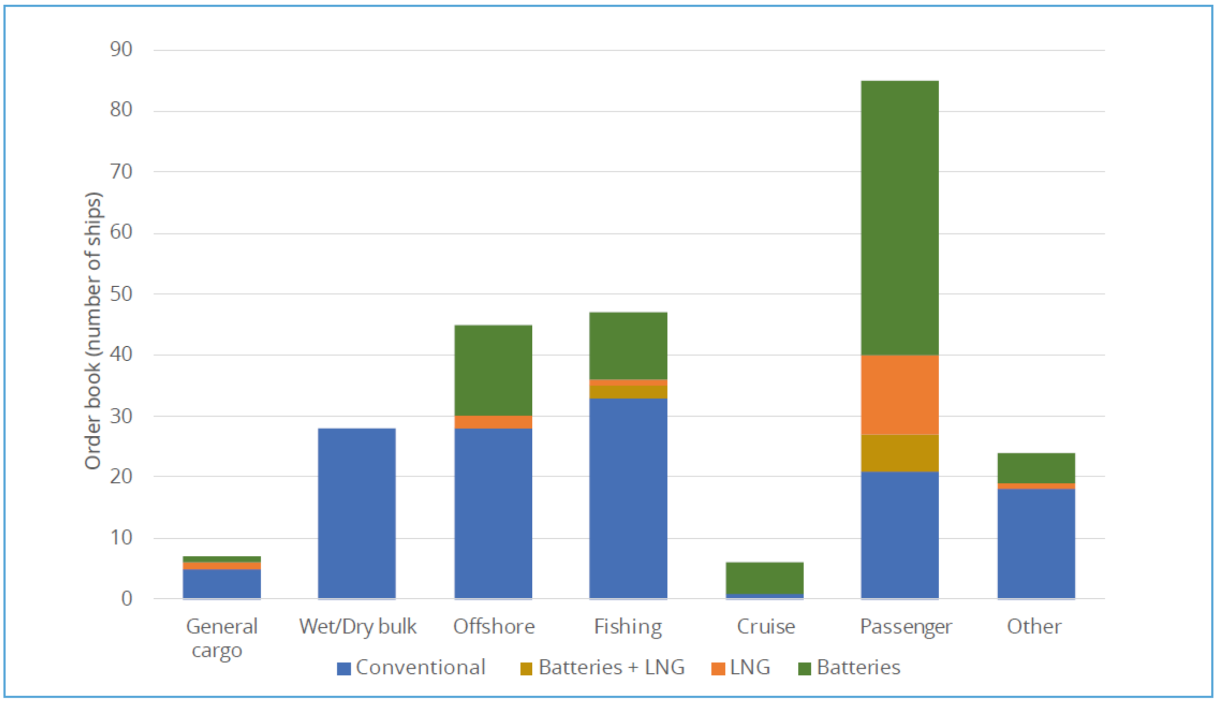


Figure 1. Order book at the end of 2017 for vessels to be operated in Norwegian waters, split by vessel category and type of technology (Norwegian Ministry of Climate and Environment, 2019a).

Norway has over 60 ports (Figure 2). The large ports are Oslo, Bergen, Bodo, Narvik, Stavanger and Tromso. The remaining ones are medium and small ports. The port call and performance statistics by vessel type in 2018 is shown in Table 4. The number of ship arrivals in 2018 totalled 524,469. Among these arrivals, most are passenger ships.

Norwegian Maritime Authority, Haugesund, Norway

Figure 2. Ports of Norway (Norwegian Maritime Authority, 2012)

Table 4. Norway: Port calls and performance statistics (UNCTADstat, *Maritime Transport*)

	Number of Arrivals	Median Time in Port (days)	Average Age of Vessels	Average Size (GT) of Vessels
All ships	524,469	0.43	17	4,310
Passenger ship	475,130	..	17	4,164
Wet bulk	5,600	0.61	15	11,449
Container ship	3,536	0.33	15	8,377
Dry breakbulk	32,692	0.34	22	2,802
Dry bulk	2,282	0.87	18	16,467
Roll-on/ roll-off ship	3,525	..	14	10,037
Liquefied petroleum gas carriers	1,142	0.75	11	10,677
Liquefied natural gas carriers	562	0.32	10	20,473

Norway's annual container port throughput were 897,502 and 763,100 Twenty Foot Equivalent Units (TEUs) in 2018 and 2017 respectively (UNCTAD, 2018). The gross weight of seaborne goods handled were 215,438,000 and 210,649,000 tonnes in 2018 and 2017 respectively (UNCTAD, 2018). The cargo transported by type is listed in Table 5.

Table 5. Norway: Port cargo by type (1000 Tonnes) (UNCTAD, 2018).

	2018	**2017**
Liquid bulk goods	85,600	89,292
Dry bulk goods	104,724	97,997
Large containers (LoLo[1])	6,575	6,359
Large containers (RoRo[2])	72	80
Mobile self-propelled units	2,366	2,369
Mobile non-self-propelled units	947	893
Other cargo not elsewhere specified	15,154	13,725
Total	215,438	210,715

[1] Lift-on/Lift-off

[2] Roll-on/Roll-off

The number of international ferry passengers transported were 6,167,601 and 6,203,531 in 2018 and 2017, respectively (UNCTAD, 2018). The number of passengers transported in the Express Coastal Liner Bergen-Kirkenes were 768,452 and 760,666 in 2018 and 2017 respectively (UNCTAD, 2018).

An inventory of the different ship types in Norwegian waters is shown in the following tables.

- Table 6 (scheduled passenger vessels and ferries)
- Table 7 (cruise ships and RoPax ferries)
- Table 8 (non-bulk cargo vessels)
- Table 9 (tankers and bulk carriers),
- Table 10 (offshore support vessels),
- Table 11 (specialised vessels and aquaculture service vessels),
- Table 12 (fishing vessels), and
- Table 13 (recreational craft).

Table 6. Scheduled passenger vessels and ferries in 2017 (Norwegian Ministry of Climate and Environment 2019a).

Sub-category	No. of ships	Average age (years)	Average size (GT)	Domestic emissions (ktonnes CO_2)	Share of total domestic shipping emissions
Ferries	203	26	1900	605	12.7 %
High-speed vessels*	74	12	250	146	3.1 %
Coastal route/exploration ships	14	25	10 400	242	5.1 %
Other passenger vessels	67	40	3000	27	0.6 %
Vessel category as a whole	358	26	1960	1 020	21.4 %

**In addition, there are approximately 130 scheduled high-speed vessels in Norway that are below the minimum size for mandatory AIS reporting. According to Selfa (2016) missions from all high-speed vessels in Norway total 233,000 tonnes CO2. Fuel consumption and emissions were estimated on the basis of route lengths, timetables and vessel properties, and smaller vessels are also included. This estimate indicates that the analyses based on AIS data covers just over 60 % of total emissions from high-speed vessels*.

Note: Selfa (2016) used size of vessel, engine type and speed to estimate fuel consumption per nautical mile. Then, added 10% premium for auxiliary engines, acceleration, handling, heating etc. to obtain total fuel consumption. Finally, emission factors were used to obtain CO2, SOx and NOx emissions.

Table 7. Cruise ships and RoPax ferries in 2017 (Norwegian Ministry of Climate and Environment 2019a).

Sub-category	No. of ships	Average age (years)	Average size (GT)	Domestic emissions (ktonnes CO_2)	Share of total domestic shipping emissions
Cruise ships	110	25	49 800	299	6.3 %
RoPax ferries	13	21	34 000	25	0.5 %
Vessel category as a whole	123	24	48 100	324	6.8 %

Table 8. Non-bulk cargo vessels in Norwegian waters (Norwegian Ministry of Climate and Environment 2019a).

Sub-category	No. of ships	Average age (years)	Average size (GT)	Domestic emissions (ktonnes CO_2)	Share of total domestic shipping emissions
General cargo vessels	1 588	17	8 000	354	7.4 %
Container vessels	126	13	33 100	69	1.4 %
Ro-ro cargo	84	19	13 800	45	0.9 %
Reefers	94	25	7 550	52	1.1 %
Group as a whole	1892	17	9850	520	10.9 %

Table 9. Tankers and bulk carriers in Norwegian waters (Norwegian Ministry of Climate and Environment 2019a)

Sub-category	No. of ships	Average age (years)	Average size (GT)	Domestic emissions (ktonnes CO_2)	Share of total domestic shipping emissions
Bulk carriers	1 032	8	64 200	112	2.3 %
Crude carriers	369	10	118 500	174	3.6 %
Product carriers	126	14	36 300	24	0.5 %
Chemical carriers	666	11	26 300	195	4.1 %
Liquefied gas carriers	187	9	25 400	89	1.9 %
Group as a whole	2 380	10	57 500	594	12.4 %

Table 10. Offshore support vessels (Norwegian Ministry of Climate and Environment 2019a).

Sub-category	No. of ships	Average age (years)	Average size (GT)	Domestic emissions (ktonnes CO_2)	Share of total domestic shipping emissions
Platform supply vessels	358	11	3450	827	17.3 %
Other offshore support vessels	204	12	5620	269	5.6 %
Vessel category as a whole	561	12	4240	1096	23.0 %

Table 11. Specialised vessels including aquaculture service vessels (Norwegian Ministry of Climate and Environment 2019a).

Sub-category	No. of ships	Average age (years)	Average size (GT)	Domestic emissions (ktonnes CO_2)	Share of total domestic shipping emissions
Well boats	76	14	1 600	-	-
Government vessels	25	18	1430	-	-
Research vessels and seismic survey vessels	120	21	2100	-	-
Tugboats	167	24	426	-	-
Vessel category as a whole	388	21	1220	344*	7.2 %

** Total emissions from this category are estimated to correspond to about 7 % of emissions from domestic shipping and fishing vessels. Figures are not available for sub-categories of vessels, for example small workboats for use in fish farms and for transporting personnel to and from fish farms. ABB and Bellona (2018) estimated that emissions from these boats total around 205 000 tonnes CO2-eq per year. Note that a further approximately 260 unique vessels/installations were identified through the AIS system. These have been omitted from this analysis since they are not relevant in the context of maritime transport (rigs, etc). Note: ABB and Bellona (2018) did not have a detailed methodology in estimating emissions. Since they showed fuel consumption data, it is likely that they used emission factors.*

Table 12. Fishing vessels (Norwegian Ministry of Climate and Environment 2019a).

	No. of vessels	Average age (years)	Average size (GT)	Domestic emissions (ktonnes CO_2)	Share of total domestic shipping emissions
Fishing vessels	826	25	680	877*	18.4 %

**) There are additional emissions from small fishing boats that are not included in the estimate from the AIS system. DNV GL's (2019) estimate for these emissions is 240 000 tonnes CO2-eq, or about 20 % of total emissions from the fishing fleet.*

Note: DNV GL was commissioned by the Norwegian Coastal Administration to compile information on shipping along the Norwegian coast using AIS data combined with information from databases containing specific information on individual vessels. Emissions from fishing vessels without AIS were estimated from a refund system on fuel purchased.

Table 13. Recreational craft (Norwegian Ministry of Climate and Environment 2019a).

Type	Number of boats	
	2012	2018
Motorboats without overnight accommodation	291 000	402 000
Motorboats with overnight accommodation	176 000	161 000
Jet skis	-	10 000
Sailing boats without overnight accommodation	17 000	13 000
Sailing boats with overnight accommodation	35 000	27 000
Sum	520 000	614 000

Note: Statistics Norway estimated that emissions from recreational craft totalled about 530,000 tonnes CO2-eq in 2017. Statistics Norway also estimated emissions from fishing vessels. According to the Ministry of Climate and Environment (2019a), Statistics Norway was using a new method based on changes in the energy balance to estimate emissions from fishing vessels, and this shows much lower emissions than DNV-GL's AIS method. In reporting emissions on fishing vessels in Table 12*, only DNV-GL data and fuel rebate data used to estimate emissions were reported. Statistics Norway data was not used. Similarly, Statistics Norway data was not reported in* Table 13*.*

2.2 The Port of Oslo

The Port of Oslo is the biggest public freight and passenger port in Norway (Figure 3 and Figure 4) (City of Oslo, 2018). It is in the North Sea, at the north end of Oslo Fjord, at about 96 km from the Gulf of Skagerrak and 270 km north-northwest of the coast of Denmark (López-Aparicio, 2017). It is an ice-free port that is open 24/7. Half of the population of Norway (5.4 million people) lives within a three-hour drive of the port and the port is a short distance from the main road network for forwarding cargo to end customers. Thus, the port is considered as a gateway to Norway. It is an intermodal port capable of handling all types of cargo. It has weekly container services to European ports (e.g. Hamburg, Bremerhaven, Rotterdam, Antwerp, Hirtshals, Eemshaven/Cuxhaven) and daily ferry services to European countries (e.g. Germany and Denmark). (Ship to Norway, 2013).

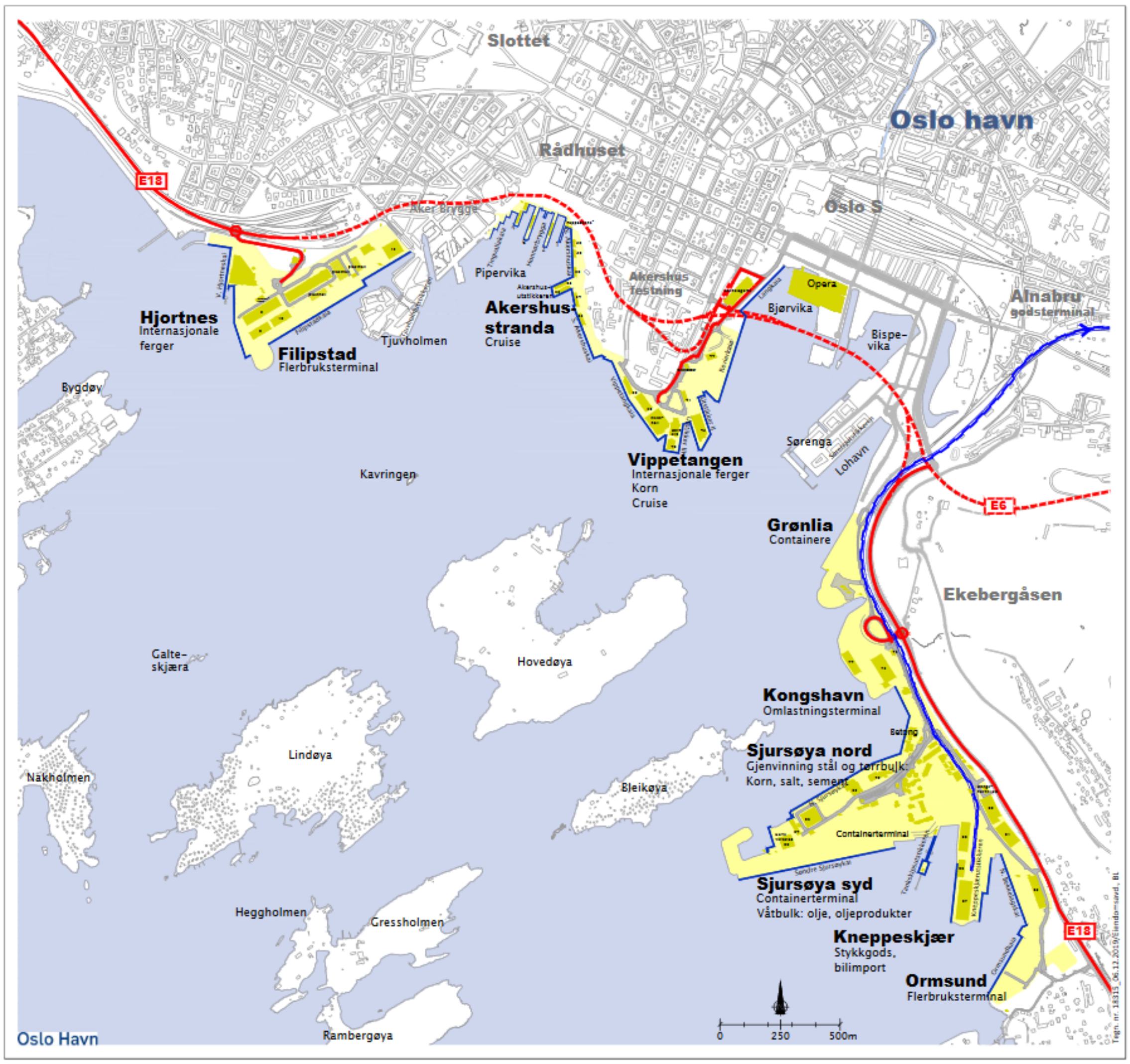


Figure 3. Map of Port of Oslo (Oslo Havn Kart)

Figure 4. Overview of terminals at the Port of Oslo, by use and freight type (City of Oslo, 2018)

The Port Authority runs the port. In a normal week, 50 to 70 ships carry freight and passengers call at the port. Each year, around 6 million tonnes of freight, 7 million passengers and 300 unique ships arrive in the port. In the port plan for the period of 2013-2030, the port is aiming for a 50% increase in freight transport and 40 percent more passengers by 2030. The growth in freight transport is expected mainly to involve groupage in larger units. The following are the detailed growth objectives defined for each market segment by 2030 (City of Oslo, 2018).

- **Foreign ferry routes:** Oslo is the biggest port in Norway for foreign ferry routes, and the aim is to bring about a 50 per cent increase in passengers for the period 2011-2030, bringing the numbers up to 3.28 million passengers.
- **Local ships operating on scheduled services:** The target for local ships is to achieve a 40 per cent increase for the period, to around 5.3 million passengers per year.

- **Cruise ships:** Cruise activity increases during the summer, and the season has also been extended. It is envisaged that there will be a 50 per cent increase in cruise passenger numbers for the period, to 0.47 million passengers.
- **Container ships/LoLo ships** 63 per cent increase in LoLo operations for the period 2011-2030, to 2.2 million tonnes per year.
- **Car carriers/RoRo ships:** 114 per cent increase in RoRo operations for the period 2011-2030, to 1.71 million tonnes of cars per year.
- **Wet bulk shipping:** 25 per cent increase in wet bulk shipping for the period 2011-2030, to 2.59 million tonnes per year.
- **Dry bulk shipping:** 31 per cent increase in dry bulk shipping for the period 20112030, to 1.75 million tonnes per year.
- **Groupage:** 82 per cent increase in groupage for the period 2011-2030, to 0.3 million tonnes per year.

The following is a description of some of the features of the Port of Oslo.

Container Terminal

The Port of Oslo's container terminal is operated by Yilport Oslo. It is Norway's largest container terminal and aims to be emissions free in the long term. It has a capacity of 275,000 twenty-foot equivalent units (TEUs) and a 2,600 m^2 warehouse space. It has the following equipment:

- electric, zero emissions container cranes
- 8 electric stacking cranes
- 12 terminal trucks (mostly electric)
- 2 reach stackers

Wet Bulk

Forty percent of Norway's fuel goes through the Sjursøya terminals at the Port of Oslo. Sisterne Drift DA operates the facilities in Ekebergåsen on behalf of the following oil companies: Uno-X Forsyning AS, St1 Norge AS, Circle K Norge AS, and Oslo Airport Tankanlegg (OLT) AS.

Dry Bulk

The Port handles grains and other dry bulk products such as salt, sand, cement and gravel. Grain is handled at the Vippetangen terminal, but most of the dry bulk cargo is offloaded at the Sjursøya terminal.

Cruise Ships and Ferries
The Port of Oslo is the sixth largest cruise port in Norway by number of passengers. In 2018, the Port had 98 vessel calls with 187,698 passengers.
Oslo is Norway's largest ferry port hosting local ferries as well as international ferries with destinations such as Denmark and Germany. Norled, in partnership with Ruter, operates local ferries which are all electric-powered. International ferry companies include Color Line (service to Kiel, Germany), DFDS Seaways (service Copenhagen, Denmark), and Stena Line (service to Fredrikshavn, Denmark).

Eco-friendly shipping is a priority of the Norwegian government. The Norwegian government has devised ambitious objectives to reduce greenhouse gas emissions by at least 50 percent by 2030 compared with emissions level in 1990. The City of Oslo has an even more ambitious target than that defined at the national level. The City of Oslo's target is to reduce its greenhouse gas emissions by 36 percent by 2020 and 95 percent by 2030, compared with emissions level in 1990. The Port of Oslo targets to reduce emissions by 85 percent by 2030, compared to emissions level in 2017.

Box 2: Port of Oslo Climate Target
Reduce emissions by 85% by 2030, compared to 2017 levels.

The Port of Oslo is one of the larger ports in Norway in terms of emissions, and reductions in emissions at the port level will be key to compliance with the national objectives. The Port of Oslo is responsible for approximately 55,000 tonnes of CO_2 emissions per year, which accounts for 4 per cent of total emissions in the City of Oslo (Figure 5) (City of Oslo, 2018).

The greatest sources of emissions at the port are foreign ferry routes (40% of greenhouse gas emissions), followed by shore activities such as cargo handling and transport on the port site (14% of greenhouse gas emissions) and local ferries (12% of greenhouse gas emissions).

The Port of Oslo has developed an action plan with 17 measures, divided into 3 main groups, to achieve the emission reduction target. The 3 groups of measures are as follows:

1. Measures that should be continued (3 measures): Measures that currently exist and should be continued with equivalent or greater focus over the next few years in order to maintain the effect of the measure in question.

2. Measures that should be reinforced (2 measures): Measures that currently exist, wholly or in part, but that require greater focus and prioritisation over the next few years in order to trigger the collective potential of the measure.

3. Recommendations for new measures (12 measures): Measures that do not exist at present but that need to be implemented in order to achieve the ambition of turning the Port of Oslo into a zero-emissions port in the long term.

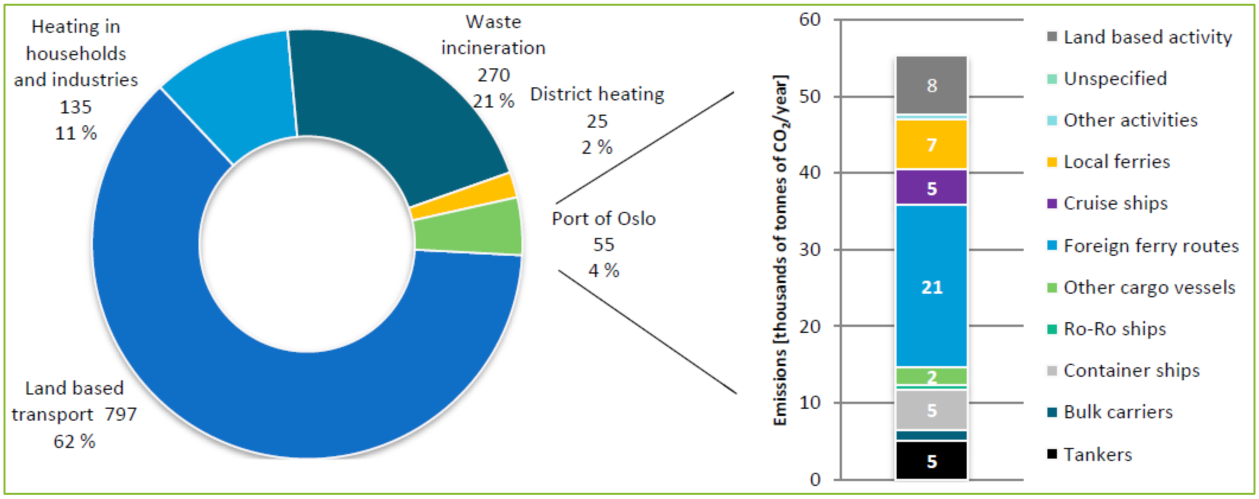


Figure 5. Distribution of greenhouse gas emissions in Oslo, per sector [thousands of tonnes of CO2e/year] and [%], and distribution of greenhouse gas emissions per shipping segment [thousands of tonnes of CO2e/year] within the Port of Oslo. (City of Oslo, 2018)

A list of the 17 measures is shown in Figure 6. These measures will result in reductions of 46,700 tonnes of CO2 per year by 2030, representing an 85 percent reduction compared with the 2017 level. The emissions level in 2017 at the Port of Oslo was 55,300 tonnes of CO2. Some measures are particularly crucial in order to approach the potential of an 85 percent reduction – reducing emissions from foreign ferry routes (5 ships) and local ferries (10 ships), while also making operations on the port site emissions-free, will reduce emissions by about two-thirds. The emission figures are based on a commissioned study by DNV GL based on activity data via Automatic Identification System (AIS).

A timeline of implementation of these 17 measures and the corresponding reduction in CO2 emissions is shown in Figure 7.

	ID	Description of measure	Phase-in time	Estimated reduction [tonnes of CO_2/year] and [% red.]
Measures that should be continued	9.1.1	Environmental differentiation of port fees in order to reward low-emissions ships via the Environmental Ship Index (ESI)	2018 - 2020	800 / 1%
	9.1.2	City of Oslo as a member of Grønt Kystfartsprogram [the Green Coastal Shipping Programme]	2018	-
	9.1.3	Update and revise the action plan for the Port of Oslo as a zero-emissions port and incorporate the measures in the climate budget	2019 - 2021	-
Measures that should be	9.2.1	Shore power for foreign ferry routes	2018 - 2020	2,300 / 4%
	9.2.2	Cooperation with other cruise ports with a view to defining collective requirements relating to shore power and other environmental measures, with Oslo taking on a proactive role	2018 - 2025	2,700 / 5%
Recommendations for new measures	9.3.1	Oslo is a driving force for moving more freight from the roads to the sea, and is working to implement equal environmental requirements for maritime transport throughout the Oslofjord in its entirety	2019 - 2030	-
	9.3.2	Emissions-free operation for Nesoddbåtene (route B10)	2018 - 2019	4,200 / 8%
	9.3.3	Emissions-free operation for Ruter express services (routes B11 and B20-B22)	2019 - 2024	2,300 / 4%
	9.3.4	Emissions-free operation for the Øybåtene service	2018 - 2021	-
	9.3.5	Requirement for zero-emissions solutions for foreign ferry routes with effect from 2025 if new routes are established, if existing routes are put out to tender, where contracts are renewed or where permitted by the situation	2018 - 2025	16,600 / 30%
	9.3.6	Environmental differentiation of port fees in order to reward docked low-emissions ships via the Environmental Port Index (EPI)	2018 - 2020	900 / 2%
	9.3.7	Establish communication with national authorities for amendment of the Act relating to ports and fairways so that requirements can be defined for zero-emissions solutions when docked	2018 - 2024	4,800 / 9%
	9.3.8	Infrastructure for piloting autonomous ships	2019 - 2024	-
	9.3.9	Emissions-free activity when handling goods and freight at the Port of Oslo, and other activities on the port site	2018 - 2025	7,500 / 14%
	9.3.10	Emissions-free road transport routes to and from the Port of Oslo	2018 - 2030	-
	9.3.11	Bonus for ships operating at reduced speed and investigation of the effect of speed limits for commercial shipping using fossil propulsion systems	2019 - 2025	1,300 / 2%
	9.3.12	Adaptation in order to meet the steam requirements of relevant ship types at the port when using renewable alternatives	2018 - 2025	3,500 / 6%
Total			**-**	**46,700 / 85%**

Figure 6. Recommended measures in the action plan, by groups of measures, phase-in time and estimated impact (City of Oslo, 2018).

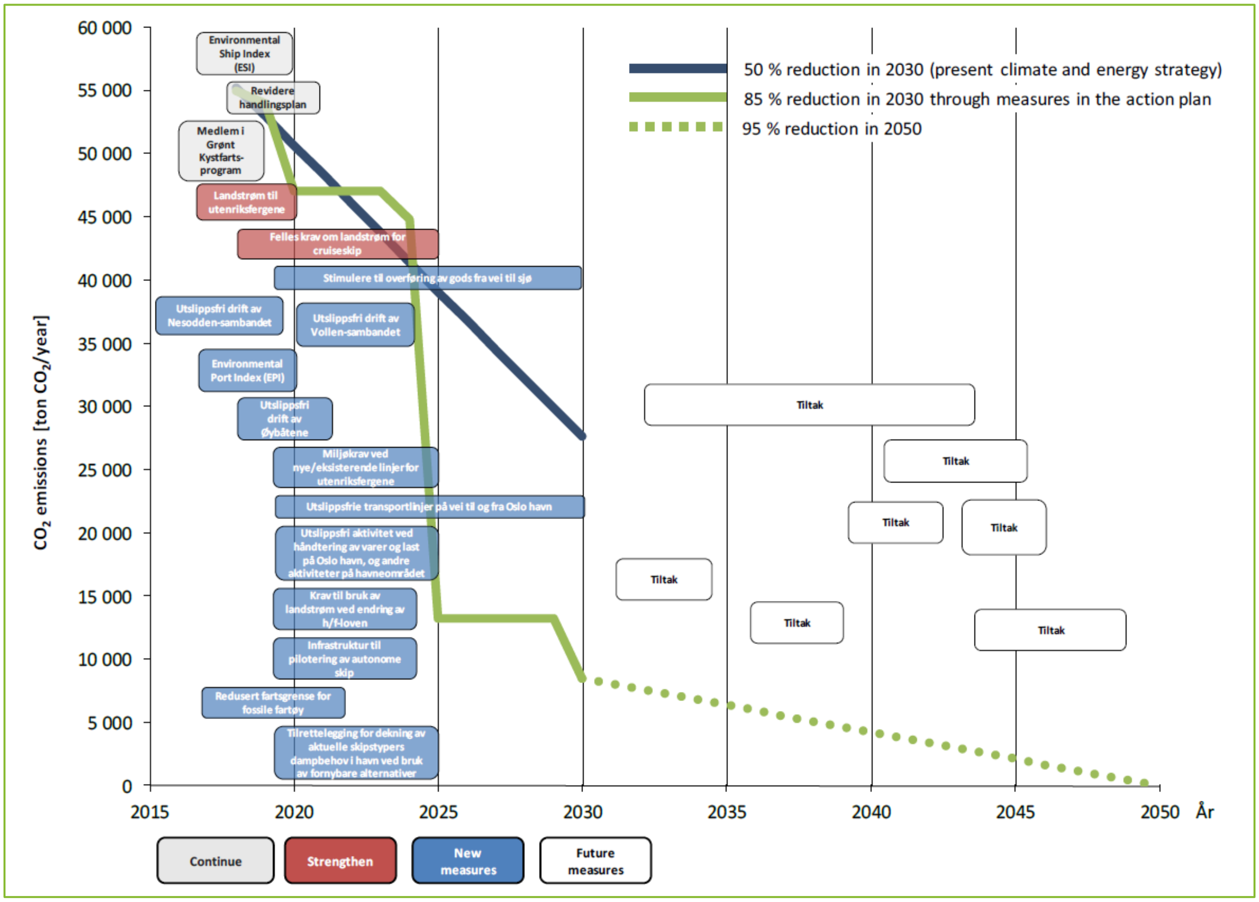


Figure 7. Forecasts for the present climate and environmental strategy for Oslo and the results of recommended measures for the action plan, distributed over groups (City of Oslo, 2018)

Translation (Norwegian to English)

Revidere handlingsplan	Revise action plan
Medlem i Grønt Kystfarts-program	Member of Green Coastal Cruise Program
Landstrøm til utenriksfergene	Shore power to foreign ferries
Felles krav om landstrøm for cruiseskip	Common port requirements for cruise ship
Stimulere til overføring av gods fra vei til sjø	Stimulate the transfer of goods from road to sea
Utslippsfri drift av Nesodden-sambandet	Emission-free operation of Nesodden
Utslippsfri drift av Vollen-sambandet	Emission-free operation of Vollen
Utslippsfri drift av Øybåtene	Emission-free operation of Øybåtene
Miljøkrav ved nye/eksisterende linjer for utenriksfergene	Environmental requirements at new / existing lines for foreign ferries
Utslippsfrie transportlinjer på vei til og fra Oslo havn	Emission-free transport lines on the way to and from Oslo harbor
Utslippsfri aktivitet ved håndtering av varer og last på Oslo havn, og andre aktiviteter på havneområdet	Emission-free activity for handling of goods and cargo at the port of Oslo, and other activities in the port area
Krav til bruk av landstrøm ved endring av h/f-loven	Requirements for use of shore power when Charging
Infrastruktur til pilotering av autonome skip	Infrastructure for autonomous ship
Redusert fartsgrense for fossile fartøy	Reduced speed for vessels
Tilrettelegging for dekning av aktuelle skipstypers dampbehov i havn ved bruk av fornybare alternativer	Adaption to meet the steam requirements in port when using renewable alternatives.

The corresponding NOx, SOx and Particulate Matter (PM) emissions are shown below.

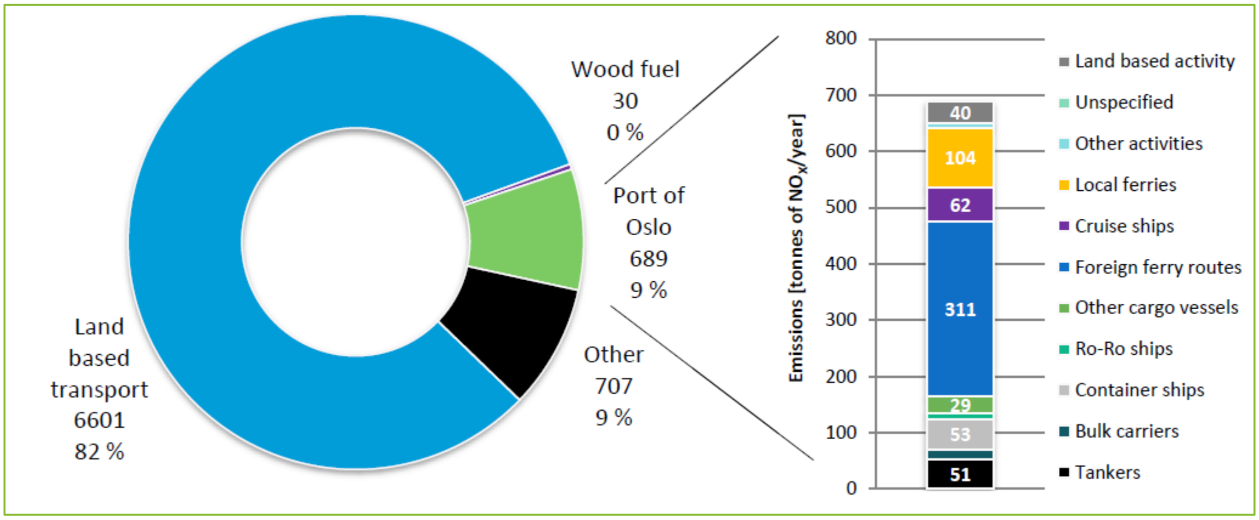


Figure 8. Distribution of NOx emissions in Oslo per sector [tonnes of NOx/year] and [%], and distribution of NOx emissions per segment [tonnes of NOx/year] within the Port of Oslo (City of Oslo, 2018).

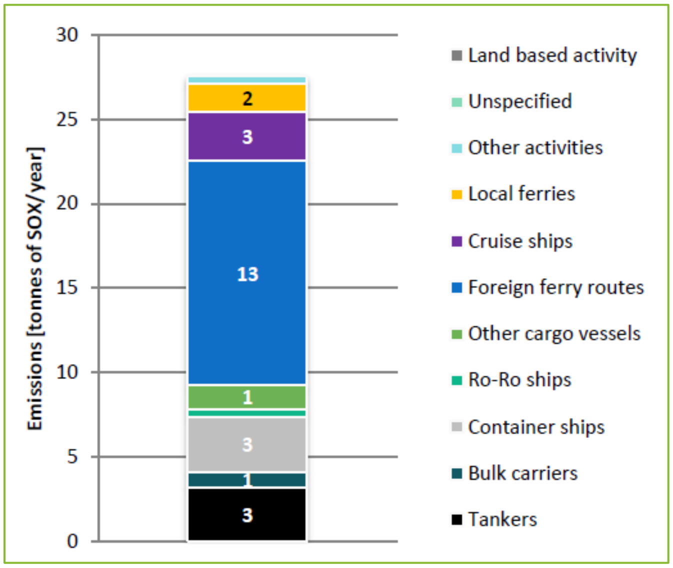


Figure 9. Distribution of SOx emissions in Oslo per segment [tonnes of SOx/year] within the Port of Oslo, based on traffic in 2017 (City of Oslo, 2018).

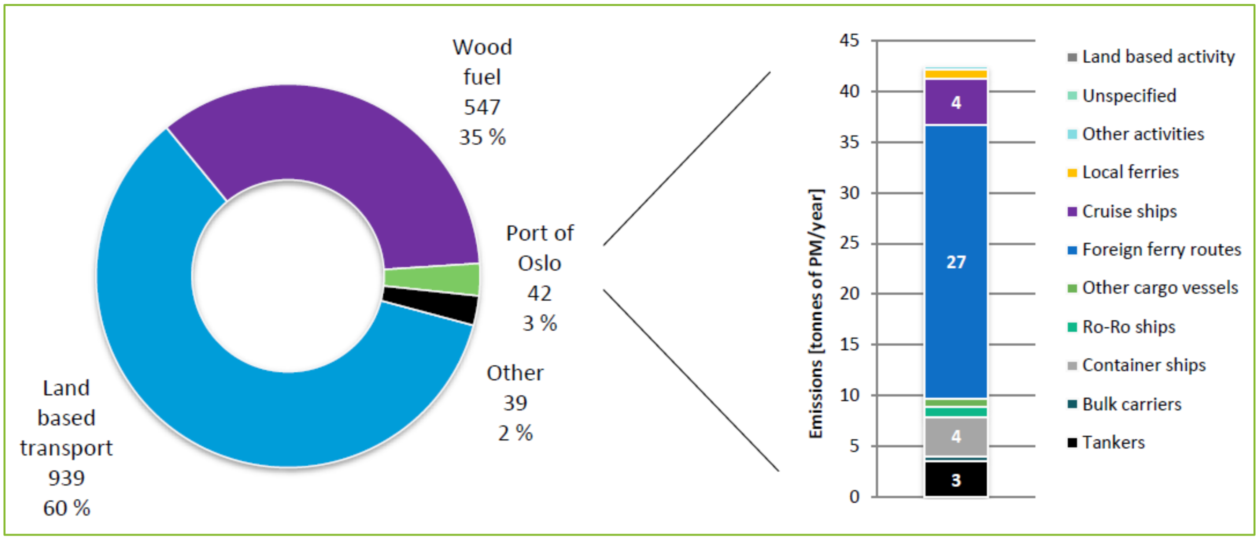


Figure 10. Distribution of PM emissions (PM_{10}) in Oslo per sector [tonnes of PM/year] and [%], and distribution of PM emissions per segment, based on traffic in 2017(City of Oslo, 2018).

Table 14. Overview of the most important segments at the Port of Oslo and key figures for the segment based on operations in 2017 (City of Oslo, 2018).

Segment	Number of ships	Number of arrivals	Arrivals per ship	Average age
Foreign ferry routes	5 (1%)	1,023 (5%)	205	20 years
Local ferries	11 (3%)	14,927 (77%)	1,357	13 years
Cruise ships	43 (12%)	99 (0.5%)	2	22 years
Container ships/LoLo ships	37 (10%)	464 (2%)	13	16 years
Car carriers/RoRo ships	5 (1%)	86 (0.4%)	17	34 years
Tankers	87 (23%)	210 (1%)	2	15 years
Bulk carriers	12 (3%)	102 (0.5%)	9	31 years
Other cargo vessels	140 (38%)	1,066 (5%)	8	26 years
Other activities	31 (8%)	1,447 (7%)	47	43 years
Land based terminal activity	-	-	-	-
Road transport to/from port	-	-	-	-
Total	**371 (100%)**	**19,424 (100%)**	**52**	**28 years**

The number of ships, number of arrivals, arrivals per ship and average age for each market segment in the Port of Oslo are shown in Table 14. The emissions from different market segments are summarized in Table 15. It shows that foreign ferries are responsible for most of the emissions of greenhouse gases (CO2, SOx, NOx and PM) and followed by local ferries. Land based terminal activities also contributed to a significant amount of emissions. Therefore, reducing emissions from these segments are critical to achieving the port's climate target.

Table 15. Overview of the most important segments at the Port of Oslo and their respective emissions of greenhouse gases per mode of operation, based on operations in 2017 (City of Oslo, 2018).

Segment	CO_2	NO_x	SO_x	PM
Foreign ferry routes	21,200 (38%)	311 (45%)	13 (48%)	27 (65%)
Local ferries	6,600 (12%)	104 (15%)	2 (7%)	1 (2%)
Cruise ships	4,600 (8%)	62 (9%)	3 (11%)	4 (10%)
Container ships/LoLo ships	5,200 (9%)	53 (8%)	3 (11%)	4 (10%)
Car carriers/RoRo ships	700 (1%)	12 (2%)	0.5 (2%)	0.9 (2%)
Tankers	5,100 (9%)	51 (7%)	3 (11%)	3 (7%)
Bulk carriers	1,400 (3%)	19 (3%)	0.9 (3%)	0.6 (1%)
Other cargo vessels	2,200 (4%)	29 (4%)	1.4 (5%)	0.9 (2%)
Other activities	700 (1%)	9 (1%)	0.4 (1%)	0.3 (1%)
Land based terminal activity	7,600 (14%)	40 (6%)	*not calculated*	*not calculated*
Road transport to/from port	*not included*	*not included*	*not included*	*not included*
Total	**55,300 (100%)**	**690 (100%)**	**27.2 (100%)**	**41.7 (100%)**

A breakdown of the greenhouse gas emissions per mode of operation (port/docking, manoeuvring, and entry/exiting) is shown in Table 16. It shows that port/docking operation has the most emissions for all market segments, except for local ferries. This means that for many vessel types, a large proportion of quay emissions from the segment can be reduced in a cost-effective manner by means of shore power.

Table 16. Overview of the most important segments at the Port of Oslo and their respective emissions of greenhouse gases per mode of operation, based on operations in 2017 (City of Oslo, 2018).

Segment	Port/docking	Manoeuvring	Entry/exiting	Total
Foreign ferry routes	12,138 (34%)	308 (55%)	8,720 (47%)	21,166 (38%)
Local ferries	1,552 (4%)	106 (19%)	4,920 (26%)	6,578 (12%)
Cruise ships	3,630 (10%)	66 (12%)	931 (5%)	4,627 (8%)
Container ships/LoLo ships	3,636 (10%)	30 (5%)	1,495 (8%)	5,161 (9%)
Car carriers/RoRo ships	405 (1%)	5 (1%)	312 (2%)	722 (1%)
Tankers	4,040 (11%)	17 (3%)	996 (5%)	5,053 (9%)
Bulk carriers	1,177 (3%)	8 (1%)	252 (1%)	1,437 (3%)
Other cargo vessels	1,360 (4%)	11 (2%)	875 (5%)	2,246 (4%)
Other activities	436 (1%)	4 (1%)	235 (1%)	675 (1%)
Land based terminal activity	7,600 (21%)	0 (0%)	(0%)	7,600 (14%)
Road transport to/from port	*not included*	*not included*	*not included*	*not included*
Total	**35,974 (100%)**	**555 (100%)**	**18,736 (100%)**	**55,265 (100%)**

The Port of Oslo has identified opportunities for zero-emissions solutions for the different market segments as follows (City of Oslo, 2018):

Foreign Ferries

- Shore power to meet the need for electricity when docked
- Use of district heating to meet the need for steam when docked
- Battery hybrid solutions on entry to and exit from the port
- Hydrogen operation (in the long term)
- Running on liquid biogas

Local Ferries

- Battery electric operation
- Running on hydrogen with fuel cell operation (in the long term)
- Running on liquid biogas

Cruise Ships

- Shore power to meet the need for electricity when docked
- Use of district heating to meet the need for steam when docked
- Battery hybrid solutions on entry to and exit from the port
- Hydrogen operation (in the long term)
- Running on liquid biogas

Container Ships / LoLo Ships

- Shore power to meet the need for electricity when docked
- Use of district heating to meet the need for steam when docked
- Battery hybrid solutions on entry to and exit from the port
- Running on liquid biogas

Car Carriers / RoRo Ships

- Shore power to meet the need for electricity when docked
- Battery hybrid solutions on entry to and exit from the port
- Running on liquid biogas

Tankers

- Shore power to meet the need for electricity when docked
- Use of district heating to meet the need for steam when docked
- Battery hybrid solutions on entry to and exit from the port
- Running on liquid biogas

Bulk Carriers

- Shore power to meet the need for electricity when docked
- Battery hybrid solutions on entry to and exit from the port
- Running on liquid biogas

Other Cargo Ships

- Shore power to meet the need for electricity when docked
- Battery hybrid solutions on entry to and exit from the port
- Running on liquid biogas

Other Ships (This category includes all smaller boats not referred to previously. Examples of these include commercial trawlers, leisure boats, working boats, marine vessels, the Bygdøy boats and private yachts.)

- Shore power to meet the need for electricity when docked
- Battery hybrid solutions on entry to and exit from the port
- Battery operation
- Running on liquid biogas

Handling of goods, cargoes, and other activities

- Handling, processing and interim storage of cargo

  In connection with new and existing terminals, the port's customers are reviewing availability and commercial opportunities for use of zero-emissions technology for loading/unloading, internal transport and terminal management, and for land-side inbound and outbound transport. The Oslo Port Authority will plan for, and ideally be at the cutting edge of developing, the necessary infrastructure when these solutions materialise and can be commissioned. The Oslo Port Authority is considering continuing the subsidy scheme in the next financial period (2019-2022) in order to demonstrate a commitment to its own customers who wish to phase in new solutions on an ongoing basis.

  Environmental requirements are being defined, and it is requested that best available technology should be assessed and ideally used as a basis for procurement procedures/rental agreements without becoming tied to a specific type of technology.

- Other activities at the port

  The Port of Oslo is building loading solutions for its own vehicles and guest car parking. Customers and tenants are doing the same thing at the Port of Oslo. The next step will be to identify standardised loading solutions for both heavier vehicles and terminal equipment. It is possible that the technology will turn out to combine electricity with other fuel.

  The Oslo Port Authority has participated in a project assessing commercial production and access to hydrogen, and found this to present a challenge. This assessment was performed on the basis of the need to transport liquid CO2 which has to be shipped out via the CO2 capture project.

  Hydrogen may still be of relevance to other user groups, but as things currently stand, it presents a challenge due to a lack of regulations in relation to production, retention, storage and filling.

The Port of Oslo has also estimated the costs and potential reductions of emissions with shore power for each market segment (City of Oslo, 2018).

Table 17. Costs and potential reductions of emissions with shore power – Foreign ferry routes

Port:	Pier II for foreign ferry routes				
Emissions reduction level [% reduction of total port emissions]	Number of ships [-]	CO_2 reduction [tonnes/year]	Investment cost at port [NOK]	Investment cost aboard ship [NOK]	CO_2 cost [NOK/tonnes of CO2 red.]
44%	1	1,432	4,600,000	4,750,000	244
84%	2	2,733	4,600,000	9,500,000	171
100%	3	3,268	6,700,000	14,250,000	212

Table 18. Costs and potential reductions of emissions with shore power – Cruise ships

Port:	Søndre Akershuskai – 75% of arrivals use this cruise quay in Oslo				
Emissions reduction level [% reduction of total port emissions]	Number of ships [-]	CO_2 reduction [tonnes/year]	Investment cost at port [NOK]	Investment cost aboard ship [NOK]	CO_2 cost [NOK/tonnes of CO_2 red.]
51%	6	986	95,600,000	35,160,000	5,740
80%	16	1,546	95,600,000	93,760,000	4,608
100%	38	1,929	95,600,000	222,680,000	5,363

Table 19. Costs and potential reductions of emissions with shore power – Container Ships / LoLo Ships

Port:	Sjursøya Container Terminal at the Port of Oslo				
Emissions reduction level [% reduction of total port emissions]	Number of ships [-]	CO_2 reduction [tonnes/year]	Investment cost at port [NOK]	Investment cost aboard ship [NOK]	CO_2 cost [NOK/tonnes of CO2 red.]
53%	5	834	5,200,000	30,100,000	1,214
80%	11	1,247	5,200,000	66,220,000	1,536
100%	36	1,562	5,700,000	216,720,000	3,652

Table 20. Costs and potential reductions of emissions with shore power – Car carriers and RoRo ships

Port:	Bekkelagskaia				
Emissions reduction level [% reduction of total port emissions]	Number of ships [-]	CO_2 reduction [tonnes/year]	Investment cost at port [NOK]	Investment cost aboard ship [NOK]	CO_2 cost [NOK/tonnes of CO_2 red.]
89%	1	282	4,900,000	5,540,000	1,360
95%	2	301	4,900,000	11,080,000	1,737
100%	4	318	4,900,000	22,160,000	2,513

Table 21. Costs and potential reductions of emissions with shore power – Tankers

Port:	The tanker pier at the Port of Oslo				
Emissions reduction level [% reduction of total port emissions]	Number of ships [-]	CO_2 reduction [tonnes/year]	Investment cost at port [NOK]	Investment cost aboard ship [NOK]	CO_2 cost [NOK/tonnes of CO_2 red.]
50%	10	1,160	6,800,000	41,000,000	1,177
80%	29	1,870	6,800,000	118,900,000	1,771
100%	83	2,342	8,900,000	340,300,000	3,822

Table 22. Costs and potential reductions of emissions with shore power – Bulk carriers

Port:	Nordre Sjursøya				
Emissions reduction level [% reduction of total port emissions]	Number of ships [-]	CO_2 reduction [tonnes/year]	Investment cost at port [NOK]	Investment cost aboard ship [NOK]	CO_2 cost [NOK/tonnes of CO_2 red.]
48%	1	665	6,800,000	4,100,000	665
80%	4	1,103	6,800,000	16,400,000	680
100%	67	1,379	8,900,000	274,700,000	5,304

3 Goals, Drivers and Motivation for Policy Changes

3.1 Policies Driving Change

There are many factors that motivated policy changes to reduce marine air emissions in Norway. These factors are documented below.

3.1.1 International Climate Commitments

Norway ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1993. It ratified the Kyoto Protocol in 2002 and became a Party when the Protocol entered into force in 2005. In 2014, Norway ratified the Doha amendment. Then, Norway ratified the Paris Agreement in 2016 (Norwegian Ministry of Climate and Environment, 2018). Thus, it is important for Norway to ensure that the country can meet its international climate commitments and its targets for emission reductions.

Under the Paris Agreement, Norway will reduce emissions by at least 50% and towards 55% by 2030, compared to the 1990 level. Emissions from domestic shipping and fishing vessels are included in Norway's commitments under the Paris Agreement. Greenhouse gas emissions from domestic shipping, fishing vessels and recreational craft account for about 22% of emissions from the transportation sector (Norwegian Ministry of Climate and Environment 2019a).

3.1.2 Norwegian Specific Drivers

Besides the international climate commitments, there are several unique Norwegian motivators that drive policy changes to reduce marine emissions.

In June 2017, the Storting adopted a Climate Change Act, which established by law Norway's emissions reduction target for 2030 and 2050 (Norwegian Ministry of Climate and Environment, 2018). Norway's climate targets are:

1. Reduce emissions by 30% by 2020, compared to emission levels in 1990
2. Reduce emissions by at least 50% and towards 55% by 2030, compared to emission levels in 1990
3. Climate neutrality by 2030
4. Low emission society by 2050

The Climate Change Act made it legally binding for Norway to be a low-emission society by 2050, through specifying target reductions of greenhouse gas emissions of the order of 80-95% compared to 1990 level. This was further strengthened by the Norwegian government's political platform that set ambition to reduce greenhouse gas emissions by 90-95%, including reduction of emissions from domestic shipping and fisheries by half by 2030 (Norwegian Ministry of Climate and Environment, 2018).

Norway has three largest sources of emissions. They are transport, petroleum activities and manufacturing industry. Therefore, the Solberg government has set 5 priority areas for Norway's climate policy as follows (Norwegian Ministry of Climate and Environment 2018).

1. Reduce emissions from transportation
2. Strengthen Norway's role as a supplier of renewable energy
3. Develop low-emission industrial technology and clean production technology
4. Promote environmentally sound shipping (green shipping)
5. Develop carbon capture

With the goal to reduce emissions from transportation and address Norway's largest direct source of microplastic from tyre wear, the Norwegian government has an ambition to transfer 30% of goods transported over distances of more than 300 km from road to rail and sea by 2030. A shift in freight transport from road to sea helps to reduce the total volume of road traffic, thus it is an important means to reduce the spread of microplastic. Norway considers shifting freight from road to sea a sound climate and environment measure even if it is a shift to ships using conventional technology.

A modal shift of freight from road to sea requires an integrated approach to logistics chains, involving cargo owners, carriers and shipping companies in planning and coordination. Norway has already demonstrated success in coordinating an integrated approach with the logistics chains. In 2017, the Norwegian government introduced a three-year pilot grant scheme to encourage a model shift of freight from road to sea. It has resulted in 5 projects to establish new maritime transport services that are expected to give a permanent shift of transport from road to sea. The projects will result in the transfer of up to 1 million tonnes of freight per year from road to sea. Over the period 2021-2030, Norway expects this modal shift to result in a reduction of greenhouse gas emissions by 1.5 million tonnes CO2-eq (Norwegian Ministry of Climate and Environment 2019a).

In addition, green shipping is also one of eight priorities in the Government's 2015 maritime strategy. The growing focus on the development of green solutions and digitalization is an important driver of developments in maritime equipment in Norway (Norwegian Ministry of Climate and Environment 2019a).

The Norwegian government also recognizes that investments made today with a long service life (e.g. new ships with a lifespan of at least 20 years) may be lock-in to an industry structure that makes it difficult to meet its climate targets without strict requirements for environmental performance and action to promote low- and zero-emission technologies.

So, the Climate Change Act, the Norwegian government's political ambition, the need to reduce emissions from transportation, Norway's maritime strategy and smart investment in green solutions that ensures the country can meet climate commitments and targets are all driving forces to reduce marine emissions. It will involve promoting the use of low- and zero-emission solutions in all vessel categories.

Norway is taking an integrated approach to green transition of its transportation sector through three national strategies (Norwegian Ministry of Climate and Environment, 2019a) –

1. Action plan for green shipping describes the possible measures and policy instruments for different categories of vessels.
(Norwegian Ministry of Climate and Environment, 2019a)

2. Action plan for public transportation describes how the Government will achieve the target of fossil-free public transport by 2025.

3. Alternative fuels for the transportation sector initiative describes the Government's involvement in efforts to establish infrastructure for alternative transport fuels to promote a green transition in the sector.

Besides vessels, the Norwegian government is working cooperatively with municipalities and port authorities to transform Norwegian ports to be emission-free by 2030. This involves ports providing onshore power, charging facilities and adequate bunkering services for sustainable fuels, such as hydrogen and biogas (Norwegian Ministry of Climate and Environment, 2019a).

Norway has smartly aligned the need to fulfill its climate commitments with its regional development and industrial policies, so the country is a key player in developing a sustainable shipping sector for the 21st century. Its focus on green shipping will (1) ensure that Norway meets its climate commitments and its targets for emission reductions in the transportation sector, (2) support regional development policy along the coast in creating opportunities for growth and jobs, and (3) promote industrial policy in developing environmental technology with export potential.

Norway will provide a framework to enable the Norwegian maritime industry to gain experience and expertise in green solutions with export potential. Norway will also continue to promote maritime clusters as drivers of innovation. Examples of strong maritime clusters along the coast include Ocean Hyway Cluster, NCE Maritime CleanTech industry cluster, CGE Blue Maritime etc. (Norwegian Ministry of Climate and Environment, 2019a)

These policies collectively are positioning Norway well as an important supplier for the forthcoming increase in demand of green marine technologies worldwide due to new international maritime requirements (e.g. requirement adopted in 2018 by IMO to cut emissions from international shipping by at least 50% by 2050) and demand from customers.

Internationally, Norway wants to play a leading role in IMO's work on reducing greenhouse emissions and strengthen cooperation with IMO on assistance to developing countries in their efforts to prevent marine pollution and reduce greenhouse gas emissions from ships (Norwegian Ministry of Climate and Environment 2019a). So, while Norway is driving changes in green transition internationally, it also has great influence on international work and regulations.

3.2 Government Initiatives

This section covers policy instruments and economic instruments. Policy instruments include regulatory measures and requirements. Economic instruments include taxation and funding instruments.

In Norway, the policy instruments have been developed in close cooperation with the industry and cover the entire value chain from research to market regulation, to stimulate the demand for climate and environmental technology. Policy instruments, funding instruments and cooperation agreements are relevant to all vessel categories (Norwegian Ministry of Climate and Environment, 2019a).

3.2.1 Regulations

In terms of regulations, there are international regulations, European Union regulations and Norwegian regulations.

International regulations related to marine air emissions that are relevant to Norway include the following (Norwegian Ministry of Climate and Environment, 2019a):

- The International Convention for Prevention of Pollution from Ships (MARPOL) has been implemented in Norwegian law.
- The strict environment rules for Emission Control Areas (ECA) in the North Sea adopted by the International Maritime Organization (IMO).
- The IMO Polar Code set out specific safety and environmental protection rules for polar waters.
- The Law of the Sea entitles coastal states to establish specific legislation in their own waters when it is important to protect the environment, but it is not possible to find a solution within the IMO system. For example, Norway's prohibition against using heavy bunker oil in the waters around Svalbard.

Norwegian regulations related to marine air emissions include the following. Akselsen (2015) stated in his presentation that Norwegian regulatory regime on emissions to air included only international regulations, meaning for example the adoption of MARPOL Annex VI and EU regulations. However, the new environmental requirements for UNESCO's World Heritage fjords, entered into force on March 1, 2019, are drawn up by

Norwegian Maritime Authority on assignment from the Ministry of Climate and Environment (Norwegian Maritime Authority, 2019b).

- The Ship Safety and Security Act provides the legal authority to prescribe regulatory measures for ships flying the Norwegian flag and for foreign ships in Norwegian territorial waters, the Exclusive Economic Zone of Norway and the Norwegian continental shelf. The Act covers environmental safety with a series of provisions that prescribe environment-related requirements for ship construction, equipment and operations (Norwegian Ministry of Climate and Environment, 2019a).

- The Pollution Control Act applies to pollution from ports and can be used to regulate greenhouse gas emissions. This may include matters such as requiring ports to provide shore power facilities, charging infrastructure or infrastructure for alternative fuels. Environmental requirements for ships may also be introduced under the Act and can be used to reduce harmful emissions to air from maritime transport (Norwegian Ministry of Climate and Environment, 2019a).

- The Regulations on Environmental Safety for Ships and Mobile Facilities is related to the Ship Safety and Security Act described above (Norwegian Maritime Authority, 2019a). It lays out the regulations governing the environmental performance of Norwegian flagged and foreign vessels, and mobile platforms operating in Norwegian waters. In 2019, the regulations were amended to include special provisions for vessels operating in the UNESCO World Heritage fjords. The relevant environmental provisions related to air emissions include (DieselNet, 2019):

  - Adoption of MARPOL Annex VI (DieselNet, 2019)

    MARPOL Annex VI was first adopted in 1997. It limits the main air pollutants contained in exhaust gas of ships, including sulphur oxides (SOx) and nitrous oxides (NOx) as well as prohibits deliberate emissions of ozone depleting substances. It also regulates the emissions of volatile organic compounds (VOC) from tankers. The revised MARPOL Annex VI entered into force on July 1, 2010. It has significantly strengthened emission limits considering technological advancements and implementation experience (International Maritime Organization (2020d).

Regulation 14 limits the sulphur content of marine fuel on a global basis to (International Maritime Organization, 2020b, Akselsen, 2015 and Larsen, 2018)

- 4.5% m/m prior to January 1, 2012
- 3.5% m/m on and after January 1, 2012
- 0.5% m/m on and after January 1, 2020

It also imposes stricter regulations in the Emission Control Areas (ECA), where the sulphur content of maritime fuel oil is not to exceed the following (International Maritime Organization, 2020b, López-Aparicio, 2017). Figure 11 shows that the Norwegian coast up to 62°N is North Sea ECA for SOx.

- 1.5% m/m prior to July 1, 2010
- 1.0% on and after July 1, 2010
- 0.1% on and after January 1, 2015

Figure 11. North Sea ECA (Akselsen, 2015)

Regulation 13 limits NOx emissions from marine diesel engines (Akselsen, 2015). It divides the NOx control requirements for marine diesel engines with a power output larger than 130kW into three different tiers, depending on when the ship was constructed. The NOx emission limits are set within each tier depending on the engine's rated speed (International Maritime Organization, 2020a, Larsen et al., 2018 and Herdzik, 2019) (Figure 12).

- Tier I applies to ships construction on or after Jan 1, 2000
- Tier II applies to ships constructed on or after Jan 1, 2011
- Tier III applies to ships constructed on Jan 1, 2021 or later and operate in North Sea ECA

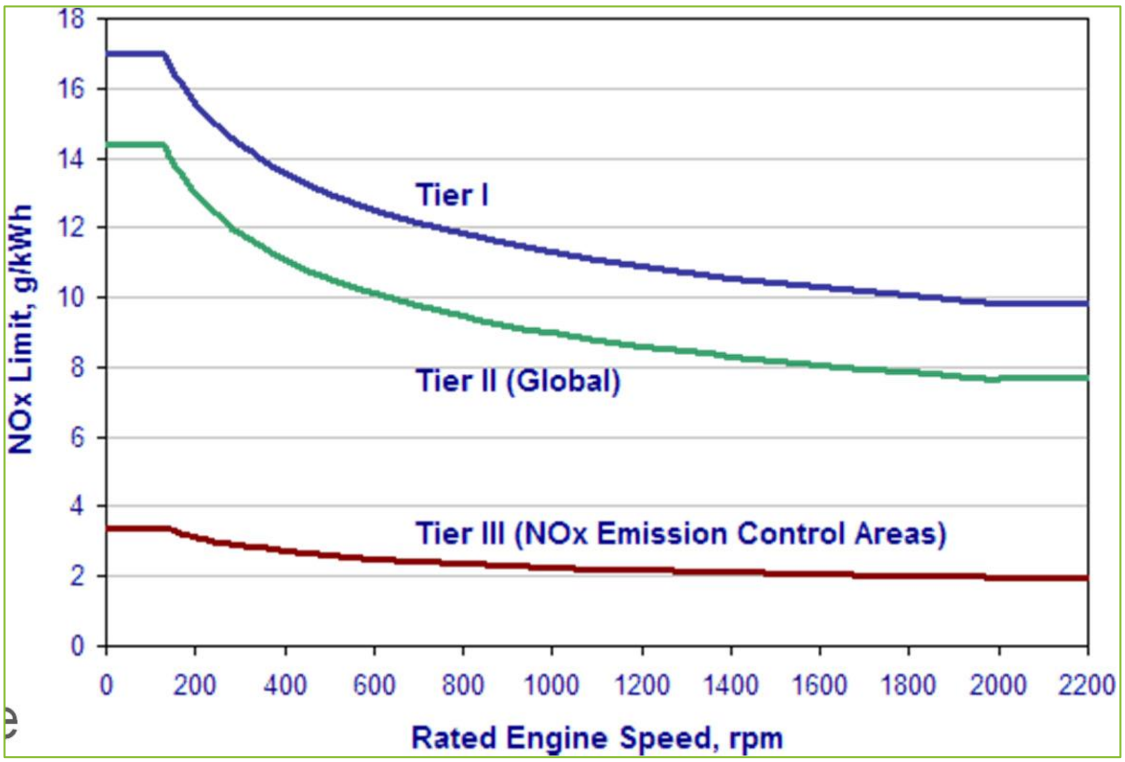


Figure 12. NOx limits vary depending on rated engine speed (Herdzik, 2019)

Regulations 30, 21, 22 sets the ship energy efficiency requirements (Akselsen, 2015).

In 2011, IMO adopted mandatory technical and operational energy efficiency measures. These mandatory measures entered into force on January 1, 2013 for all vessels exceeding 400 gross tonnes in international waters. The purpose is to improve energy efficiency of both new and existing vessels, which will result in reduction of all fuel-related emissions to air, such as CO2, NOx, SOx, PM etc. IMO regulations on fuel efficiency will soon be in force for vessels trading exclusively in national waters (Norwegian Maritime Authority, 2016b).

The measures include the following (Norwegian Maritime Authority, 2016a):

- Energy Efficiency Design Index (EEDI)
  EEDI is an important technical measure for new ships aimed at promoting the use of more efficient equipment and engines. All new ships, under certain categories, constructed on or after January 1, 2013 must have its achieved EEDI equal to or lower than the ship-specific reference value. The categories of vessels include bulk carriers, gas tankers, tankers, container ships, cargo ships, and refrigerator and combination vessels. The ship-specific reference value will be progressively lowered through four phases.

  It is a non-prescriptive, performance-based mechanism that allows industry to choose the technologies to use in a specific ship design. However, it requires a minimum energy efficiency level per capacity mile for different ship types and sizes.

  The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide per ship's capacity-mile and is calculated by a formula based on the technical design parameters for a given ship. The smaller the EEDI reflects the more energy efficient the ship's design (International Maritime Organization, 2020c).

- Ship Energy Efficiency Management Plan (SEEMP)
  SEEMP is an operational measure for all ships that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. It provides a way for shipping companies to manage ship and fleet efficiency performance over time using Energy Efficiency Operational Indicator (EEOI) as a monitoring tool (International Maritime Organization, 2020c). From January 1, 2013, all ships are required to have a SEEMP onboard and there will be periodic inspection on the International Air

Pollution Prevention (IAPP) certificate.

- Adoption of European Union (EU) Monitoring, Reporting and Verification Regulations (MRV) on greenhouse gas emissions from ships (DieselNet, 2019)

  The EU MRV Regulation entered into force in 2015 and the first reporting period started 1 January 2018. Companies operating ships of over 5000GT, which carry passengers or cargo for commercial purposes to or from European ports, regardless of the flag they fly, must submit their monitoring plans to an accredited verifier. Companies are required to monitor and report fuel use for all voyages within the scope of the MRV Regulation, and are responsible for developing a plan to monitor the following information (International Chamber of Shipping, 2018):
    - port of departure and port of arrival;
    - the date and hour of departure and arrival;
    - quantity of fuel used, each type of fuel used and emission factor for each type of fuel;
    - CO2 emitted;
    - distance travelled;
    - time spent at sea;
    - cargo carried;
    - transport work; and
    - information relating to the ship's ice class and to navigation through ice, where applicable.

- Adoption of EU Sulphur Directive, Directive (EU) 2016/802, that restricts the sulphur contents of fuels (DieselNet, 2019):
    - When ships are moored for more than 2 hours to a maximum limit of 0.1%.
    - For passenger ships in scheduled service in Norway's Exclusive Economic Area (EEA) to 1.5%.

- Special requirements on emission of SOx and NOx in the World Heritage fjords drawn up by Norwegian Maritime Authority on assignment from the Ministry of Climate and Environment (DieselNet, 2019):
    - Ship fuel is limited to maximum 0.1% mass sulphur or a closed-loop scrubber with an anti-vapour plume device must be used.

    - All ships, new or old, exceeding a gross tonnage of 1000 are limited in the emissions of NOx as follows:
        i. IMO Tier I from 2020.01
        ii. IMO Tier II from 2022.01
        iii. IMO Tier III from 2025.01
    - Ships exceeding a gross tonnage of 10,000 are subjected to smoke and particulates limitations, which include:
        i. Operational and technical measures to reduce particulates emissions and visible smoke, and
        ii. Speed reduction as a measure to reduce emissions.

- Besides the Regulations on Environmental Safety for Ships and Mobile Facilities, the Norwegian Parliament passed a resolution in 2018 to phase in low- and zero-emission solutions for shipping in World Heritage fjords by 2030, including the introduction of a zero-emission requirement for cruise ships and ferries no later than 2026 (DieselNet 2019, UNESCO 2018).

- Adoption of EU implementing decision on frequency of sampling of marine fuels being used on board ships (Akselsen, 2015)

    - Commission Implementing Decision (EU) 2015/253 is documented in The European Commission (2015b).

- EU trans-European transport network (TEN-T) (City of Oslo, 2018)
    - It provides guidelines on how ports included in the network should approach various alternative fuels as part of the initiative towards more eco-friendly transport.

3.2.2 Requirements

In addition to regulations, the Norwegian government's policy instrument has different requirements to reduce undesirable emissions to the environment.

The Norwegian Carbon Credit Procurement Program was set up in 2007 and is now managed under the Ministry of Climate and Environment. Procurement of carbon credits supplements national measures to reduce global greenhouse gas emissions, allowing Norway to take a more ambitious emissions reduction target than if all the reductions were to be taken domestically. The Ministry has a mandate to procure carbon credits from new, not yet commissioned, projects and from vulnerable projects. Vulnerable projects are registered and commissioned projects that are either stranded or on the verge of shutting down due to the lack of revenues from Certified Emissions Reduction (CER) sales. The Ministry has contracts to deliver about 47 million CERs under the bilateral procurement program and through carbon funds under Nordic Environment Finance Corporation (NEFCO) and the World Bank (Norwegian Ministry of Climate and Environment, 2019b).

Recognizing that it is important to have strict requirements for environmental performance and action to promote green technologies to guide long-term investment, the Norwegian government made the decision in 2015 that all new ferry tenders must have low or zero-emission technology on board. As a result of this decision, over 60 electric ferries will be launched in Norway in the next few years (UNESCO, 2018). This surge in deployment of green solutions is helping Norway to meet its climate commitments and targets.

3.2.3 Taxation

Pricing of emissions is one of the main instruments of Norway's climate policy. OECD (2019) stated the following main specific taxes on energy use in Norway:

- the Road Usage Tax on Engine Fuel (Veibruksavgift på drivstoff);
- the Base Tax on Mineral Oil (Grunnavgift på mineralolje);
- the Tax on Lubricating Oil (Avgift på smøreolje);
- the CO2 Tax on Mineral Products (CO2-avgift på mineralske produkter) with a nominal tax rate of NOK 500 per tonne of CO2 (approximately EUR 54) levied onliquid and gaseous fossil fuels;
- Tax on the Emission of CO2 in Petroleum Activities on the Continental Shelf (Avgiftpå utslipp av CO2 i petroleumsvirksomheten på kontinentalsokkelen); and
- the Electricity Tax (Avgift på elektrisk kraft).

Base tax on mineral oil: The base tax is intended to correct any adverse effects arising from the introduction of an electricity tax in the year 2000. The tax is levied on all mineral oil, with the following exceptions: all mineral oil where a diesel tax applies and jet fuel. Mineral oil used for the following purposes is also exempt: international shipping, goods and passenger traffic in international waters, construction on the continental shelf, supply shipping, high-seas fishing, and production in the fishmeal industry. The tax is refunded for fishing within the economic zone. High-sea fishing is exempted from these taxes (OECD, 2012).

A carbon dioxide tax is levied on all mineral oil, with the exemption of mineral oil used for international shipping, international flight, and fishing within the economic zone and high-seas fishing. The tax is fully refunded for fishing within the economic zone, whereas vessels fishing in high seas are exempt from the tax (OECD, 2012).

To account for environmental costs of marine air emission, the most relevant taxes are on carbon and NOx emissions and electricity.

Emissions of greenhouse gases and other pollutants are often closely related to the use of fossil energy. In an unregulated market, the environmental costs of emissions are not reflected in energy prices. So, polluters are not made responsible for the full costs to society of their energy-using activities. This encourages excessive use of fossil energy. Properly designed taxes correct this situation by increasing the price of using fossil energy to reflect the full costs to society. Over time, this will result in changes to production and consumption patterns and encourage the development and deployment of new technology (Energy Facts Norway, 2017).

3.2.3.1 Carbon Tax

Carbon tax was implemented in Norway in 1991. About 50 per cent of Norwegian emissions are covered by the EU Emission Trading System (EU-ETS). More than 80 per cent of domestic emissions is subject to mandatory emissions trading, a CO2 tax, or both (Norwegian Ministry of Climate and Environment, 2019b). These apply mainly to emissions from the use of fossil energy sources (Energy Facts Norway, 2017).

Carbon tax is a technology-neural instrument that provides incentives to achieve emission cuts at the lowest possible cost to society. Measures that cost less than the carbon tax rate give a return on the investment (Norwegian Ministry of Climate and Environment, 2019a)

The EU-ETS is a cornerstone of the EU’s policy in combating climate change and is a key tool for reducing greenhouse gas emissions cost-effectively. It is the world’s first major carbon market and remains the biggest one. The EU-ETS operates in all EU countries plus Iceland Liechtenstein and Norway. It covers about 45% of the EU’s greenhouse gas emissions. Participation in the EU-ETS is mandatory for companies in the specified industrial sectors (European Commission, 2015a).

The EU-ETS works on the ‘cap and trade’ principle. A cap is set on the total amount of certain greenhouse gases that can be emitted by installations covered by the system. The cap is reduced over time so total emissions fall. A limit on the total number of allowances available ensures that they have a value. Within the cap, companies receive and buy emission allowances, which they can trade as needed. They can also buy a limited amount of international credits from emission-saving projects around the world.

After each year, a company must surrender enough allowances to cover its emissions or face heavy fines. If a company reduces its emissions, it can keep the spare allowances to cover future needs or sell them to another company that is short of allowances. Trading brings flexibility that ensures emissions are cut where it costs the least to do so. A robust carbon price also promotes investment in green technologies.

In Norway, the standard carbon tax rate applies to shipping. In 2019, the normal tax rate for mineral oil is NOK 1.35 per litre, which corresponds to NOK 508 per tonne CO2-eq. From January 1, 2018, the standard carbon tax rate has also applied to liquefied natural gas (LNG) and liquefied petroleum gas (LPG) for domestic shipping. The tax rates in 2019 are NOK 1.02 per Sm3 for LNG, and NOK 1.52 per Sm3 for LPG, corresponding to NOK 508 per tonne CO2-eq for LNG and NOK 507 per tonne CO2-eq for LPG respectively. A reduced carbon tax rate applies for mineral oil used in fisheries less than 250 nautical miles from the coast and the use of LNG and LPG in these fisheries is exempt from the carbon tax (Norwegian Ministry of Climate and Environment, 2019a).

The Norwegian government has announced that the carbon tax rate will be increased by 5% per year from 2020 to 2025. Predictable stepwise increases in the carbon tax will make it easier for shipowners to take future carbon prices into account when making investment decisions. The revenue will be used to reduce taxation of groups affected by the increases to ease the transition. Rates of other relevant taxes, for example on HFCs and PFCs, will be increased correspondingly.

Norway recognizes that carbon pricing is often insufficient to justify the costs of developing new environmental technology. So, the government is also providing support schemes (e.g. funding and other incentives) to compensate for high costs and risk levels in the transitional period. (Norwegian Ministry of Climate and Environment, 2019a).

In the agriculture and fisheries sector, diesel used for fishing in domestic water is subject to the carbon tax with a reduced rate (NOK 109 per tonne of CO_2) but exempted from other energy taxes. Natural gas and LPG used for fishing is not taxed.

Norway's taxation rates for fossil energy are some of the highest in the world. The OECD has compared the tax rates in the transport sector for different countries. It found that the UK was the only country that had a higher tax than Norway in the transport sector. Tax rates in Switzerland are like those in Norway. In the US, the tax rate is equivalent to NOK 100 per tonne CO_2-eq. (Energy Facts Norway, 2017).

3.2.3.2 NOx Tax

Through the Gothenburg Protocol, Norway is limiting NOx emissions to a maximum of 156,000 tonnes per year from 2010. On January 1, 2007, a tax on NOx emissions was introduced in Norway as an incentive to reduce emissions of NOx. In 2013, the tax was NOK 17.01/kg of NOx emitted (Norwegian Maritime Authority, 2016b). In 2020, the tax is NOK 22.69/kg of NOx emitted (NOx-fondet, 2019b).

The tax applies to the offshore and shipping industry, as well as large land-based industries (Norwegian Maritime Authority, 2016b). Specifically, it applies to all ships with propulsion machinery that have a total installed capacity of over 750kW (Norwegian Ministry of Climate and Environment, 2019) within Norwegian territorial waters irrespective of nationality. However, for Norwegian registered vessels, the tax applies to emissions in "near waters", which are defined as sea areas within 250 nautical miles of the Norwegian coast. Ships in international traffic are exempt, including vessels operating in direct traffic between Norway and foreign ports (IACCSEA, 2019).

The tax is calculated based on actual NOx emissions. If these are not known, it is calculated based on a source-specific emission factor. If neither actual emissions nor the source specific factor is known, factors determined by standard values are used (IACCSEA, 2019).

3.2.3.3 Electricity Tax

A tax is levied on all electric power supplied in Norway. A reduced tax rate applies to commercial vessels (The Norwegian Tax Administration, 2019). Since January 1, 2017, a reduced electricity tax rate was introduced for commercial shipping. In 2019, the reduced tax rate was NOK 0.005 per kWh (the standard rate is NOK 0.1558 per kWh).

The reduced rate is determined by the minimum level of taxation set out in the EU Energy Taxation Directive. The reduced rate provides an incentive for commercial shipping to use onshore power and electric propulsion. (Norwegian Ministry of Climate and Environment, 2019a).

3.2.4 Funding and Other Initiatives

3.2.4.1 EU Funding

The following are two examples of projects co-funded by the EU. In 2018, the Port of Kristiansand opened Europe's largest onshore power facility, which provides even the largest cruise ships with enough electricity to meet their needs. The project was co-funded by the EU's Horizon 2020 programme. In 2018, a project coordinated by Rogaland county with NCE Maritime CleanTech Industry Cluster to develop a fully electric high-speed vessel was awarded EUR 12 million from the Horizon 2020 research programme.

3.2.4.2 Norwegian Government Funding Programs and Initiatives

3.2.4.2.1 Enova SF

Enova SF is a state enterprise owned by the Norwegian Ministry of Climate and Environment. It is managed through a rolling four-year agreement, which ensures that the resources from the Climate and Energy Fund are managed in accordance with the goals. Its primary objective and the purpose of the Climate and Energy Fund are to contribute to reductions in greenhouse gas emissions, improved security of energy supply, and the development of technology that will bring about reductions in greenhouse gas emissions in the longer term (Norwegian Ministry of Climate and Environment, 2019a and Enova SF, 2018). Figure 13 shows the key figures of the Climate and Energy Fund.

Key figures for the Climate and Energy Fund

Key figures	2018	2017	2016	Description
New commitments (NOK MILLION)	2 326	2 582	2 570	New commitments show how much Enova has allocated from the Climate and Energy Fund to support projects, contractual activities and administrative remuneration.
Disbursed from the Climate and Energy Fund (NOK MILLION)	2 356	2 356	2 151	Disbursed from the Climate and Energy Fund shows how much has been disbursed to projects, contractual activities and administrative remuneration. Disbursements were made during the year to projects adopted during the period 2008-2018.
Added to the Climate and Energy Fund (NOK MILLION)	2 792	2 659	2 290	The key figure shows how much was added to the Climate and Energy Fund through allocations via the Fiscal Budget, parafiscal charge on the grid tariff and interest.
No. of projects	987	931	1 008	Number of projects allocated support from the Energy Fund, except measures funded through the Climate and Energy Fund.
Number of disbursements from the Enova Subsidy	14 487	8 123	6 468	Shows the number of implemented measures that have received a disbursement from the Enova Subsidy.

Figure 13. Key figures for the Climate and Energy Fund (Enova SF, 2018)

Enova provides funding for investments in climate and energy projects in all sectors. It had more than NOK 3 billion (Canadian $410 million) in the 2019 budget (Norwegian Ministry of Climate and Environment, 2019a). Norway is Europe's largest petroleum producer after Russia. They export almost all of its reserves. This is one reason why Norway can have such a large budget for Enova and this is only one source of Norwegian government funding available for green projects (Smithsonian Magazine, 2018). In 2018, Enova received nearly NOK 2.8 billion and has granted support amounting to more than NOK 2.3 billion to about 1,000 energy and climate projects.

The results of Enova's key performance indicators for 2017-2018 are shown in Figure 14. The allocations of the Climate and Energy Fund are shown in Figure 15. It shows that the transportation sector received most of the funding. An activity overview of the Climate and Energy Fund is shown in Figure 16. It shows that Norway invested significantly in green solutions for marine transportation (e.g. energy and climate measures in ships and onshore power for ships).

Performance indicator	2017	2018	Total
Climate result (ktonne CO_2-eqv.)	287	242	529
Energy result (GWh)	1 693	1 561	3 255
Reduced peak demand (MW)	133	123	256
Triggered innovation capital (NOK million)	1 620	1 197	2 817

Performance indicator results 2017-2018

Figure 14. Enova performance indicator results 2017-2018 (Enova SF, 2018)

Climate and Energy Fund's allocations

	2017	2018	Total
Sector/activity	NOK million	NOK million	NOK million
Industry	431	407	838
Transport	992	817	1 809
Energy system	192	160	352
Non-residential buildings and property	429	444	873
Households and consumers	165	275	440
International	2	4	6
Counselling and communication	54	45	99
External analyses and development measures	40	20	60
Administration remuneration	157	155	312
Total	**2 461**	**2 326**	**4 787**

Figure 15. Allocations of Climate and Energy Fund (Enova SF, 2018)

Activity overview for the Climate and Energy Fund 2018 Sector	No. of applications	No. of projects supported	Contractual support
	stk	stk	MNOK
Industry	**347**	**191**	**407**
Pilot testing of new energy and climate technology in industry	6	4	8
Demonstration of new energy and climate technology	3	2	28
Full-scale innovative energy and climate technology	13	8	197
Pre-project support for new energy and climate technology in the industry	8	3	23
Support for energy and climate measures in industry and plants	113	70	120
Pre-project support for energy and climate measures in the industry	4	3	1
Support for introducing energy management	200	101	29
Transport	**452**	**203**	**817**
Pilot testing of new energy and climate technology in transport	5	1	8
Full-scale innovative energy and climate technology	6	4	46
Support for energy and climate measures in ships	38	30	276
Electrification of maritime transport	10	1	1
Support for energy and climate measures in ground transport	32	21	53
Hydrogen infrastructure	6	4	24
Onshore power for ships in Norwegian ports	21	15	131
Support for infrastructure for municipal and county authority transport services	11	7	187
Support for charging infrastructure for electric cars (rights-based)	35	29	8
Support for introducing energy management	287	90	45
Support for production of biogas and biofuel	1	1	39
Energy system	**58**	**34**	**160**
Demonstration of new energy and climate technology	2	2	7
Full-scale innovative energy and climate technology	9	6	39
Large-scale demonstration and pilot project unit	15	0	-
Support for district heating	32	26	115
Non-residential buildings and property	**773**	**556**	**444**
Introduction of new technology in buildings and areas	35	29	102
Commercial testing	9	7	12
Innovative solutions in the Energy service market for buildings	30	10	8
Support for energy-efficient new buildings	0	3	26
Support for new technology for the future's buildings	2	0	-
Best available technology in existing buildings	155	92	92
Comprehensive mapping of buildings	32	19	3
Mapping support for existing buildings	21	20	2
Support for existing buildings	184	138	147
Support for concept assessment in new construction and areas	61	37	25
Support for heating plants	244	201	28
Households and consumers (the Enova Subsidy)	**20 230**	**14 487**	**275**
International (IEA Main Project)	**3**	**3**	**3**
Total	**21 863**	**15 474**	**2 106**

Figure 16. Activity overview for Climate and Energy Fund 2018 (Enova SF, 2018)

Enova assesses its own performance by evaluating projects funded under three performance indicators – climate, innovation and energy and demand. Figure 17 shows the expected climate results (ktonnes of CO2 equiv.) in projects awarded support from the Climate and Energy Fund in 2017 and 2018. The climate result is the sum of changes in greenhouse gas emissions, not subject to carbon credits, as a result of various measures in the projects that Enova has supported. It shows the projects funded under the Transportation sector are showing a promising reduction in emissions.

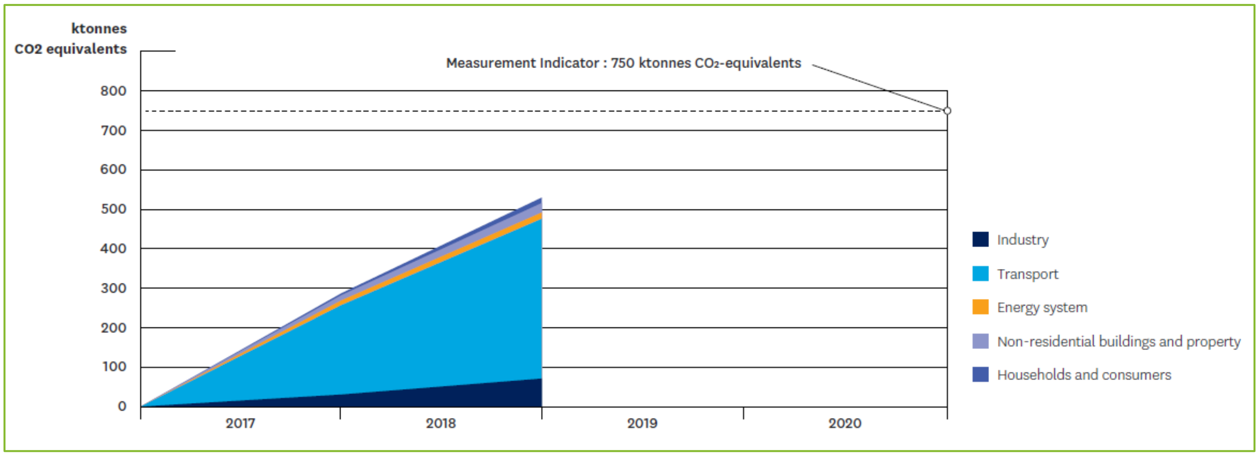


Figure 17. Expected climate results (ktonnes of CO2 equiv.) in projects awarded support from the Climate and Energy Fund in 2017 and 2018 (Enova SF, 2018)

3.2.4.2.2 Innovation Norway

Innovation Norway's activities are intended to advance restructuring of Norwegian business and industry, with a strong focus on sustainable solutions and innovation in areas relevant to major social challenges that can boost Norway's future competitiveness. Innovation projects dealing with green shipping may be eligible for several Innovation Norway's financial, profiling and expertise-building services (Norwegian Ministry of Climate and Environment, 2019a).

Innovation Norway's environmental technology scheme provides risk reduction for companies that are developing and testing new technology and provides support for projects that are expected to boost value creation in Norway. The maritime industry is the second largest recipient of funding, receiving an estimated NOK 73 million in 2017. Grants have been provided for a wide variety of projects, for example on charging and mooring systems for electric ferries, smart charging, heating and energy management systems, and systems for hydrogen bunkering.

Innovation Norway's innovation contract scheme is designed for small and medium-sized enterprises that are seeking to develop new, innovative products, services and technologies in close cooperation with pilot customers. The scheme is open to all sectors. The maritime sector receives an estimated NOK 25 million per year through the scheme. Many of the maritime projects have a green profile.

Innovation loans and low-risk loans are also attractive forms of financial risk reduction for innovation projects on green shipping.

A grant scheme for pilot and demonstration projects in the marine and maritime sectors was established in Innovation Norway, with NOK 30 million in funding available. The scheme supports pilot and demonstration projects for new technology, systems and processes in the marine and maritime sector.

'The Explorer' is a digital showcase that is designed to strengthen Norway's green international profile and function as a channel to international markets. It is being developed as an important arena for the promotion of green Norwegian innovations.

3.2.4.2.3 The Research Council of Norway

The MAROFF programme is the Research Council's most important research programme for maritime research and innovation. Funding for maritime research is intended to stimulate investment in research and innovation projects that will make the maritime industry more competitive and adaptable and strengthen cooperation between research groups and the industry. Research projects in fields such as autonomous technology and digitalisation, green shipping and new opportunities in the ocean industries are being given high priority. In 2017, the Ministry of Trade, Industry and Fisheries allocated NOK 169.3 million to the MAROFF programme. After budget negotiations were completed, the allocation to the programme was increased by NOK 25 million. In addition, the Research Council received a further NOK 17 million earmarked for maritime technology development and maritime innovation (Norwegian Ministry of Climate and Environment, 2019a).

The SkatteFUNN tax incentive scheme provides tax deductions for business expenses for research and development. In 2017, companies in the maritime sector received tax deductions totalling NOK 480 million under the scheme. Small and medium-sized enterprises can claim 20% of project costs as tax deductions, and larger firms can claim 18% (Norwegian Ministry of Climate and Environment, 2019a).

The PILOT-E and PILOT-T Schemes

The PILOT-E scheme was launched by Innovation Norway, the Research Council of Norway and ENOVA in 2016. Its aim is to speed up the development and deployment of novel products and services in the field of environment-friendly energy technology so that emissions are reduced both in Norway and internationally. Through close coordination between funding agencies, PILOT-E can assist companies through the entire technology development pathway from concept to market (Norwegian Ministry of Climate and Environment, 2019a).

The zero-emission vessel Future of the Fjords is the first PILOT-E project that has reached the commercialisation stage. This is the world's first all-electric sightseeing vessel constructed using carbon-fibre composite materials. The shipbuilding company Brødrene Aa received a grant of NOK 10 million through the PILOT-E scheme to develop the vessel.

The Pilot-T scheme is part of the Government's innovation initiative, which was announced in the white paper Norwegian National Transport Plan 2018–2029 (Meld.St.33 (2016–2017)).The scheme involves cooperation between the Research Council and Innovation Norway, and offers Norwegian companies opportunities to take part in the development of new technology and new solutions for the transport sector. The Research Council has issued calls for proposals for projects in the research stage, with up to NOK 40 million in funding available, and Innovation Norway has allocated up to NOK 25 million to development and demonstration projects (Norwegian Ministry of Climate and Environment, 2019a).

3.2.4.2.4 Maritime Clusters and Test Facilities

Norwegian Innovation Clusters is a programme run by Innovation Norway, Siva and the Research Council of Norway. It is intended to enhance innovation and collaboration within regional innovation clusters by expanding cooperation between businesses, knowledge institutions and public development agencies (Norwegian Ministry of Climate and Environment, 2019a).

The programme provides support for clusters on three levels. Arena is for immature clusters in an early phase of organised collaboration. Norwegian Centres of Expertise

(NCE) includes mature clusters with an established organisation, and systematic collaboration that have already achieved results through cooperation projects. Global Centres of Expertise (GCE) are mature clusters that are engaged in systematic collaboration in strategic areas, both within the cluster and internationally with R&D institutes and other relevant partners. The companies in a GCE cluster must be part of a global value chain, and they must have considerable potential for growth in national and international markets.

Several clusters with members previously providing goods and services in the oil and gas sector are now looking at new maritime opportunities, particularly opportunities for supplying green solutions. Other mature clusters are changing their strategies and new clusters have emerged to focus on areas such as renewable solutions and offshore wind power.

NCE Maritime Cleantech focuses on clean maritime transport solutions. The Ocean Hyway Cluster achieved Arena status in 2018, and its ambition is to become a cluster for the entire value chain for hydrogen technology. The mature maritime clusters, such as CGE Blue Maritime, are world leaders in their areas. Brand Norway concept will be further developed and adapted for the maritime sector.

3.2.4.2.5 Private-Sector Cooperation Forums

The Maritime Battery Forum was established in 2014 to promote collaboration between individuals and organisations established in Norway that are interested in battery-propelled ships. It functions as an arena for the exchange of information and cooperation between the industry, authorities and research groups (Norwegian Ministry of Climate and Environment, 2019a).

The Norwegian Forum for Autonomous Ships was established in 2016 as a cooperation forum for stakeholders working on autonomous shipping. Its members represent large parts of the maritime industry in Norway, and include the Norwegian Coastal Administration, the Norwegian Maritime Directorate and employees' and employers' organisations (Norwegian Ministry of Climate and Environment, 2019a).

3.2.4.2.6 The Norwegian Catapult

The Norwegian government is supporting the development of test facilities for the development and deployment of new technology in all branches of industry. The Norwegian Catapult Programme was established in 2017 and supports the establishment of national centres that offer facilities and expertise for testing and simulation of new technologies and new solutions. Their purpose is to help companies accelerate the process from concept to market launch of their products and to do so effectively at low cost. The main target group is small and medium-sized enterprises, but larger companies and research and educational institutions can also use the catapult centres (Norwegian Ministry of Climate and Environment, 2019a).

Three new catapult centres, all of which focus on the ocean industries, were established in 2018.The Ocean Innovation Catapult Centre is based in Bergen and focuses on the development of new solutions for growth and green restructuring in the ocean industries. The Sustainable Energy Catapult Centre on Stord is a test facility for maritime and decentralised energy systems (batteries, fuel cells and hybrid systems) for the ocean industries and related industries. The focus areas for the DigitCat Catapult Centre in Ålesund are simulation, digital twins and virtual prototyping.

3.2.4.2.7 The Norwegian Export Credit Guarantee Agency (GIEK) and Export Credit Norway

Ships and related equipment made up about 85% of Export Credit Norway's lending balance and about 75% of GIEK's outstanding guarantee liabilities from 2015 to 2018. The 2018 budget established a scheme making it possible for GIEK and Export Credit Norway to finance vessels built at shipyards in Norway for use in Norway. So far, GIEK has only provided one guarantee under the scheme, for nine electric ferries, and Export Credit Norway has concluded a loan agreement for the building of a stern trawler (Norwegian Ministry of Climate and Environment, 2019a).

GIEK's building loan guarantee scheme provides guarantees during the building period or during modification of ships and offshore installations. The purpose of the scheme is to ensure that Norwegian shipyards, offshore yards and other relevant companies can obtain loans by reducing the risk for private banks, and thus increase the level of activity. The scheme is intended to make Norwegian shipyards more competitive.

3.2.4.2.8 NOx Fund

Companies can get an exemption from NOx tax by entering into an Environmental Agreement with the government on measures to reduce NOx (Norwegian Maritime Authority, 2016b). In 2017, 15 Norwegian business organizations entered into an Environmental Agreement with the Ministry of Climate and Environment to reduce the effective tax, which led to the formation of the NOx Fund. Figure 18 illustrates how the NOx Fund works. Its purpose is to encourage companies in Norway to carry out measures to reduce NOx emissions (Norwegian Ministry of Climate and Environment, 2019a).

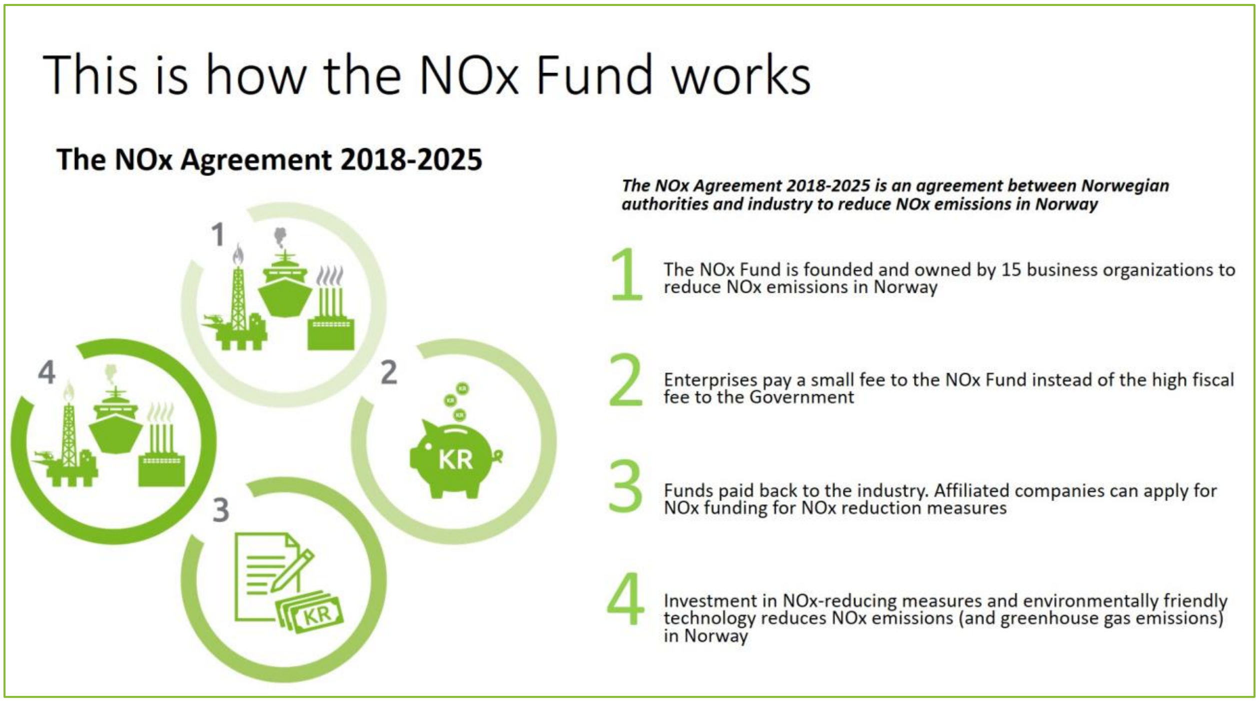


Figure 18. Illustration of how the NOx Fund works (NOx-fondet, 2019a)

According to IACCSEA (2019), the Fund quickly became a success to accelerate efforts to cut NOx emissions while providing industry financial support to implement competitive green technology. For participating business organizations, payment to the NOx Fund replaced the NOx tax. Business organizations that sign an Environmental Agreement to pay NOK 4 per kg of emissions to the NOx Fund are exempt from paying NOx tax for a period of three years. In return, they commit themselves to investigate investments required to reduce NOx and to report back to the Board of the NOx Fund. The Board picks the most cost-effective projects, which may receive 75% of the investment costs from the NOx Fund. The NOx Fund also supports operational costs, such as urea for the Selective Catalytic Reduction (SCR) reactor. The incentive for urea is 1.5 NOK per kg of urea used.

The rates of payment to the NOx Fund in 2020 are NOK 16.50 per kg NOx for the offshore industry (emission connected to oil and gas extraction) and NOK 10.50 per kg NOx for the other sectors (shipping, fishing, land-based industry, aviation, district heating etc.) (NOx-fondet, 2019b)

NOx-fondet (2019a) reported that from 2008 to the end of 2019, the NOx Fund has:

- provided support for approximately 1,330 projects,
- paid over NOK 4.4 billion for NOx-reducing measures,
- reduced over 39,000 tonnes of NOx,
- reduced over 1 million tonnes of CO2,
- contributed to Norway's international commitments to reduce NOx emissions, and
- contributed to significant development and deployment of environmental technology.

Most of the support granted by the NOx Fund has been for projects in the maritime sector, and projects in this sector also account for about 60 % of the emission reductions that have been achieved. Measures to reduce NOx emissions by reducing fuel consumption or switching to other forms of energy also result in lower CO2 emissions. It is estimated that projects supported by the NOx Fund, and projects that have been granted support but not yet carried out, may have reduced annual CO2 emissions by about 400 000 tonnes CO2-eq (Norwegian Ministry of Climate and Environment, 2019a).

A new NOx agreement has been signed for the period 2018-2025, with commitment to reduce NOx emissions by a combined total of 172,510 tonnes for 2024 and 2025.

3.2.4.2.9 Cooperation Between the Authorities and the Business Sector

The purpose of Shortsea Promotion Centre Norway is to obtain and communicate knowledge and act as a forum for information and contact between stakeholders in the transport market. The Centre also plays a role in encouraging cooperation between companies to strengthen short sea transport services. The project is being run by the Ministry of Trade, Industry and Fisheries and the Ministry of Transport. The Maritime

Forum is hosting the project in the period 2018–2023. The maritime transport industry and logistics organisations are included in the steering group for the Centre (Norwegian Ministry of Climate and Environment, 2019a).

The Green Shipping Programme is a private-public partnership that was established in 2015 on DNV GL's initiative. The vision for the programme is to establish the world's most efficient and environmentally friendly coastal shipping fleet.

The Green Shipping Programme aims to find scalable solutions for efficient and environmentally friendly shipping. The results will be cost-effective emission cuts, economic growth, increased competitiveness, and new jobs in Norway. Both authorities and industry actors participate in the programme and are working together to achieve these goals.

In the first phase, which started in 2015, the potential for battery and gas-based maritime transport in Norway was assessed. In the second phase, which started in spring 2016, business cases were developed. The programme has defined possible regulatory and financial incentives and instruments. The third phase of the programme started in 2018 and was focused on eliminating barriers to zero- and low-emission solutions in shipping. In addition, detailed implementation plans will be developed. In the fourth phase of the programme, up to 2030, its stakeholders will seek to scale up the solutions that have been developed through pilot projects.

The programme's studies and pilot projects are helping to identify and develop zero- and low-emission solutions that can be put into practice rapidly. NOK 7 million was allocated to the Green Shipping Programme in the 2019 budget (Norwegian Ministry of Climate and Environment, 2019a).

Pilot projects include the following (See Appendix A for details) (DNV-GL, 2020):

1. Logistics 2030
2. Maritime transport of raw building material and grain
3. Fleet renewal, next generation coastal bulk carrier
4. Port transition barometer
5. Hydro(gen)ship
6. Multimodal transport system with autonomous sea drones
7. Hydrogen by the sea
8. Environmental Port Index (EPI)
9. Green financing solutions

10. Green smart vessel
11. Plug-in hybrid fishing vessels
12. Sea-based transport system for fresh fish
13. Biodiesel-powered plug-in hybrid ferry
14. Hydrogen powered passenger boat
15. Autonomous battery-powered container ship
16. Battery hybrid shuttle tanker
17. Hybrid aquaculture vessel
18. Green port

3.2.4.2.10 Ship Registers

Norway has two ship registers, NIS and NOR. Attractive ship registers are important for Norway's position internationally and for the competitiveness of the Norwegian shipping industry. The Norwegian Maritime Authority is responsible for ensuring that there are predictable, effective processes for approving and certifying ships that use innovative climate and environmentally friendly technology. The Norwegian government will consider whether to introduce incentives for zero- and low-emission ships in the NIS and NOR ship registers (Norwegian Ministry of Climate and Environment, 2019a).

This is aimed to promote the implementation of environmental measures for the existing fleet under the Norwegian flag and to encourage owners to register zero- and low-emission ships in the Norwegian registers. Incentives could include better services from the Norwegian authorities and financial advantages, such as lower fees.

3.2.4.2.11 Environmental Requirements in Public Procurement Processes

The inclusion of environmental requirements in procurement processes by Norwegian government agencies and county authorities, combined with support from funding agencies, such as Enova and the NOx Fund, has proved to be effective in promoting the development of zero- and low-emission ferries. In Norway, public agencies are carrying out procurement processes in a way that reduces harmful environmental impacts and promotes climate-friendly solutions (Norwegian Ministry of Climate and Environment, 2019a).

Similarly, funding from Enova and PILOT-E scheme as well as innovation contracts are being used in Norway to drive hydrogen innovation. The Norwegian government will also ensure that requirements in public procurement processes combined with grant schemes can also be used as a means of realising emission-free solutions for public high-speed vessel services wherever feasible.

In addition, the Norwegian government will prepare an action plan to increase the proportion of green public procurement and green innovation processes, for example, by improving advisory and capacity building services provided by the Agency for Public Management and eGovernment. The government will, whenever feasible, ensure the inclusion of requirements relating to zero-emission transport in public procurement processes and open opportunities and provide incentives to develop and deploy zero-emission vehicles and vessels. Such requirements must not be designed in a way that weakens the competitive position of maritime transport relation to freight transport by road (Norwegian Ministry of Climate and Environment, 2019a).

3.2.4.2.12 Innovative Procurement

The public procurement legislation allows buyers and suppliers to cooperate on innovative procurement. Contracting authorities can encourage innovation by engaging in market dialogue and using open specifications describing functional requirements (Norwegian Ministry of Climate and Environment, 2019a).

3.2.4.2.13 Innovative Partnership

Innovative partnership is one of several types of procurement procedures that can be used to promote innovation and the development of new products and solutions that are not currently commercially available. In an innovative partnership, innovative solutions are developed through a public-private partnership. The contracting authority can then choose to purchase the solution that has been developed. Innovation Norway provides support for innovation in public procurement through its innovation contract scheme, which makes grants available to public-private development contracts such as innovation partnerships (Norwegian Ministry of Climate and Environment, 2019a).

3.2.4.2.14 The National Programme for Supplier Development

The National Programme for Supplier Development was setup to promote innovation in public procurement, and climate and transport are priority areas for the programme. It involves collaboration between the Confederation of Norwegian Enterprise, the Norwegian Association of Local and Regional Authorities, the Agency for Public Management and eGovernment, Innovation Norway and the Research Council of Norway (Norwegian Ministry of Climate and Environment, 2019a).

3.2.4.2.15 Common Approach to the Cruise Industry by Norwegian Ports

Thirteen large cruise ports in Norway have recently agreed on a common approach to the cruise industry, with 14 joint measures to reduce emissions and make ports greener (Norwegian Ministry of Climate and Environment, 2019). Some of these joint measures include:

- requiring cruise ships in Norwegian fjords, vulnerable areas in Norwegian waters and Norwegian cruise ports to operate in accordance with the requirements that apply to shipping in the West Norwegian Fjords World Heritage Site;
- introducing a joint requirement for cruise ships to use onshore power in all Norwegian cruise destinations with effect from 2025;
- introducing a joint requirement for emission-free operation of cruise ships, including ships entering and leaving port, as soon as this is technically feasible;
- from 2021, give priority when allocating slots and berths to cruise ships that can document that they have implemented climate and environmental measures;
- work together for annual stepwise increases in central government fees for the use of fairways for cruise ships that do not use onshore power when at berth in ports where it is available;
- make annual stepwise increases in municipal harbour dues for cruise ships that do not use onshore power when at berth in ports where it is available; and
- advocate new legislation providing the legal authority for ports to restrict the number of cruise passengers per day and the number of cruise ships calling per day.

3.2.4.2.16 Green Barometer

DNV GL was commissioned by the Ministry of Climate and Environment to survey the technology status of different vessel categories in Norway's domestic fleet. The results of the survey can be considered as a 'green barometer' of the speed of change in the shipping industry. The barometer shows the status for implementation of low- and zero-emission technology in the current fleet and what changes are expected in the next few years, based on the order book for the Norwegian fleet. Figure 1 is an output of the DNV GL study.

3.2.4.2.17 Voluntary Initiatives

The Maersk Group recently announced the company's target of making its fleet carbon-neutral by 2050. To achieve this goal, carbon neutral vessels must be commercially viable by 2030, and an acceleration in new innovations and adaption of new technology is required. This will require transforming to new carbon neutral fuels and supply chains.

Currently, Maersk´s relative CO2 emissions have been reduced by 46% (baseline 2007), approximately 9% more than the industry average. Over the last four years, Maersk had invested around USD 1 billion and engaged 50+ engineers each year in developing and deploying energy efficient solutions. Going forward Maersk cannot do this alone. Research and Development are key to developing innovative green solutions. Maersk hopes to generate a pull towards researchers, technology developers, investors, cargo owners and legislators that will activate strong industry involvement, co-development, and sponsorship of sustainable solutions (Maersk, 2018).

For offshore supply vessels, Equinor includes requirements to use battery-hybrid vessels and shore power and to implement energy efficiency measures when entering new long-term contracts. Equinor also introduced an incentive scheme under which savings from reductions in fuel consumption are shared with the shipping company (Norwegian Ministry of Climate and Environment, 2019a).

3.3 Targets and Rationale of Targets

The current Norwegian climate targets and regulations were reviewed in Sections 3.1 and 3.2. The current climate targets for the Port of Oslo were reviewed in Section 2.2. Some new targets on the horizon are summarized in this section.

Under the Paris Agreement, Norway will reduce emissions by at least 50% and towards 55% by 2030, compared with the 1990 level (established in February 2020). Norway is working towards joint fulfilment of this target with the EU. Emissions that fall outside the scope of the EU Emissions Trading System (EU ETS) are to be reduced by 45% by 2030 compared with the 2005 level (Norwegian Ministry of Climate and Environment 2019a). (This may be revised considering the new emissions target.)

At IMO, a two-pronged approach is used to address GHG emissions from international shipping through regulatory work supported by capacity-building initiatives (International Marine Organization, 2020e). First, IMO has adopted regulations to address the emission of air pollutants from ships and has adopted mandatory energy-efficiency measures to reduce emissions of greenhouse gases from international shipping, under Annex VI of IMO's pollution prevention treaty (MARPOL). (Section 3.2.1 of this report). Second, IMO is engaging in global capacity-building projects to support the implementation of those regulations and encourage innovation and technology transfer.

Building on this approach, IMO adopted an Initial IMO Strategy on reduction of GHG emissions from ships in April 2018. It sets the level of emission reduction by at least 50% by 2050 compared with the 2008 level. The vision is to phase out greenhouse gas emissions from the industry as soon as possible in this century. The IMO strategy also includes ambitions (1) to improve the energy efficiency of each ship and (2) to reduce the carbon intensity of the whole sector by reducing emissions per unit of transport work done by at least 40% by 2030 and further towards 70% by 2050. Figure 19 shows the IMO strategy. (Norwegian Ministry of Climate and Environment 2019a).

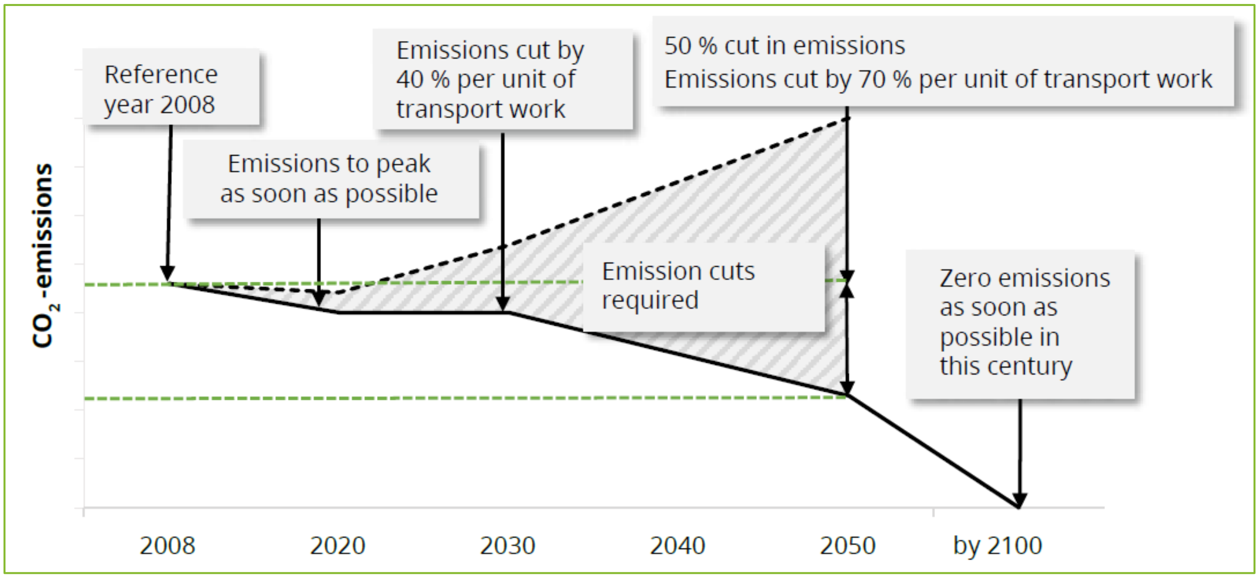


Figure 19. IMO's vision and levels of ambition for greenhouse gas emissions. The dotted line shows the projected emission trend under a business-as-usual scenario. The solid line shows an emission trajectory in line with IMO's strategy (Norwegian Ministry of Climate and Environment 2019a).

According to the Norwegian Ministry of Climate and Environment (2019a), Norway's international efforts are based on three main priorities below. These priorities are reflected in information summarized in earlier sections.

1. Norway intends to be a driving force in efforts to strengthen IMO's environmental protection rules and will promote the adoption of Norwegian innovations as the international standard. Norway chaired the negotiations that resulted in the climate strategy adopted by IMO in April 2018.

2. Norway will pursue an ambitious national policy for the development of low- and zero-emission solutions with global potential. Some countries must lead the way to ensure that the global targets are achieved, both to demonstrate possibilities and to develop technology that has a potential for global diffusion.

3. Norway will use aid funding to assist developing countries to make the necessary changes in their shipping sectors. NOK 10 million has been allocated for this purpose in the 2019 budget, and Norway plans to increase its efforts in the years ahead.

Rationale for Norwegian Climate Targets

Fuel efficiency

Rationale for improving fuel efficiency is to reduce all fuel induced emissions to air (e.g. CO2, NOx, SOx, PM etc.). (Norwegian Maritime Authority, 2016b)

CO2 emission

Rationale for reducing CO2 emission is to target main emission sources of ship operations, including combustion of fossil fuels in main and auxiliary engines, boilers, incinerators and firefighting systems. (Norwegian Maritime Authority, 2016b)

SOx emissions

Rationale for reducing SOx emission is because marine fuels typically have higher sulphur content compared to fuels used on land. In Europe, marine fuels constitute approximately 20% of SOx emitted. However, the share of SOx emission from marine operations is expected to grow in the future as land-based sources reduce their SOx emission more relative to shipping. (Norwegian Maritime Authority, 2016b)

NOx emissions

Rationale for reducing NOx is because shipping is one of the major sources of man-made NOx emissions in Norway. Domestic shipping and fishing account for about a third of the total emissions. (Norwegian Maritime Authority, 2016b)

NOx, formed in the heat of the marine engine, is a dangerous, acidic pollutant that can be transported over many hundreds of miles and deposited as acid rain. It promotes the formation of ground level ozone, detrimental to human health and is known to exacerbate heart and lung complaints. NOx acidifies its environment and damages plant life in the sea and on land (IACCSEA, 2019). The harmful effects of NOx include:

- toxic and acidic local pollutant,
- detrimental to human health,
- damages plant life in the sea and on land, and

- 50 billion euro in expected social cost of NOx pollution from shipping in Europe alone in 2020

VOC emissions

Rationale for reducing VOC emissions is because the handling of oil products is the most significant emission source related to shipping. In Europe, the most important source of VOC emissions is from loading of crude oil onto tankers. VOCs are also generated during combustion. Additional gas may also be released from the cargo during the voyage that causes the tank pressure to exceed the limit of the pressure relief valves, and tank gas containing VOCs are emitted. Furthermore, inert gas is added to the cargo tanks during unloading, which affects the amount of VOCs in the tanks after unloading is completed. Most of the remaining VOCs are emitted during the loading operation (Norwegian Maritime Authority, 2016b).

4 Economics for the Changes

4.1 Incentives and Other Measures by Vessel Categories

The information on incentives and measures by vessel categories was provided by Norwegian Ministry of Climate and Environment (2019a).

4.1.1 Scheduled Passenger Vessels and Ferries

In Norway, the Norwegian government is responsible for procurement of ferry services through the Norwegian Public Roads Administration for the national road system. The remaining ferry services are part of the county road system and procurement is the responsibility of the county authorities.

In 2016, the Norwegian government provided NOK 20 million grants to build up expertise in municipality and county authorities, so they could include environmental requirements in their procurement processes for ferries and high-speed vessels.

In 2018, the Norwegian government provided NOK 100 million to counties in non-earmarked funding to strengthen the ferry and high-speed vessel sector. The allocation was repeated in 2019.

Enova also allocated NOK 665 million in grants towards charging infrastructure for electric ferries, making it possible for counties to include stricter environmental requirements in their calls for tenders. Currently, 33 routes are partly or all electric. The Norwegian government will continue to facilitate the rapid deployment of charging infrastructure throughout the country using a combination of public funding and market-based solutions.

It is more costly for the counties to procure battery-propelled ferries than conventional ferries. Operating battery-propelled ferries will reduce the costs of some services but increase the costs of others. DNV-GL estimated that the net additional cost in using zero- and low-emission ferries is about 5% for the contract period than new diesel ferries. The costs vary between ferry services and whether the ferry company has support from the NOx Fund. The Norwegian government will consider the higher costs to provide ferry and high-speed passenger services with requirements to have zero- and low-emissions when revising the revenue system for the counties.

As an example of innovative procurement, the Norwegian Public Roads Administration awarded an innovation contract to develop a zero-emission solution for a ferry service where all-electric operation is not suitable. A hydrogen-electric ferry can be used instead where electricity supplies are limited or if the service requires too much energy. The Norwegian Maritime Authority and the Norwegian Directorate for Civil Protection have drawn up a framework for approval of hydrogen vessels. The Directorate for Civil Protection will prepare guidelines for onshore handling of hydrogen and bunkering ships.

In addition, the Coastal Administration can make use of instruments such as differentiating rates of maritime safety fees on environmental grounds and innovation procurement.

The inclusion of environmental requirements in procurement processes by Norwegian government agencies and county authorities, combined with support from funding agencies, such as Enova and the NOx Fund, has proved to be effective in promoting the development of zero- and low-emission ferries. The rapid deployment of green solutions in the ferry sector is an important step in the green transition in the maritime sector. The results are widely applicable in other parts of the maritime industry. For example, in the case where the ferry uses liquid hydrogen, it will help Norway to gain experience in using liquid hydrogen.

The Norwegian government will also ensure that requirements in public procurement processes combined with grant schemes can also be used as a means of realising emission-free solutions for public high-speed vessel services wherever feasible. In 2019, the government allocated NOK 25 million to support the development of zero- and low-emission high-speed vessels.

In 2018, Trøndelag county awarded innovation contracts for the development of zero-emission high-speed vessels, with aim to publish a call for tenders of the world's first zero-emission high-speed vessels in early 2020s. Experience gained will also be used to scale up hydrogen solutions.

4.1.2 Cruise Ships and International Passenger Ferries

Norway introduced strict emission regulations in the UNESCO World Heritage fjords because air pollutants have significant adverse impacts on air quality and public health. Air pollutants are also unsightly and have negative impacts on the characteristics that justified the inscription of the fjords on the UNESCO World Heritage List. Shipping in the fjords is prohibited from using heavy fuel oil, except for ships with closed loop scrubbers.

While abatement technology makes it possible for current ships to comply with environmental regulations, reducing greenhouse gas emissions will require the implementation of new solutions. Several new passenger ships are being built with LNG engines. Liquefied biogas (LBG) can directly replace or be mixed with LNG using existing infrastructure and engine technology. This will reduce greenhouse gas emissions and local air pollution.

Enova has provided funding for a highly effective propulsion system and hybrid technology on Hurtigruten's new exploration ships. Hurtigruten has announced that it will be introducing LBG as a fuel for the ships sailing the coastal route Bergen–Kirkenes. Enova has also supported Havila Kystruten's four new ships so they can maximize energy recovery and re-use. Enova's initiative for the development of shore power makes it possible for large passenger ships to shut down their engines while in port.

The Norwegian government will continue to seek reduction in GHG emissions and local air pollution from cruise ships in Norwegian waters; require cruise ships and ferries sailing in West Norwegian Fjords World Heritage Site to be emission-free as soon as it is technologically feasible, and the latest by 2026; consider extending the environmental requirements for shipping in the West Norwegian Fjords World Heritage Site to other fjords in Norway.

4.1.3 Cargo Vessels

There are two groups of cargo vessels – (1) non-bulk cargo vessels that carry breakbulk, containers and refrigerated /frozen goods and (2) tankers and bulk carriers, which carry bulk commodities, either wet or dry. Tankers and bulk carriers are generally larger and newer than non-bulk cargo vessels. The ships that are responsible for the largest share of domestic emissions are smaller and older than the average. So, renewal of the cargo fleet is of crucial importance in the development of environmentally friendly freight transport in Norway and funding must be available both for refitting and purchasing new ships. Also, a policy that ensures the introduction of zero- and low-emission solutions for cargo vessels in short sea shipping will contribute greatly to achieving IMO's emission targets.

In addition, increasing the degree of hybridisation by installing batteries and energy recovery during cargo handling is resulting in lower emissions and lower operating costs. Enova's support for projects in this area is helping to bring about a market change so that solutions of this type gradually become standard.

However, shipping companies' activity and earning power are the basis for fleet renewal on ordinary commercial terms. The Norwegian short sea shipping fleet, including non-bulk cargo vessels, tankers and bulk carriers, tends not to operate under long-term contracts and includes many small companies. Margins are small especially for small general cargo vessels. Thus, it is difficult for companies to accumulate enough investment capital for renewal projects. The creditworthiness of the short sea shipping companies is the greatest barrier to using the existing industry-oriented government funding instruments and to obtain commercial funding for shipbuilding.

On the other hand, Norway also has an ambition to transfer 30% of goods transported over distances of more than 300 km from road to rail and sea by 2030.

The Norwegian government will identify challenges in funding green fleet renewal for the short sea cargo fleet; review options available for green fleet renewal in current funding instruments; use incentive schemes for short sea shipping to reduce total emissions from freight transport; include zero-emission requirements in public procurement processes; and take steps to realise the ambition of a shift in freight transport from road to rail and sea.

4.1.4 Offshore Support Vessels

This category of vessels includes platform supply vessels and other types of offshore support vessels, for example, oil spill response vessels, anchor handling tug vessels, offshore construction vessels and pipe laying vessels. Offshore support vessels are relatively new, with an average age of about 12 years.

The offshore shipping companies and the oil companies have been developing more energy-efficient vessels by introducing battery hybridisation, using LNG as a fuel and testing immature technologies. For example, Equinor includes requirements to use battery-hybrid vessels and shore power and to implement energy efficiency measures when entering new long-term contracts. The company also introduced an incentive scheme under which savings from reductions in fuel consumption are shared with the shipping company.

Enova has awarded grants for battery hybridisation of several vessels used in offshore oil and gas and offshore wind industries. There are examples of battery-hybrid vessels being built in Norway and other countries without public funding, which indicates that the market is developing in the right direction. Also, Enova's shore power initiative is reducing emissions from vessels in port.

The government will consider introducing requirements to use zero- and low-emission solutions for new support vessels. The introduction of environmental requirements may result in more rapid phase-in of low- and zero-emission solutions than is being achieved with the carbon tax and existing grant schemes.

4.1.5 Specialised Vessels including Aquaculture Service Vessels

This category of vessels includes well boats, fish feed barges, various types of service boats, research vessels, seismic survey vessels, tugboats and government vessels. Well boats are used to transport live farmed fish and smolt.

The carbon tax and support from Enova gave the aquaculture industry incentives to develop and deploy low- and zero-emission solutions. Also, the Norwegian Food Safety Authority's new wastewater treatment requirements for well boats will enter into force in 2021. This will likely result in a generational shift in the fleet because it is not practical to retrofit older well boats.

Enova had provided support for several aquaculture-related projects, including grants for workboats and well boats and shore power initiative. For example, the world's first battery-hybrid workboat for the fish farming industry was launched in 2017, and a battery-hybrid fish processing and transport vessel is also in operation.

The Norwegian government will consider introducing requirements for zero- and low-emission solutions in aquaculture service vessels. Norway is speeding up the phase-in of new technologies and solutions through a combination of support from funding agencies, the use of environmental requirements and regulatory measures.

For government vessels, Norway's procurement legislation requires contracting authorities to give weight to environmental considerations in procurement processes. The same applies to tugboats and other vessels that are hired for government contracts.

4.1.6 Fishing vessels

Fishing vessels are divided into two groups – coastal vessels and ocean-going vessels based on size and partly on their fishing rights and the fishing gear they carry. There is a refund system for part of the carbon tax on fuel bought for use in fisheries less than 250 nautical miles from the coast. From the refund application, the amount of fuel involved is available. Thus, it is possible to calculate fuel consumption and emissions. This is used to supplement the Norwegian AIS emission inventory.

Enova has supported many projects in the fisheries sector. It allocated more than NOK 25 million to Batsfjord port for onshore power. Enova also provided grants for various technological measures on vessels, including battery-hybrid propulsion, heat recovery, electrification of fishing gear and other climate- and energy-related measures. These projects are also part of an initiative to develop value chains for zero-emission technology, such as batteries and charging infrastructure that can lead to lasting market change.

A committee including industry representatives was appointed to consider the possibility of gradually increasing the carbon tax rate for the fishing industry and to propose other measures to reduce greenhouse gas emissions. The committee has completed its report. The Norwegian government will follow up the recommendations of the committee. If the recommendations do not result in lasting emission reductions, exemptions from the carbon tax and reduced tax rates will be abolished in 2020.

4.1.7 Recreational Crafts

Norwegian households own more than 600,000 motor and/or sailing boats. Petrol for use in recreational craft is subject to the carbon tax and road use duty. Diesel is subject to the carbon tax and the basic tax on mineral oil. The Norwegian government has announced that the carbon tax rate will be increased by 5 % per year from 2020 to 2025.

There is currently a limited choice of off-the-shelf models of recreational craft and boat engines based on zero- and low-emission technology. More knowledge is needed to determine how to reduce emissions from recreational craft. So, the Norwegian Environment Agency is compiling a knowledge base on emissions and emission reduction potential for non-road mobile machinery, including recreational craft. The Norwegian government will review emissions from recreational craft and the emission reduction potential, as well as consider policy instruments to promote zero- and low-emission solutions.

4.2 Incentives and Other Measures for Ports

In 2019, the Norwegian government allocated NOK 50 million to a temporary three-year grant scheme for investments in environmentally friendly ports. The purpose of the scheme is to use investments in ports to make the logistic chain more efficient, which will result in reducing transport costs, shifting freight transport from road to sea, and contributing to climate and environmental benefits.

Battery hybridisation opens the way for charging from onshore sources and partial electrification of operations. For example, the new ferry route for the Sandefjord–Strømstad in the Port of Oslo will be running on battery power for part of the crossing.

Onshore power for cruise ships is a high-cost mitigation measure compared with onshore power for vessels in ordinary traffic. Until recently, projects of this kind have not been successful in obtaining funding from Enova. In order to be eligible for support from Enova, municipalities or other stakeholders must share a larger portion of the cost, like the Port of Bergen. The Port of Bergen is building an onshore power facility for cruise ships from 2020. Enova granted NOK 50 million towards the facility.

The Port of Kristiansand also opened Europe's largest onshore power facility for cruise ships in 2018. The Port of Oslo has recently opened its shore power facility, which serves the Stena Line and DFDS ferries. Color Line's ships already run on shore power in Oslo.

In addition, 13 cruise ports in Norway are taking a common approach to the cruise industry, with 14 joint measures to reduce emissions and make ports greener (Section 3.2.4. Funding and Other Initiatives).

4.3 Certificate or Incentive Programs Similar to Green Marine

4.3.1 Global Incentives

4.3.1.1 Environmental Ship Index (ESI)

Key ports in the world are committed to reducing emissions from ships through the World Ports Sustainability Program (WPSP). Within WPSP, the Environmental Ship Index (ESI) identifies ships that perform better in reducing air emissions than required by the current IMO requirements. ESI evaluates the amount of nitrogen oxide (NOx) and sulphur oxide (SOx) that is emitted by a ship. It includes a reporting scheme on the greenhouse gas emissions from the ship.

The main characteristics of ESI are as follows (World Port Sustainability Program, 2019):

- It is a voluntary system designed to improve the environmental performance of oceangoing vessels.
- It gives a numerical representation of the environmental performance of ships regarding air pollutants and CO2.
- It scores NOx and SOx emissions directly and proportionally and gives a fixed bonus for documentation and management of energy efficiency.
- It only includes ships that perform over and above current international legislation (IMO).
- It enables ports and other interested parties to stimulate ships to improve their environmental performance.
- It is straightforward and simple in approach and presentation.
- It can be applied to all types of oceangoing ships.
- It is automatically calculated and maintained.
- It is free of charge for ship owners.

The intent of the Index is for ports to use the ESI to differentiate and reward ships, as well as to promote green shipping. It can also be used by shippers and ship owners as their own promotional instrument (World Port Sustainability Program, 2019). This is similar to the Green Marine environmental certification program.

Participation in the ESI is on a voluntary basis. Ships that participate provide data to the ESI. Using the data, each ship is rated and awarded a certificate that serves as the basis for environment-based discount on the tonnage charges payable. Currently, over

8,000 ships and 50 international ports are participating in ESI (IACCSEA, 2019 and World Port Sustainability Program, 2019).

Several Norwegian ports have introduced discounts for green ships based on information from the Environmental Ship Index (ESI). Port of Alesund, Port of Bergen, Port of Flåm and Gudvangen, Port of Florø (Alden), Port Authority of Fredrikstad and Sarpsborg, Karmsund Port Authority, Port of Drammen, Port of Trondheim, StormGeo (Oslo), Port of Oslo, Port of Kristiansand, Norwegian Coastal Administration (Kystverket) and Port of Stavanger are participants of ESI. In Canada, only two ports are participating in the ESI – Prince Rupert Port Authority and Vancouver Fraser Port Authority (Port of Vancouver).

4.3.1.2 Green Award

The Green Award is a certification and incentive program for shipping. Green Award certifies ships that go above and beyond the industry standards in terms of safety, quality and environmental performance, acts as a quality mark and brings benefits to its holders. Holders of a Green Award certificate reap various financial and non-financial benefits, such as discount on port dues (typically 5-6%), discount on services, discount on products, special extra services or products, promotion, charter preference, lower insurance premiums, better reputation, motivation and pride of the crew etc.

Green Award is open to oil tankers, chemical tankers, dry bulk carriers, container carriers and inland navigation vessels. The certification procedure is carried out by the Bureau Green Award, the executive body of the independent non-profit Green Award Foundation. Criteria related to air emissions can contribute a maximum of 10% of the total number of ranking points available. Points are awarded for NOx emissions of no more than 17 g/kWh. (IACCSEA, 2019, Green Award, 2019).

The key benefits of Green Award are shown in Figure 20. The Green Award features are as follows (Green Award, 2019):

- established in 1994;
- non-profit, independent, international;
- quality mark for high performing vessels;
- own in-house developed requirements;
- a network of ports, ship managers, charterers, maritime service providers and authorities;

- governed by the key industry representatives;
- for both ocean and river;
- audits and certifies ships and shipping companies;
- 30+ countries in Europe, Asia, Africa, Australia and South and North Americas participate;
- over 900 ships certified (inland and sea) and over 140 incentive providers which include ports and maritime service providers participate; and
- Corporate Social Responsibility (CSR) tool for ports and companies.

The Green Award is an active member and Incentive Provider to Environmental Ship Index (ESI). The Green Award integrates the ESI initiative into the Green Award checklist requirements.

Figure 20. Benefits of Green Award (Green Award, 2019)

Currently, Teekay Shipping Norway AS, KNOT management AS, OSM Ship Management AS are certified Green Award companies in Norway (Green Award, 2019). Green Award is another certification scheme that is similar to the Green Marine environmental certification program.

4.3.2 Norwegian Incentives

4.3.2.1 Environmental Port Index (EPI)

From 2019, a consortium of Norwegian cruise ports, in collaboration with DNV-GL, developed a new approach in characterising cruise ships' environmental imprint called Environmental Port Index (EPI). This index was developed in Norway as a pilot project in the Green Shipping Programme (See Appendix A for more details). It is an incentive to introduce environmentally friendly solutions for shipping (Norwegian Ministry of Climate and Environment, 2019a).

EPI awards a score to each cruise ship for each call based on a defined evaluation of that vessel's environmental performance while in port. This score is subsequently converted into an adjustment factor applied to the port fees. The aim is to reward responsible environmental performance (Port of Bergen, 2019).

Upon departure, each ship completes a web-based form, providing information about energy consumption and other details. The data is reported into a central database held at DNV-GL, who acts as a hub for data collection, quality control and index (score) calculation (Figure 21). Only the ports will have access to the final score of the ship.

Several ports are introducing a system of rebates based on the Environmental Port Index. For example, the Port of Bergen links the EPI with fees regarding cruise ship arrival in the Port of Bergen. This includes quay dues, passenger fees, ISPS-fee and fairway dues.

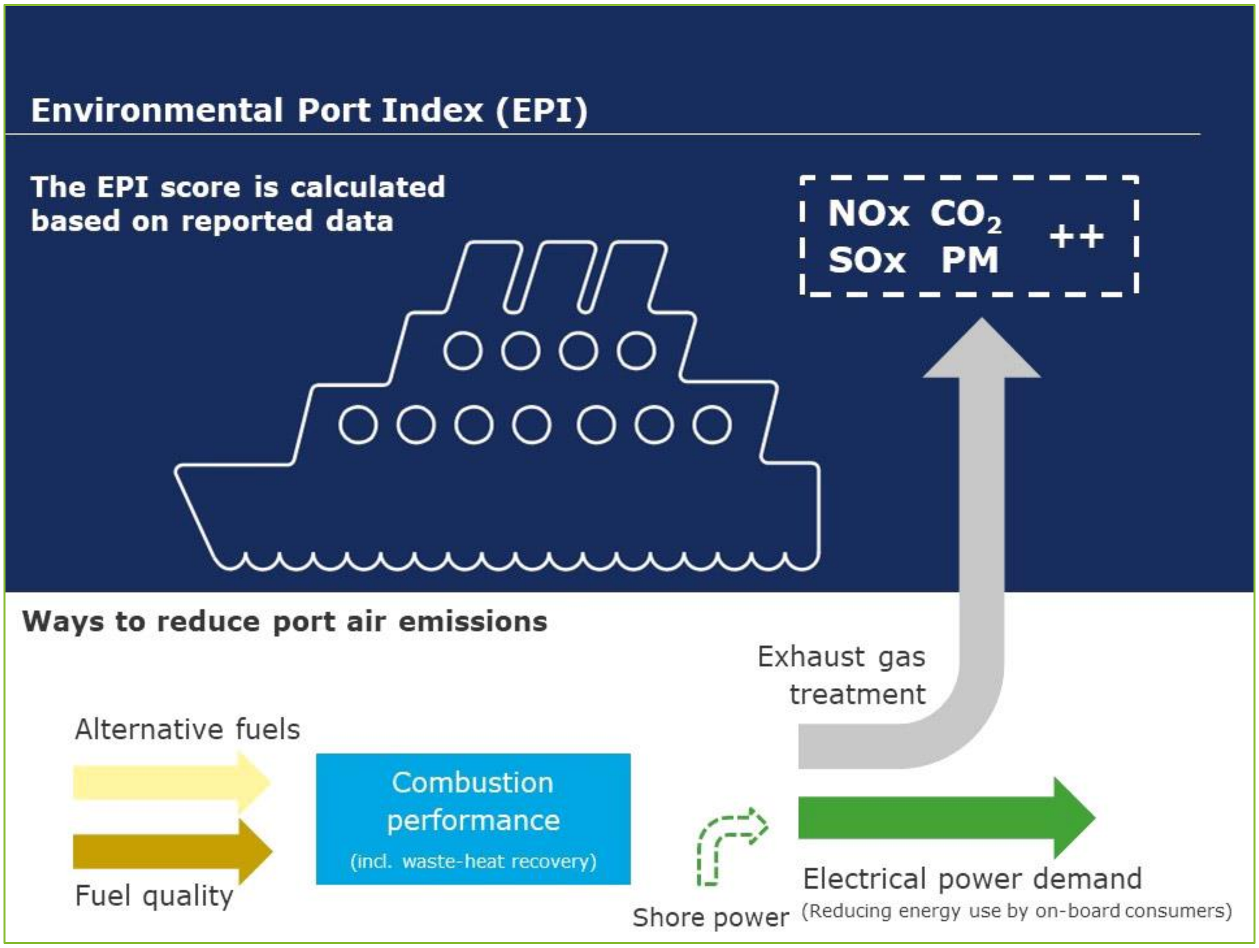


Figure 21. Environmental Port Index (DNV-GL, 2020)

4.4 Economics

Bunker prices at international ports are readily available from paid services such as Ship & Bunker (https://shipandbunker.com/prices), BunkerEx (https://www.bunker-ex.com/), BunkerWorld (https://www.bunkerworld.com/prices/) etc. However, this study is limited to researching free public domain data. It was determined that fuel pricing information specific to Norway is extremely limited on public domain, and the information presented in this study could only provide a general picture of price differences for different types of fuel. If detailed pricing at a given time and historical pricing are needed for cross comparison between ports or jurisdiction, it is recommended that paid services be used.

The bunker fuel prices for the Port of Bergen in Norway and the Port of Vancouver are shown in Figure 22 and Figure 23 respectively (Oil Monster, 2020). Bunker fuel prices for the Port of Bergen are presented because prices for the Port of Oslo were not found.

BERGEN BUNKER FUEL PRICES				
COMMODITY	PRICE	CHANGE	UNIT	UPDATED
IFO 180	481.00	29(6.42%)	$US/MT	09 May 2019
IFO 380	256.00	-325(-55.94%)	$US/MT	11 Nov 2019
MGO	639.00	0(0%)	$US/MT	02 Jan 2020

Figure 22. Port of Bergen bunker fuel prices

VANCOUVER BUNKER FUEL PRICES				
COMMODITY	PRICE	CHANGE	UNIT	UPDATED
IFO 180	373.00	1(0.27%)	$US/MT	31 Dec 2019
IFO 380	232.00	0(0%)	$US/MT	07 Apr 2020
LSMGO 0.1%	337.00	0(0%)	$US/MT	07 Apr 2020
MGO	678.00	5(0.74%)	$US/MT	31 Dec 2019
MGO 0.1%	627.00	-20(-3.09%)	$US/MT	27 Jan 2020
VLSFO 0.5%	307.00	0(0%)	$US/MT	07 Apr 2020

Figure 23. Port of Vancouver bunker fuel prices

IFO180 – Intermediate Fuel Oil with a maximum viscosity of 180 centistokes (<3.5% sulfur)
IFO380 – Intermediate Fuel Oil with a maximum viscosity of 380 centistokes (<3.5% sulfur)
MGO – Marine Gasoil
LSMGO – Low sulphur Marine Gasoil
VLSFO – Very Low Sulphur Fuel Oil

While the update periods do not match exactly between the two ports, the biggest difference in update times (for IFO 180) is still within 8 months of each other. The differences in update times for IFO 380 and MGO are much closer, within 5 months and 2 days between the two ports respectively. A coarse comparison of bunker fuel prices between the two ports shows that IFO 180, IFO 380 and MGO are all more expensive in the Port of Bergen than in the Port of Vancouver.

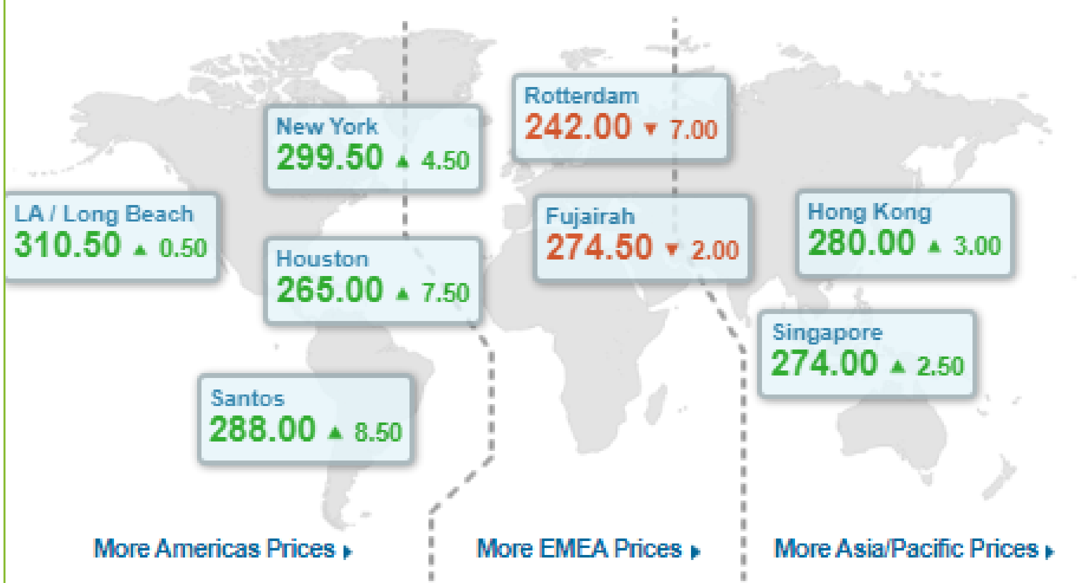
Norwegian Centres of Expertise – NCE Maritime CleanTech (2019) also compared the price of liquid Hydrogen with several other types of marine fuels in Norway (Figure 24). It included current maritime fuels and future alternatives. The prices were for fuel delivered at or near the end user. Prices were based on the industrial knowledge of the project partners and information from suppliers. The price of Ammonia was gathered from ISPT (2017). Some prices were converted from NOK to Euro with a conversion rate of 9,84 EUR/NOK.

Fuel	*Retail price EUR/kg (ex. vat)*[168]	*Calorific value (kWh/kg)*	*Spec. fuel Consumption (g/kWh)*	*Efficiency powertrain*	*Cost in EUR per kWh*	*Corresponding LH_2-price EUR/kg LH_2*
LH_2 Norway	15,4	33,3	60,1	50 %	0,92	**N.A.**
LH_2 Europe	7,1	33,3	60,1	50 %	0,43	**N.A.**
LH_2 US	5,4	33,3	60,1	50 %		**N.A.**
CH_2 (250 bar) Norway	10,2	33,3	60,1	50 %	0,61	**10,2**
MGO	0,61	11,97	185,6	45 %	0,11	**1,9**
Bio-diesel	1,68	10,20	188,3	45 %	0,32	**5,3**
LNG	0,76	12,50	177,8	45 %	0,14	**2,3**
LPG	1,10	12,90	172,3	45 %	0,19	**3,2**
Ammonia (fuel cell)	0,51	5,17	193,4	55 %	0,18	**3,0**
Ammonia (combustion)	0,51	5,17	193,4	50 %	0,20	**3,3**
Methanol	0,8	6,39	313	50 %	0,25	**4,2**

Figure 24. Marine Fuel Price Comparison in Norway

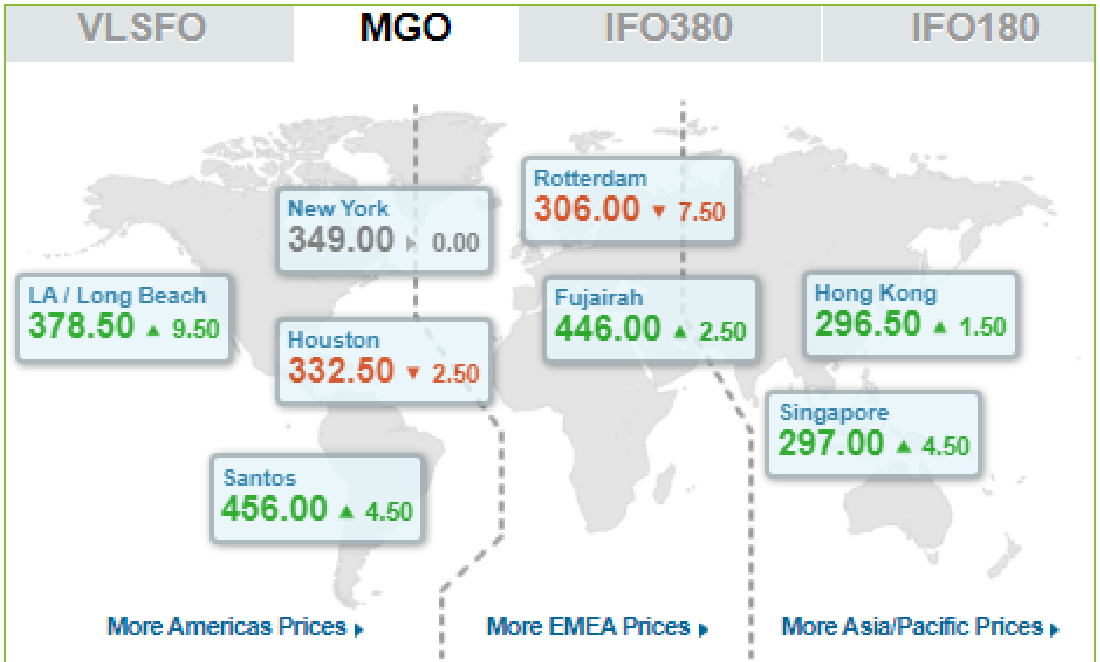
The general price variability of VLSFO, MGO, IFO380 and IFO180 globally on April 7, 2020 are shown in Figure 25 to Figure 28 respectively. The global and regional price variability of VLSFO, MGO, IFO380 and IFO180 on April 7, 2020 are shown in Figure 29.

VLSFO | MGO | IFO380 | IFO180



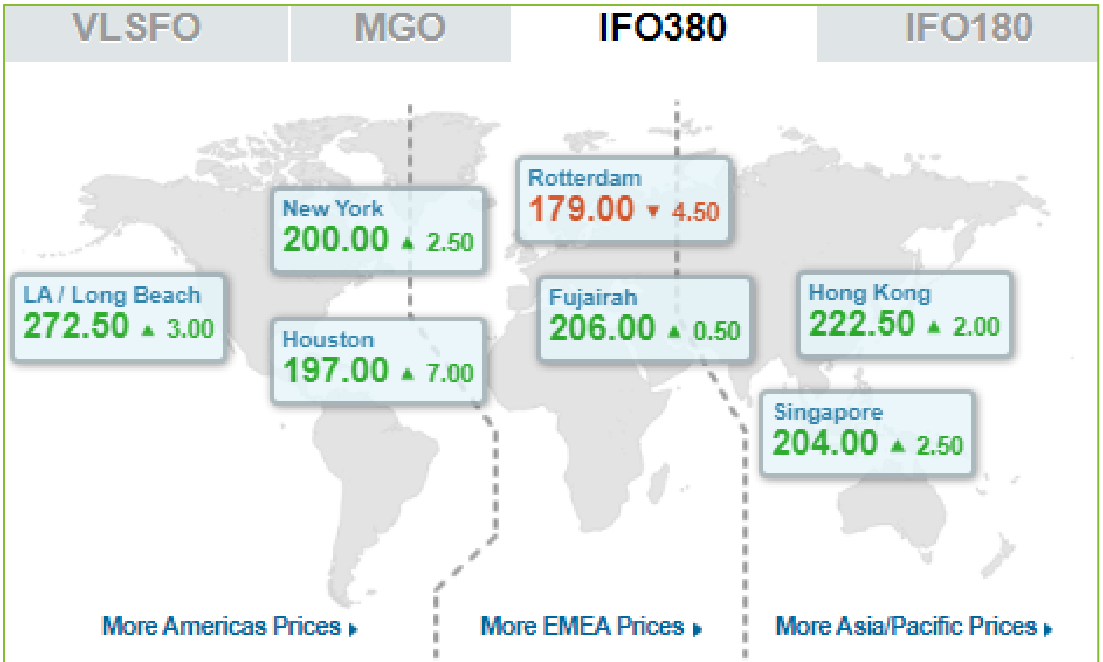
	Price $/mt	Change	High	Low	Spread
Global 20 Ports Average	279.00 ▲	+1.50	279.00	279.00	0.00
Global 4 Ports Average	264.00 ▲	+0.50	264.00	264.00	0.00
Global Average Bunker Price	328.50 ▲	+1.00	328.50	328.50	0.00
Americas Average	363.00 ▲	+1.50	363.00	363.00	0.00
APAC Average	333.50 ▼	-0.50	333.50	333.50	0.00
EMEA Average	298.00 ▲	+1.00	298.00	298.00	0.00
Singapore	274.00 ▲	+2.50	295.00	263.00	32.00
Rotterdam	242.00 ▼	-7.00	260.00	232.00	28.00
Houston	265.00 ▲	+7.50	292.50	236.50	56.00
Fujairah	274.50 ▼	-2.00	300.00	252.50	47.50
LA / Long Beach	310.50 ▲	+0.50	335.00	295.00	40.00
Hong Kong	280.00 ▲	+3.00	291.00	258.00	33.00
New York	299.50 ▲	+4.50	320.00	275.00	45.00
Santos	288.00 ▲	+8.50	290.00	286.00	4.00

Figure 25. General price variability of VLSFO geographically (Ship and Bunker, 2020)



	Price $/mt	Change	High	Low	Spread
Global 20 Ports Average	363.00 ▼	-1.00	363.00	363.00	0.00
Global 4 Ports Average	345.50 ▼	-0.50	345.50	345.50	0.00
Global Average Bunker Price	472.50 ▶	0.00	472.50	472.50	0.00
Americas Average	522.50 ▼	-1.00	522.50	522.50	0.00
APAC Average	490.50 ▲	+0.50	490.50	490.50	0.00
EMEA Average	387.50 ▶	0.00	387.50	387.50	0.00
Singapore	297.00 ▲	+4.50	307.50	280.00	27.50
Rotterdam	306.00 ▼	-7.50	324.00	292.50	31.50
Houston	332.50 ▼	-2.50	350.50	315.00	35.50
Fujairah	446.00 ▲	+2.50	478.00	428.00	50.00
LA / Long Beach	378.50 ▲	+9.50	390.00	367.00	23.00
Hong Kong	296.50 ▲	+1.50	307.50	286.00	21.50
New York	349.00 ▶	0.00	358.00	340.00	18.00
Santos	456.00 ▲	+4.50	458.00	454.00	4.00

Figure 26. General price variability of MGO geographically (Ship and Bunker, 2020)



	Price $/mt	Change	High	Low	Spread
Global 20 Ports Average	217.50 ▲	+2.00	217.50	217.50	0.00
Global 4 Ports Average	196.50 ▲	+1.50	196.50	196.50	0.00
Global Average Bunker Price	261.00 ▲	+17.50	261.00	261.00	0.00
Americas Average	341.50 ▲	+19.50	341.50	341.50	0.00
APAC Average	207.00 ▼	-15.00	207.00	207.00	0.00
EMEA Average	208.00 ▲	+10.00	208.00	208.00	0.00
Singapore	204.00 ▲	+2.50	245.00	185.00	60.00
Rotterdam	179.00 ▼	-4.50	219.00	160.00	59.00
Houston	197.00 ▲	+7.00	206.00	185.00	21.00
Fujairah	206.00 ▲	+0.50	230.00	185.00	45.00
LA / Long Beach	272.50 ▲	+3.00	298.50	257.00	41.50
Hong Kong	222.50 ▲	+2.00	245.00	198.50	46.50
New York	200.00 ▲	+2.50	220.00	182.00	38.00

Figure 27. General price variability of IFO380 geographically (Ship and Bunker, 2020)

	Price $/mt	Change	High	Low	Spread
Singapore	345.00 ▲	+8.00	345.00	345.00	0.00
Rotterdam	320.00 ▲	+10.00	320.00	320.00	0.00
Houston	375.00 ▶	0.00	375.00	375.00	0.00
Fujairah	350.00 ▲	+10.00	350.00	350.00	0.00
LA / Long Beach	529.00 ▲	+1.00	529.00	529.00	0.00
Hong Kong	423.00 ▲	+3.00	424.00	422.00	2.00
New York	383.50 ▼	-10.00	386.00	381.00	5.00

Figure 28. General price variability of IFO180 geographically (Ship and Bunker, 2020)

Global Average Bunker Prices

Port Name	VLSFO	MGO	IFO380	IFO180	
Global 20 Ports Average	279.00 ▲ 1.50	363.00 ▼ 1.00	217.50 ▲ 2.00	-	Apr 07
Global 4 Ports Average	264.00 ▲ 0.50	345.50 ▼ 0.50	196.50 ▲ 1.50	-	Apr 07
Global Average Bunker Price	328.50 ▲ 1.00	472.50 ► 0.00	261.00 ▲ 17.50	-	Apr 07

Regional Average Bunker Prices

Port Name	VLSFO	MGO	IFO380	IFO180	
Americas Average	363.00 ▲ 1.50	522.50 ▼ 1.00	341.50 ▲ 19.50	-	Apr 07
APAC Average	333.50 ▼ 0.50	490.50 ▲ 0.50	207.00 ▼ 15.00	-	Apr 07
EMEA Average	298.00 ▲ 1.00	387.50 ► 0.00	208.00 ▲ 10.00	-	Apr 07

Figure 29. Global and regional average bunker price (Ship and Bunker, 2020)

Bergen and Omland Port Authority (2018) conducted a study on onshore power supply for cruise ships in the Port of Bergen. They concluded that onshore power could be sold to ships at an average price of around EUR 115 per MWh (or NOK 1278 per MWh or NOK 1.278 per kWh.). The rational of this average price of EUR 115 per MWh is documented below.

Box 3: Electricity price for sales to cruise ships (Bergen and Omland Port Authority, 2018)

The price of electricity produced by ships' auxiliary engines based on MGO is assumed to be EUR 125 per MWh. A shift from using MGO to shore power while at berth requires the ship owners to invest in onboard OPS equipment on their cruise vessels. This involves a cost for the ship owners and it is assumed that the ship owners must be provided with an incentive to bear these costs. In the business cases, it is assumed that ship owners need a cost reduction of around 10 percent to accept shore power. Based on this, it is expected that shore power could be sold to ships at an average price of around EUR 115 per MWh in the five ports.

It may be that ship owners are willing to accept a higher sales price of electricity than assumed in the business cases. A desire to demonstrate environmental responsibility or offer increased comfort to its passengers in the form of reduced noise and pollution while at berth could be possible reasons for increased willingness to pay for shore power. It is also likely that total electricity charges in different ports will affect ship owners' willingness to pay for electricity. In ports with relatively low total electricity charges it can be expected that cruise vessels willingness to pay is lower than in ports that face higher total electricity charges.

Figure 30 shows the household and non-household electricity rate in European countries between 2017 and 2019. The non-household electricity rate in Norway in 2019 was 0.0829 euro per kWh (or NOK 0.93 per kWh) (Eurostat, 2020 and Statistics Norway, 2020).

Figure 31 shows a comparison of the electricity price for industrial consumers of different countries in Europe in 2015 (Eurostat, 2017), with indication of production cost, network costs and taxes and levies. In 2015, the electricity price for industrial consumers in Norway was about 75 euro per MWh (or NOR 840 per MWh or NOK 0.84 per kWh).

The port purchase price of electricity in 2019 and projected price in 2030 for different European ports are shown in Figure 32 (Bergen and Omland Port Authority (2018). The total electricity price paid by the Port of Bergen in 2019 was about 100 Euro per MWh (or NOK 1120 per MWh or NOK 1.12 per kWh) and over half of the rate paid is related to full grid tariff.

Electricity prices, first semester of 2017-2019
(EUR per kWh)

	Households (¹)			Non-households (²)		
	2017S1	2018S1	2019S1	2017S1	2018S1	2019S1
EU-28	0.2043	0.2066	0.2159	0.1146	0.1152	0.1251
Euro area	0.2210	0.2214	0.2294	0.1224	0.1215	0.1306
Belgium	0.2857	0.2733	0.2839	0.1104	0.1085	0.1147
Bulgaria	0.0955	0.0979	0.0997	0.0763	0.0810	0.0887
Czechia	0.1438	0.1573	0.1748	0.0688	0.0733	0.0768
Denmark	0.3049	0.3126	0.2984	0.0845	0.0807	0.0707
Germany	0.3048	0.2987	0.3088	0.1519	0.1499	0.1557
Estonia	0.1207	0.1348	0.1357	0.0870	0.0865	0.0917
Ireland	0.2305	0.2369	0.2423	0.1237	0.1321	0.1400
Greece	0.1711	0.1672	0.1650	0.1073	0.1038	0.1059
Spain	0.2296	0.2383	0.2403	0.1061	0.1059	0.1148
France	0.1704	0.1748	0.1765	0.0978	0.0982	0.1024
Croatia	0.1196	0.1311	0.1321	0.0874	0.0994	0.1034
Italy	0.2132	0.2067	0.2301	0.1477	0.1423	0.1661
Cyprus	0.1863	0.1893	0.2203	0.1414	0.1405	0.1619
Latvia	0.1586	0.1531	0.1629	0.1179	0.1039	0.1052
Lithuania	0.1116	0.1097	0.1255	0.0837	0.0838	0.0926
Luxembourg	0.1615	0.1671	0.1798	0.0780	0.0833	0.0897
Hungary	0.1125	0.1123	0.1120	0.0772e	0.0840	0.0970
Malta	0.1328	0.1285	0.1305	0.1351	0.1346	0.1392
Netherlands	0.1562	0.1706	0.2052	0.0822	0.0863	0.0941
Austria	0.1950	0.1966	0.2034	0.0930	0.0997	0.1076
Poland	0.1446	0.1410	0.1343	0.0866	0.0876	0.1003
Portugal	0.2284	0.2246	0.2154	0.1145	0.1123	0.1186
Romania	0.1198	0.1333	0.1358	0.0769	0.0831	0.0972
Slovenia	0.1609	0.1613	0.1634	0.0784	0.0860	0.0959
Slovakia	0.1435	0.1566	0.1577	0.1118	0.1166	0.1286
Finland	0.1581	0.1612	0.1734	0.0667	0.0681	0.0709
Sweden	0.1936	0.1891	0.2015	0.0648	0.0684	0.0738
United Kingdom	0.1766	0.1887	0.2122	0.1264	0.1337	0.1517
Iceland	0.1598	0.1545	0.1406	0.0795p	0.0769e	0.0579
Liechtenstein	0.1724	:	:	0.1296	:	:
Norway	0.1642	0.1751	0.1867	0.0711	0.0778	0.0829
Montenegro	0.0983	0.1024	0.1032	0.0775	0.0810	0.0868
North Macedonia	0.0820	0.0781	0.0783	0.0524	0.0624	0.0687
Albania	0.0844	:	:	:	:	:
Serbia	0.0664	0.0705	0.0706	0.0639	0.0704	0.0833
Turkey	0.1048	0.0904	0.0847	0.0634	0.0589	0.0706
Bosnia and Herzegovina	0.0859	0.0864	0.0873	0.0594	0.0661	0.0667
Kosovo (³)	0.0662	0.0633	0.0600	0.0798	0.0746	0.0660
Moldova	0.0977	0.1020	0.0936	0.0828	0.0880	0.0771
Georgia	:	0.0685	0.0809	:	0.0489	0.0595
Ukraine	0.0393	0.0410	0.0442	:	0.0595	0.0656

(:) not available
(p) Provisionnal

(¹) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(²) Annual consumption: 500 MWh < consumption < 2 000 MWh.
(³) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

Source: Eurostat (online data codes: nrg_pc_204 and nrg_pc_205)

Figure 30. Electricity prices 2017-2019 (EUR per kWh) Eurostat, 2020

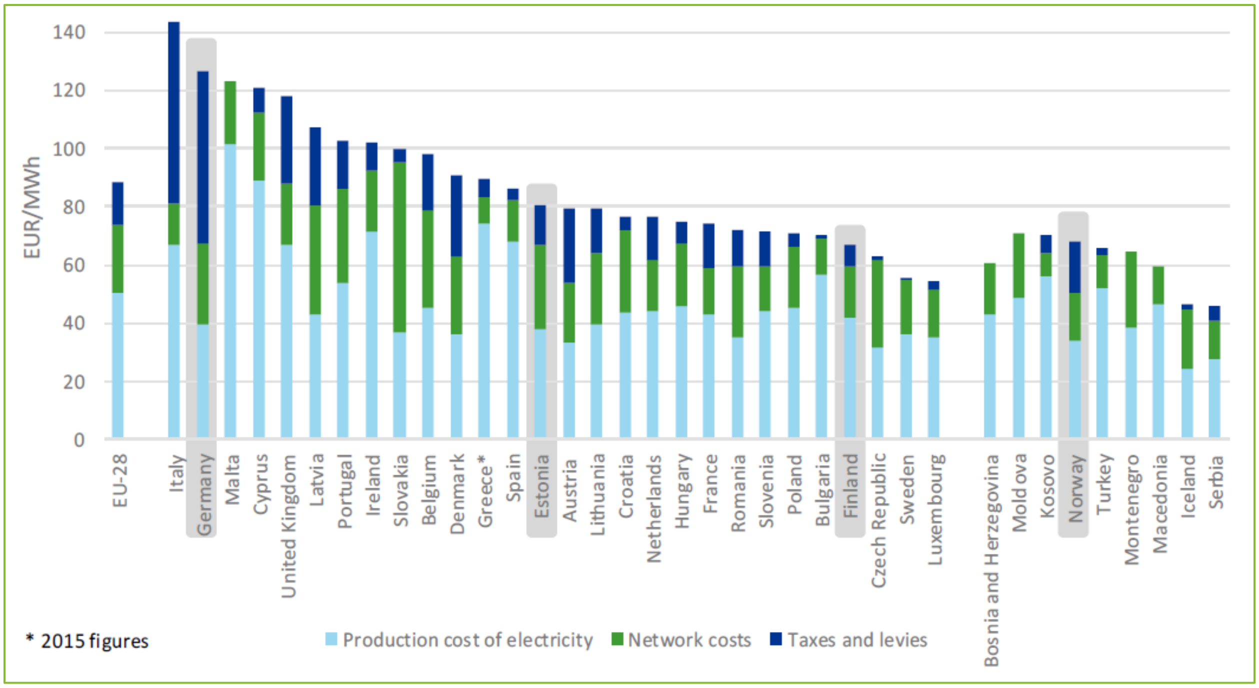


Figure 31 Electricity price for industrial consumers in different countries with electricity consumption from 2000 MWh to 20000 MWh, 2016 (Eurostat, 2017)

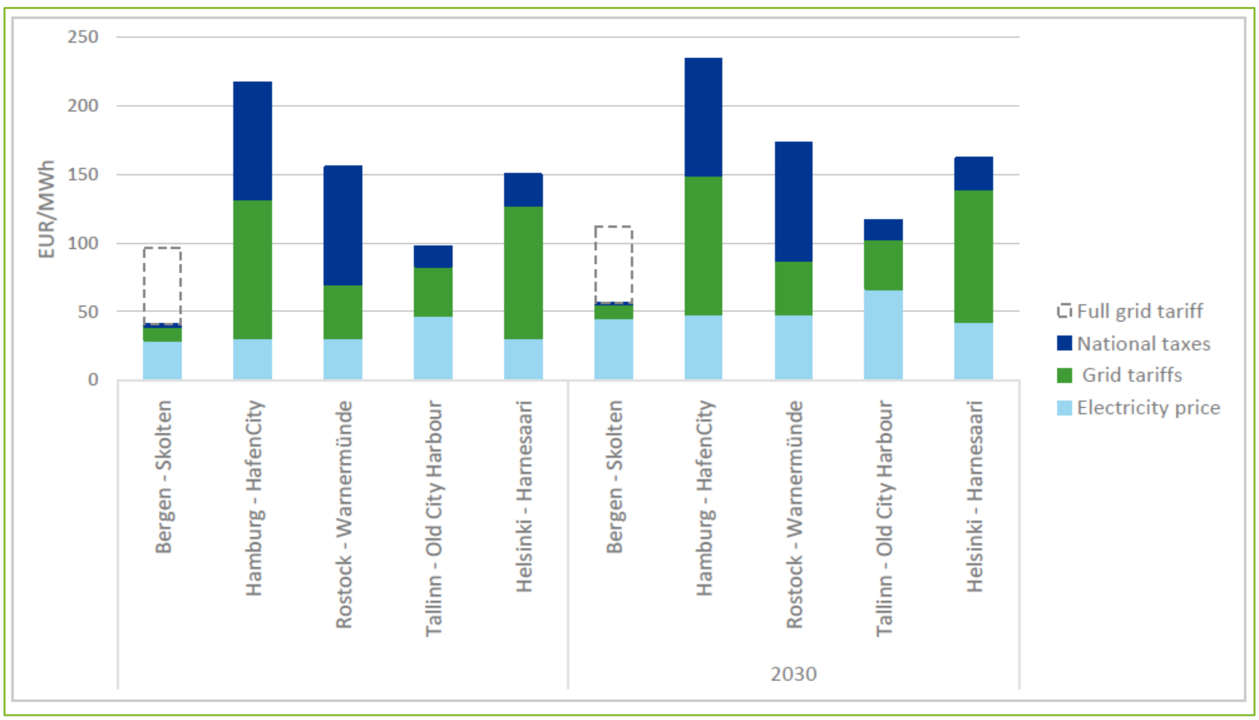


Figure 32. Total electricity charges or port purchase price of electricity (Bergen and Omland Port Authority, 2018)

The Large General Service Electricity Rate for BC Hydro in 2020 is shown in Figure 33. The Large General Service rate is for business customers with an annual peak demand of at least 150 kW, or that use more than 550,000 kWh of electricity per year. They receive service under rate schedules 1600, 1601, 1610, or 1611 of the Electric Tariff. In British Columbia, Canada, the electricity rate for large general service in 2020 is C$ 0.06 per kWh (or NOK 0.44 per kWh), which is 40% of the electricity rate for the Port of Bergen in 2018.

According to the Port of Oslo (Askvik, 2019), when the ferries are connected to shore power, they use between 5 000 000 – 6 000 000 kWh annually. This corresponds to the annual power consumption of almost 400 Norwegian homes. The shore power station has a cost of approximately NOK 17 Million. DNV-GL Recharge project had developed a cost calculator to provide estimates of cost and reduction potential for onshore power infrastructures. Several case studies from the Port of Oslo are summarized in Figure 34.

The Global Maritime Energy Efficiency Partnerships Project (GloMEEP) (2020), an IMO initiative aimed at reducing GHG emissions from shipping, estimated the total cost of implementing shore power onboard different categories of ships of various sizes. These estimates are shown in Table 23.

Basic Charge A small, daily amount that partially recovers fixed customer-related costs, including customer service channels, metering, billing, payment processing, collections, and distribution system costs that are customer-related (electrical lines and transformers).	$0.2646 per day.
Demand Charge The rate electricity is used, typically measured in kilowatts (kW). Peak demand is the highest rate of electricity use during a period of time.	$12.22 per kW.
Energy Charge	$0.0600 per kWh.
Minimum Charge A charge that covers the costs of maintaining our equipment year round for customers with high electricity usage in the winter but low electricity usage in the summer.	Equal to 50% of the highest Demand Charge during the previous November 1 to March 31 period. The Basic Charge, Energy Charge, and Demand Charge are replaced by the Minimum Charge if their sum is less than this amount.
Power Factor Surcharge A measure of efficiency, and the ratio of usable power (kW) to reactive power (kVar) in a circuit. It varies between 0 and 1, and is normally given as a percentage (1 to 100%). We apply a power factor surcharge to business customers whose power factor drops below 90%.	Applicable if power factor is below 90%.
Discounts	1.5% on entire bill if electricity is metered at primary potential. $0.25 per kW if customer supplies transformation from a primary to a secondary potential. If eligible for both, the 1.5% discount is applied first.

Figure 33. BC Hydro Large General Service Electricity Rate (BC Hydro, 2020)

Sjursøya container terminal:

- 45 ships called the berth in 2016, whereas 5 contributed to 50% of the consumption
- A power output of 946kW is needed to serve existing traffic
- A LV shore connection system is needed
- Average lay time is 12,5 hours per ship
- Total yearly emission reduction potential is; 1 129mt fuel, 3 579mt CO_2 and 49 680kg NO_x
- Total cost of connecting 5 ships is estimated to 4,2 million USD, 77 USD/ CO_2-tonne and 5,5 USD/NO_x-kg

Vippetangen ferry terminal:

- 3 ships called the berth
- A power output of 1 194kW is needed to serve existing traffic
- A HV shore connection system is needed
- Average lay time is 4,4 hours per ship
- Total yearly emission reduction potential is; 1 022mt fuel, 3 241mt CO_2 and 15 272kg NO_x
- Total cost of connecting 3 ships is estimated to 2,2 million USD, 23 USD/CO_2-tonne and 4,8 USD/NO_x-kg

Plug-in Ro-Pax

- Battery power between Port of Oslo and Filtvedt
- Power output of 3 631kW is needed
- A HV shore connection system is needed
- Average lay time is 4,4 hours
- Total yearly emission reduction potential is; 2 499mt fuel, 7 921mt CO_2 and 179 901kg NO_x
- Total cost of the project is estimated to 15,2 million USD, 64 USD/CO_2-tonne and 2,8 USD/NO_x-kg

Figure 34. Case study results of potential onshore power projects from the Port of Oslo

Table 23. Estimated cost for implementing shore power on board vessels

Investment cost for vessel (USD)	1000 – 4999 GT	5000 – 9999 GT	10000 – 24999 GT	25000 – 49999 GT	50000 – 99999 GT
Crude tankers	$50 000 – $350 000	$100 000 – $400 000	$100 000 – $400 000	$100 000 – $400 000	$300 000 – $750 000
Chemical / product tankers	$50 000 – $350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000	
Gas tankers	$50 000 – $350 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 – $750 000
Bulk carriers	$50 000 – $350 000	$50 000 – $350 000	0,5 – 3 Mill	0,5 – 3 Mill	$100 000 – $400 000
General cargo	$50 000 – $350 000	$50 000 – $350 000	0,5 – 3 Mill	$100 000 – $400 000	
Container vessels	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000
Ro Ro vessels	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000	$100 000 – $400 000	$300 000 – $750 000
Reefer	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000		
Passenger ship	$50 000 – $350 000	$50 000 – $350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000
Offshore supply ship	$50 000 – $350 000	$100 000 – $400 000			
Other offshore service ships	$50 000 – $ 350 000	$100 000 – $400 000	$100 000 – $400 000	$100 000 – $400 000	$100 000 – $400 000
Other activities	$50 000 – $ 350 000	$100 000 – $400 000	$300 000 – $750 000	$300 000 – $750 000	$300 000 – $750 000
Fishing vessels	$50 000 – $ 350 000	$100 000 – $400 000			

4.5 Technologies Used to Reduce Emissions

4.5.1 Vessel Zero- and Low-Emission Fuel Solutions

4.5.1.1 Battery-electric Operation

At present, all-electric solutions are mainly only suitable for short routes where frequent recharging is possible, for example, ferries. Electric operation will result in lower energy consumption due to higher efficiency compared with conventional diesel engines (Norwegian Ministry of Climate and Environment, 2019a).

Electricity does not have direct emissions, although emissions can be linked with the generation of electricity. In Norway, electricity generation is almost exclusively renewable with hydropower, wind energy and thermal power plants accounting for 96%, 2% and 2% of the electricity generation respectively. In addition, the large energy-intensive industries are using electricity from the grid rather than producing its own energy from fossil fuels (Norwegian Ministry of Climate Change and Environment, 2018).

By contrast, in Canada, hydropower, nuclear, coal, gas/oil/other and non-hydro renewables account for 60%, 15%, 9%, 10% and 7% of the electricity generation, respectively. Approximately, 67% of Canada's electricity comes from renewable sources and 82% from non-GHG emitting sources (Natural Resources Canada, 2017).

Using electricity as the only energy carrier for ships requires robust battery solutions and development of infrastructure for onshore charging. The charging process is power-intensive, and the low-voltage supply network at the quay is required to supply sufficient power for charging ships. It is also possible to use stationary, land-based battery packs that are used as a buffer for charging batteries aboard ships. This reduces the need to upgrade the power grid (City of Oslo, 2018).

In Norway, electrification of the ferry fleet is already well under way, and many ferries will be replaced in the next few years. By 2022, over 80 ferries will run partly or entirely on batteries and more than one-third of Norway's car ferries will use electric propulsion systems. Various types of workboats, crew transfer vessels and service vessels used in the aquaculture industry are also good candidates for battery-electric operations.

A Norwegian pilot project led by Kongsberg is currently developing a battery-powered autonomous container ship (see Appendix A – Autonomous battery-powered container ship). Due to launch in 2020, Yara Birkeland will be the world's first autonomous fully electric container ship operating between Herøya-Brevik-Larvik. This pilot project is proof that full electrification in container ships and some sight-seeing vessels may be possible in some short, regular routes (Norwegian Ministry of Climate and Environment, 2019a).

4.5.1.2 Plug-in Hybridisation, Partial electrification (Battery Hybrids)

Plug-in hybrid ships run partly on batteries charged on land, in combination with an internal combustion engine. Both fossil fuels and biofuels can be used in the internal combustion engine, and the batteries facilitate more optimal use of the internal combustion engine. This reduces emissions of greenhouse gases, NOx and other emissions. The reduction of emissions of greenhouse gases and other air pollutants is dependent on how much the ship runs on electricity, whether the ship uses fossil fuel or biofuel, and whether the engines run on gas or diesel. Hybrid solutions are generally suitable in applications where there are major fluctuations in power takeoff, where the battery bank can handle the power peaks while the engines constantly operate consistently within the optimum range (City of Oslo, 2018).

The offshore sector was one of the first to start using ships with battery technology, often in combination with LNG. Battery hybrid solutions have already been installed on more than 20 supply ships (Norwegian Ministry of Climate and Environment, 2019a).

In the aquaculture sector, hybrid well boats, fish feed barges and service boats can be used to reduce emissions (Norwegian Ministry of Climate and Environment, 2019a). ABB/Kystrederiene has initiated a pilot project to use LNG in combination with batteries to improve energy efficiency and reduce emissions significantly in the vessels used in the aquaculture industry (see Appendix A).

It is also an option for fishing vessels. In Norway, there is already one fishing boat that runs on electricity during fishing operations and there are several battery-hybrid fishing boats (Norwegian Ministry of Climate and Environment, 2019a). Fiskebåt (The Norwegian Fishing Vessel Owners' Association) is leading a pilot project to use hybrid technology to reduce GHG emissions from the fishing fleet by at least 40%. Canadian company, Corvus Energy is a participant in the project (see Appendix A)

In addition, battery hybridisation is a possibility for international passenger ferries. The Color Line and Hurtigruten shipping companies are planning to use this solution for their exploration ships (Norwegian Ministry of Climate and Environment, 2019a).

Battery hybridisation may also be a cost-effective solution for some cargo ships, especially general cargo ships that have a variable operational profile and frequent calls at ports for loading and unloading that require a substantial amount of energy. Increasing the degree of hybridisation by installing batteries and implementing energy recovery during cargo handling could result in lower emissions and operating costs (Norwegian Ministry of Climate and Environment, 2019a). Currently, a pilot project led by Teekay is also investigating how to use batteries and vapor from the oil cargo to improve shuttle tankers' operation, lower fuel cost and reduce emissions (see Appendix A).

Propulsion solutions based on battery hybridisation can also improve the environmental profile of large ocean-going vessels. A new Coastal Administration vessel, the OV Ryvingen, will have 35% lower greenhouse gas emission than the first multipurpose vessels. The reduction may be up to 70% when the ship has access to onshore power (Norwegian Ministry of Climate and Environment, 2019a).

4.5.1.3 Hydrogen (H2)

Hydrogen is a pure energy carrier that will permit genuine zero-emissions solutions on board ships (City of Oslo, 2018). It will be possible in the future to use hydrogen to replace fossil fuels for shipping, particularly in segments where battery-electric solutions are difficult to use or inappropriate. Examples are vessels that have high energy needs or must sail long distances between ports, and segments where there are constraints in terms of weight and options for energy storage (Norwegian Ministry of Climate and Environment, 2019a). This is because hydrogen has a higher energy density (both volume and weight) than batteries, so hydrogen operation is better suited for longer, more energy-intensive routes than using batteries.

Electrical energy can be produced in fuel cells aboard ships that run on hydrogen, usually in a hybrid solution with batteries. Hydrogen is stored in tanks aboard the ship and the fuel cells produce power for electric motors. Tanks and fuel cells are very heavy, so using hydrogen as a fuel aboard ships may result in a weight increase compared with a conventional system, thus more energy will be required to push the hull through the water.

Propulsion based on hydrogen used in fuel cells will eliminate emissions of CO2, NOx and other pollutants. Thus, hydrogen is a true zero-emission energy carrier. For other energy carriers, there will be some emissions linked with the production and distribution from a life cycle perspective. This will be dependent on the value chain and on whether production is based on renewable energy or other sources (e.g. fossil fuels, nuclear power etc.). As an energy carrier, hydrogen is of interest for storage of renewable energy. In Norway, hydrogen is produced from electrolysis and reformation of natural gas, and as a by-product of industrial processes.

Hydrogen use is restricted by factors such as space availability for storage tanks aboard the ship and access to bunkering facilities. Both pressurised hydrogen and liquid hydrogen require larger tanks than conventional fuels due to the lower energy density of hydrogen (by volume). It is anticipated that liquid hydrogen will be most appropriate for storage of the large quantities of hydrogen needed as fuel for long-distance shipping. Hydrogen needs to be cooled to -253 °C to transform it to a liquid state, and production, storage, transportation and bunkering are all energy-intensive processes. Transforming the hydrogen into liquid results in energy loss in addition to the energy used for producing hydrogen gas (City of Oslo, 2018).

Initially, ferries, high-speed vessels and other ships on scheduled routes are most suitable for hydrogen trials. From 2021, Norled AS will be operating a hydrogen-electric ferry in Rogaland. If hydrogen fuelling infrastructure is developed in areas where there is a high density of other shipping, this may make hydrogen a more attractive option for other types of ships sailing in the same areas.

In addition, Hydro is leading a pilot project Hydro(gen)ship to study the feasibility of a hydrogen driven bulk carrier. Another project, Hydrogen by the Sea, led by Equinor is investigating how hydrogen could best contribute to zero-emission shipping. The municipality of Flora is also leading a pilot project to develop a ship design for a 100-passengers hydrogen-power fast boat (see Appendix A).

In the PILOT-E funding scheme, there were three projects in 2018 involving hydrogen technology. Selfa Arctic AS and Flying Foil AS are each heading a consortium to develop solutions for high-speed vessels that improve energy efficiency and make it possible to use propulsion systems based on batteries or fuel cells. The Havyard Group ASA is heading a project to achieve emission free operations in the World Heritage

Fjords and along parts of the coastal route Bergen–Kirkenes by combining batteries and hydrogen fuel cells. Samskip AS is leading a project to develop and realise profitable container transport by sea using hydrogen fuel cells for emission-free propulsion, making it possible to transfer goods from road to sea (Norwegian Ministry of Climate and Environment, 2019a).

At present, main barrier to using hydrogen as a shipping fuel is cost, which is considerably higher than conventional fuel. Also, an effective approval process must be established for the commercialisation of hydrogen solutions. The necessary legislation will have to be developed in parallel with technology development and testing. Safety challenges related to storage and handling of hydrogen, low availability, high investment costs and uncertainty in operational costs are additional barriers (City of Oslo, 2018; Norwegian Ministry of Climate and Environment, 2019a).

A development process involving qualification and upscaling of solutions for bunkering, marinization of fuel cells and storage of hydrogen aboard ships is needed so that these can be adapted to suit relevant maritime requirements and conditions. It will also be important to share knowledge from publicly funded hydrogen projects throughout the value chain: from shipping companies and shipyards to the supplier industry. These will help to reduce the barrier for wider use of hydrogen. The Norwegian government will develop an integrated strategy for hydrogen as an energy carrier, including research, technology development, scaling up solutions and the use of hydrogen in the maritime industry (Norwegian Ministry of Climate and Environment, 2019a; City of Oslo, 2018).

4.5.1.4 Ammonia

Ammonia is a potential carbon free, zero-emission marine fuel. A key advantage of ammonia is that it can be liquefied and its energy density is considerably higher than that of hydrogen. However, the technology is immature for maritime use, and widespread use will not be possible for some time. Engine manufacturers report that the first engines adapted to use ammonia could be on the market within three years.

Currently, ammonia is largely produced from natural gas by means of energy- and emission-intensive processes. However, it is possible to produce ammonia from renewable sources by electrolysis.

In the long term, it will be possible to use ammonia both in fuel cells and in internal combustion engines. There are difficulties that need to be overcome before ammonia can be used safely and effectively as a fuel. It is toxic, and there are challenges related to its combustion characteristics and corrosive nature. Legislation governing the use of ammonia on ships will also have to be developed (Norwegian Ministry of Climate and Environment, 2019a).

4.5.1.5 Biodiesel and Biogas

Biofuel is a renewable energy carrier that is extracted from biogenic material and made from a broad range of organic materials such as edible crops (e.g. corn), non-edible crops (marginal crops that do not compete with food production), sludge, timber and compost, food waste/fat and algae (experimental production) (City of Oslo, 2018). Using a greater proportion of biofuels in marine fuels would reduce emissions from shipping. To ensure global climate and environmental benefits, advanced biofuels should be used, based on feedstock such as biological residues and waste (Norwegian Ministry of Climate and Environment, 2019a).

Biofuels can be used as “drop-in fuels” to replace marine fuels where there is compatibility with existing infrastructure and engine systems or by modifying infrastructures and engine systems (City of Oslo, 2018).

Biodiesel can be blended with marine diesel and used in existing ships’ engines up to a certain percentage depending on the quality and type of biodiesel used. However, biodiesel may, to a varying extent, have negative long-term effects on ships’ engines. This applies particularly if lower-quality biodiesels are used in blending, typically conventional biodiesel (Norwegian Ministry of Climate and Environment, 2019a). In Norway, there are currently two types of liquid biofuel being considered for shipping – Conventional biodiesel is a fuel resembling diesel that is produced from vegetable oils or animal fat; and Synthetic renewable diesel that is made from waste products from agriculture, forestry and food (City of Oslo, 2018).

Biogas is the same as natural gas (primarily methane) in terms of chemical composition and therefore has the same properties as natural gas. Biogas can be cooled and condensed into liquid (LBG) and used on LNG ships in the same way as LNG. No additional investment costs are associated with the use of LNG with admixed LBG.

Liquefied biogas (LBG) can directly replace or be mixed with LNG using existing infrastructure and engine technology. This will reduce greenhouse gas emissions and local air pollution (Norwegian Ministry of Climate and Environment, 2019a). As LNG and LBG can be used interchangeably on ships and use the same infrastructure, LNG may pave the way for LBG and trigger further greenhouse gas reductions. LNG ships can be used to build a market for LBG (City of Oslo, 2018).

Biogas can be produced by the decomposition of a broad range of biogenic material such as food waste, sludge, timber, compost and other waste and by-products. Zero CO2 emissions are ascribed to the use of biogas. The reduction in NOx emissions is equivalent to the use of LNG, with a reduction of up to 90% depending on engine technology. The use of all forms of advanced biofuel means that emissions of SOx are eliminated (City of Oslo, 2018). However, there are still substantial barriers to the introduction of biogas relating to availability, infrastructure and price (Norwegian Ministry of Climate and Environment, 2019a).

Hurtigruten has announced that it will be introducing LBG as one fuel for the ships sailing the coastal route Bergen–Kirkenes. The LBG that Hurtigruten plans to use is produced from various types of wet organic waste, including waste from the fishing industry. It is an important resource that can also solve a waste problem (Norwegian Ministry of Climate and Environment, 2019a).

In the plug-in hybrid fishing vessels pilot led by Fiskebåt, plug-in hybrid solutions with batteries as well as LNG and biofuel have been assessed for the different ship types. Torghatten is also leading another pilot project to investigate a biodiesel powered plug-in hybrid ferry (see Appendix A).

4.5.1.6 Liquefied Natural Gas (LNG)

LNG is a natural gas that is cooled and condensed to liquid. LNG is mainly produced in order to facilitate transportation and storage of the gas. It is the most common alternative fuel for ships at present (City of Oslo, 2018). Emissions of NOx, SOx and particulate matter from maritime transport can be considerably reduced by using LNG. CO2 emissions are also lower than from diesel operations.

Bunkering infrastructure is in place in Norway to an extent, and infrastructure is also being constructed elsewhere in the world. However, there is still inadequate infrastructure globally for broad use of LNG as a marine fuel. The price of LNG and the additional investments in ships are the deciding factors (City of Oslo, 2018). Currently, there are 300 LNG ships globally. Among these, 165 ships are in operation and the remaining 154 ships are in order. It took 13 years for LNG fuel to expand outside

Norway. As of May 2019, 74% of these ships are based outside Norway (DNV GL AS Marine, 2019)

As a marine fuel, LNG has several key advantages. First, there is a 25% reduction in carbon dioxide emissions, a 90% reduction in NOx emissions and 100% reduction in SO_2 and fine particle emissions compared to traditional heavy fuel oils. Second, LNG is the primary energy offering the best thermodynamic yields and hence the best energy efficiency. Third, the cost of LNG is considerably more competitive than that of other low-sulphur fuels, such as MGO (Elengy, 2020). In addition, it is commercially ready.

SEA\LNG (a UK-registered not-for-profit collaborative industry foundation to further the use of LNG) had commissioned DNV-GL AS Marine (2019) to compare different alternative marine fuels using a set of 11 key performance parameters. Their findings are summarized in Figure 35. To inform policy recommendations, Steen et al. (2019) used a Technological Innovation Approach (TIS) to analyze four low- and zero-carbon energy solutions (biodiesel, liquefied biogas, hydrogen, battery electric storage) that can replace or supplement fossil fuels in the Norwegian maritime shipping sector. The TIS framework is one of the main approaches used in the field of sustainability transitions research. Their analysis results are summarized in Figure 36. Their policy recommendations are shown in Appendix B.

SEA\LNG and The Society for Gas as a Marine Fuel (SGMF) (a non-governmental organisation (NGO) established to promote safety and industry best practice in the use of gas as a marine fuel) also commissioned Thinkstep (a consulting service) to assess the lifecycle GHG emissions from LNG as a marine fuel. The study concluded that the Well-to-Wake emissions reduction benefits for gas fuelled engines today compared with HFO fuelled ships were between 14% to 21% for 2-stroke slow speed engines, and between 7% to 15% for 4-stroke medium speed engines (Thinkstep, 2019a).

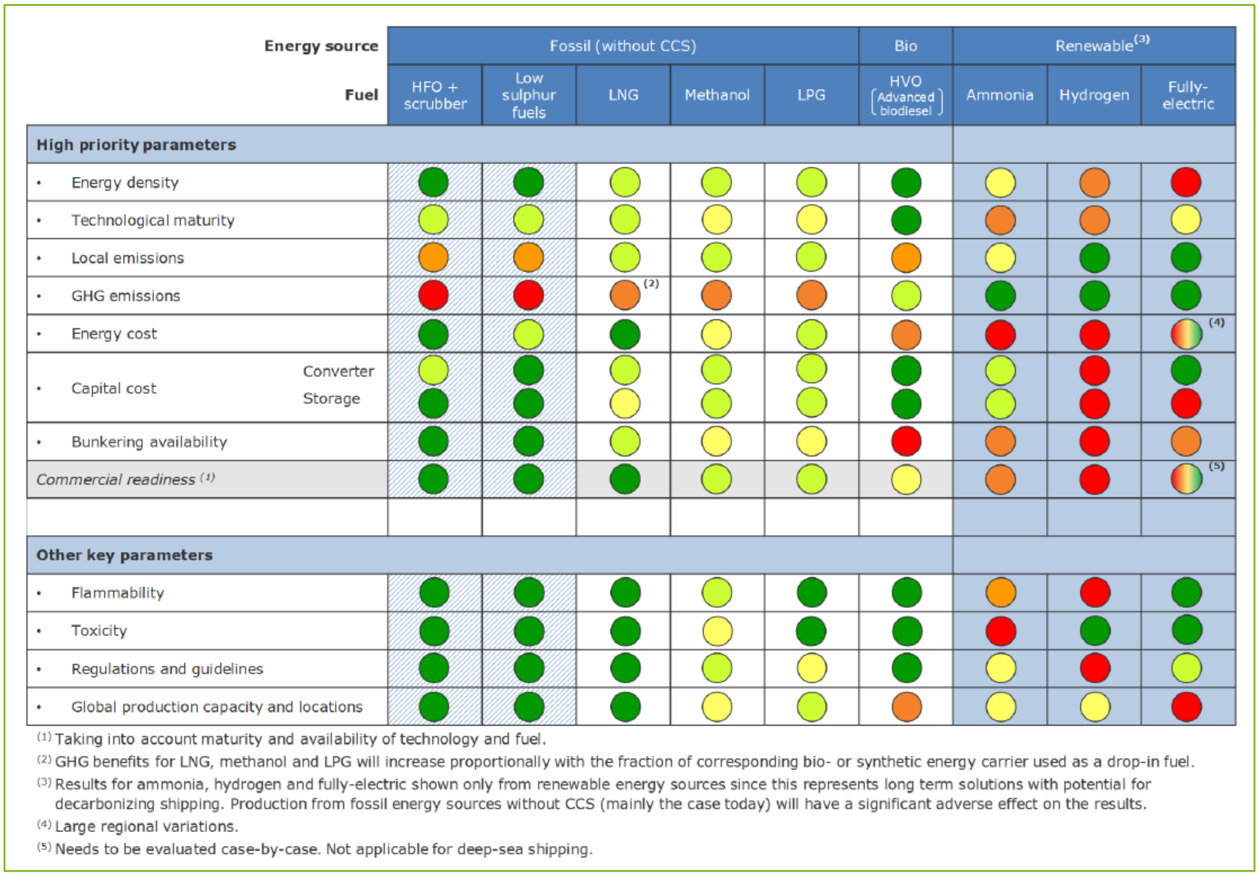


Figure 35. Status of viability for different alternative fuels (internally rated) (DNV-GL AS Marine, 2019)

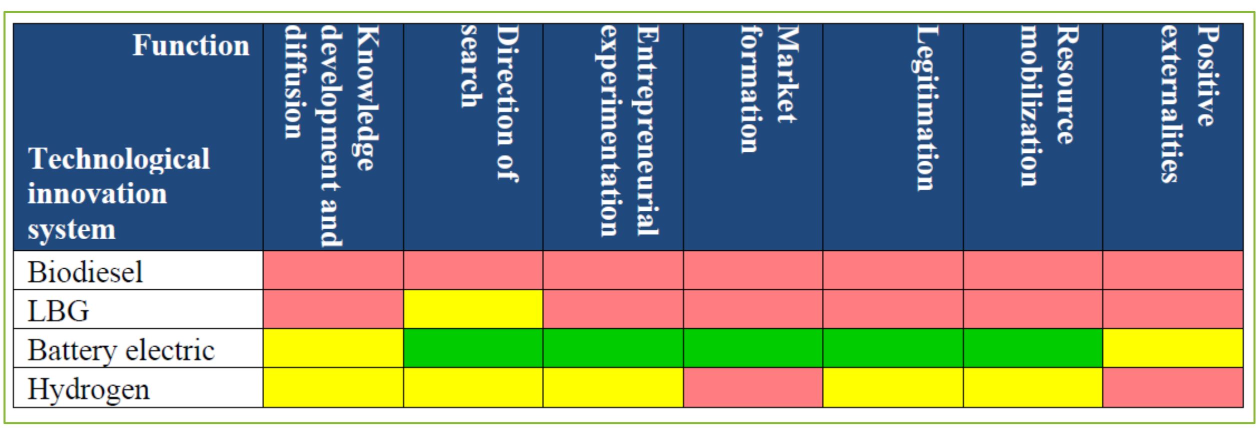


Figure 36. Comparison of TIS functions for biodiesel, LBG, hydrogen, and battery electric in the context of Norwegian maritime shipping sector (red = weak, yellow = intermediate, green = strong) (Steen, 2019)

Function	Description
Knowledge development and diffusion	Broadening and deepening of the knowledge base of a TIS, sharing of knowledge between actors within the system and new combinations of knowledge as a result of these processes.
Entrepreneurial experimentation	Problem-solving and uncertainty reduction through real-world trial-and-error experiments at different scales and with new technologies, applications and strategies.
Market formation	The opening up of a space or an arena in which goods and services can be exchanged in semi-structured ways between suppliers and buyers, including articulation of demand and preferences, product positioning, standard setting, and development of rules of exchange.
Influence on the direction of search	Mechanisms that influence what opportunities, problems and solutions firms and other actors apply their resources, incentivizing and pressuring them to engage in innovative work within a particular technological field and determining what strategic choices they make within that field.
Resource mobilization	The system's acquisition of different types of resources for the development, diffusion and utilization of new technologies, products and processes, most notably capital, competence and manpower, and complementary assets (e.g. infrastructure).
Legitimation	The process of gaining regulative, normative and cognitive legitimacy for the new technology, its proponents and the TIS in the eyes of relevant stakeholders (i.e. increasingly being perceived as complying with rules and regulations, societal norms and values, and cognitive frames).
Development of positive externalities	The creation of system-level utilities (or resources), such as pooled labour markets, complementary technologies and specialized suppliers, which are available also to system actors that did not contribute to building them up.

While the DNV-GL and Thinkstep results reinforced the advantages of LNG and highlighted its market readiness and cost competitiveness compared to other fuel options, there are recently some serious concerns raised that LNG may not be achieving its emission benefits and cost advantages that industry, engine manufacturers, shipyards and LNG producers had claimed.

Different types of LNG engines are used in different shipping segments, and the real reduction in greenhouse gas emissions may be considerably lower because of the presence of unburnt methane (CH_4) in the exhaust gas. Methane is a potent greenhouse gas, and the level of emissions varies with the type of LNG engine technology used (Norwegian Ministry of Climate and Environment, 2019a).

According to the Intergovernmental Panel on Climate Change, IPCC (2013), un-combusted methane is a greenhouse gas that has an impact 28-34 times greater than that of CO_2 and has a Global Warming Potential Factor (GWP) of 28. Norwegian Authorities use a GWP of 25 to account for methane emission.

Stenersen and Thonstad (2017) studied greenhouse gas and NOx emissions from ship gas fuelled engines. Low pressure natural gas-powered engines had low NOx emissions but suffered from increased methane slip compared to diesel operation. There are various engine concepts to compete in different ship segments. In Norway, Lean Burn Spark Ignition (LBSI) engines are the preferred solution for ferries and 4 stroke Low Pressure Dual Fuel (LPDF) engines are typically selected for offshore vessels. The main reason for choosing the LPDF is the diesel oil as backup fuel and the ability to operate on diesel oil. With a NOx tax regime, there are economic benefits for the ship owner to achieve low NOx factors, and the engine could be adjusted to obtain as low of a NOx factor as possible. The penalty is higher methane slip and CO_2 emissions. The study found that the average methane emissions from all LNG engine types was 5.3 g/kWh produced. Lindstad and Bo (2018) demonstrated that this basically cancels out the advantage of LNG in GHG emissions over conventional fuels.

Lindstad et al. (2017) determined the best options for existing vessels to comply with IMO regulations to reduce sulphur emissions from maritime shipping starting 2020. The study accounted for fuel choice and retrofit as a function of ship type, engine size, operational pattern and remaining use time. The results showed that for vessels with the highest fuel consumption, continued use of HFO (with sulphur content up to 3.5%) with on-board exhaust gas scrubbing had the lowest cost while complying with IMO regulations. Distillates (diesel) with sulphur content less than 1.0% was an attractive option for smaller vessels. For all vessels, except for the largest fuel consumers, residual fuels desulphurised to less than 0.5% sulphur (e.g. LSHFO) were also good abatement options. Retrofitting existing vessels for LNG tended to be too costly.

Lindstad and Bo (2018) also investigated the best options for new ships to meet IMO EEDI requirements. While retrofitting existing ships for LNG are too costly, LNG is an option for new builds. The study used an Alframax tanker as illustration and accounted for operational profiles, fuel consumption, capital expenditure, operational expenditure and the fuel cost of alternative options. The scenarios considered were standard hull and slender hull, each using HFO, LNG and a hybrid system as fuel source. The research showed that LNG solutions were more expensive than HFO with scrubber and hybrid system. The reductions in GHG emissions ranged from 5% with standard LNG technology (low-pressure dual fuel technology) to 20% with the best LNG technology (high-pressure technology). The study also highlighted a critical shortcoming in EEDI, which only accounts for CO2 emissions and ignores the adverse impact of well-to-wake emissions of other more potent greenhouse gas (e.g. methane).

In June 2019, Lindstad (2019) conducted a critical review of the Thinkstep report (Thinkstep, 2019a) and pointed out several important concerns.

- Firstly, considering combustion only, LNG in theory could result in 25% lower GHG emissions than diesel (MGO) or bunker oil (HFO). However, considering (1) larger well-to-tank (WTT) emissions from production, processing and delivery of LNG through the supply chain and (2) un-combusted methane from the ship's engine, these might more than nullify any GHG reduction benefits (Stenersen and Nilsen, 2010; Lindstad and Sandaas 2016; Stenersen and Thonstad, 2017, Lindstad and Bo, 2018).

- Second, the use of (1) higher thermal efficiency for LNG than for diesel in the engine combustion process; (2) low amounts of un-combusted methane in the exhaust gas from the ship's engines from testbed data; and (3) a different conversion from gram of CO_2 per MJ to gram of CO_2 per kWh; gave more favourable results for LNG in the Thinkstep report.

- Third, the selection of the environmental impact method, Global Warming Potential (GWP) with a 100-year timeframe instead of a shorter 20-year timeframe also gave more favorable results for LNG. A 20-year timeframe was motivated by the need to rapidly reduce GHG emissions and account for its greater warming impact (warming impact of methane in a 20-year timeframe is 85 times larger than CO_2 while its warming impact in 100-year timeframe is 28-34 times higher than CO_2).

By correcting the above using data available to SINTEF Ocean (formerly Marintek) and other research organizations, Lindstad (2019) showed that the only LNG option that contributed to reducing GHG emissions was the 2–stroke high pressure dual fuel engine (HP-DF-LNG). For all other LNG options, the GHG emissions increased or were equal to using MGO or HFO (Figure 37 and Figure 38).

Abbreviations used in Figure 37 and Figure 38

Well-to-wake (WTW)
Well-to-tank (WTT)
Tank-to-wake carbon dioxide (TTW CO2)
Tank-to-wake methane (TTW CH4)
Low-pressure dual-fuel LNG (LP-DF-LNG)
High-pressure dual-fuel LNG (HP-DF-LNG)
Marine gas oil (MGO)
Heavy fuel oil (HFO)
Global warming potential with a 100-year timeframe (GWP 100)
Global warming potential with a 20-year timeframe (GWP 20)

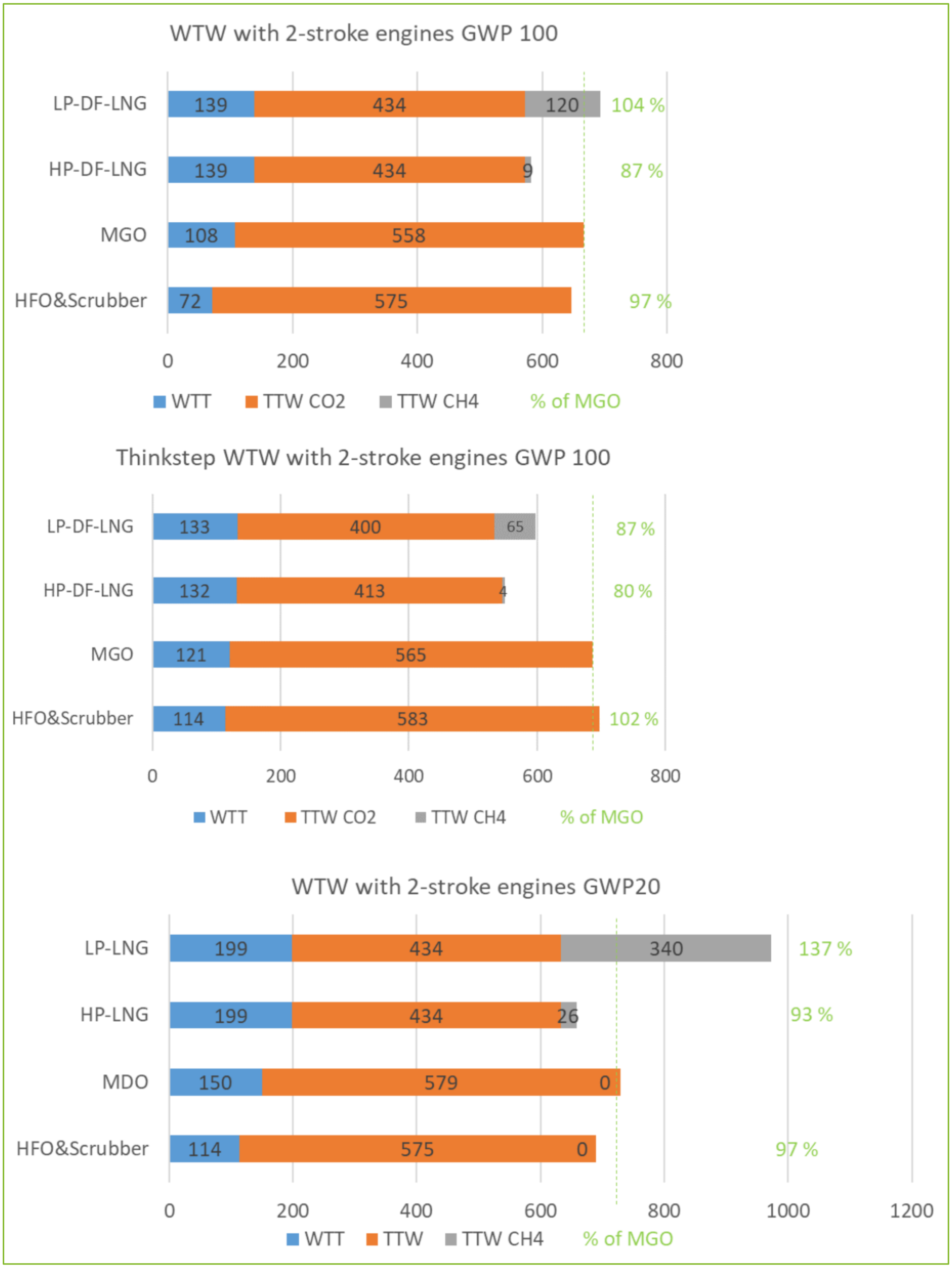


Figure 37. Comparison of WTW emissions as a percentage of MGO for 2-stroke engines between Lindstad (2019) and Thinkstep (2019a)

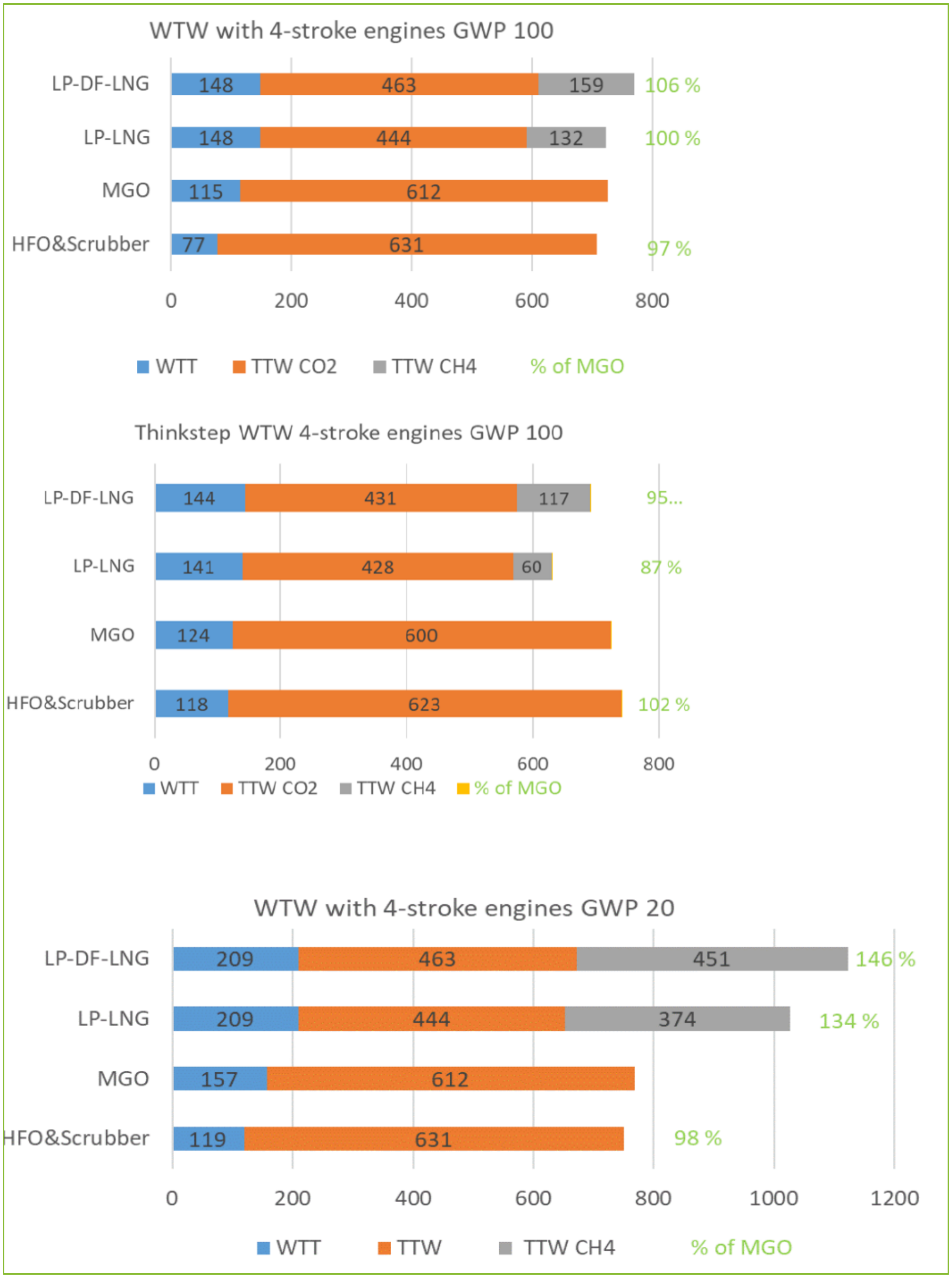


Figure 38. Comparison of WTW emissions as a percentage of MGO for 4-stroke engines between Lindstad (2019) and Thinkstep (2019a)

Thinkstep (2019b) published an addendum to address the main critiqued points of Lindstad (2019). Thinkstep agreed that (1) many studies have been performed over the last years demonstrating different GHG impacts from the use of LNG as a marine fuel; (2) the environmental impact method, such as GWP, is essential for deriving objective conclusions from the study results; and (3) methane emissions of LNG vessels depend on the engine load point of operation. Thinkstep also supported the use of onboard measurement data instead of steady-state, testbed data for the combustion of fuels.

However, Thinkstep insisted that GWP with a 100-year timeframe is the best practice partly because it is compulsory for the UNFCCC national GHG inventory reporting. Thinkstep argued that HFO should be accountable for certain refinery emissions. In addition, Thinkstep insisted that their conversion method is justified because more specific engine efficiencies were used, and pilot fuel and urea use were considered. Thinkstep also considered that running LNG fuelled engines on low load points would be neither environmentally friendly nor economically beneficial and that the IMO E2/E3 cycle is an accepted methodology in the absence of broadly measured data.

Pavlenko et al. (2020) published new findings comparing the life-cycle GHG emissions of LNG, MGO, very low sulphur fuel oil and HFO when used as fuels for international shipping. The analysis included upstream emissions, combustion emissions, methane slip and evaluation of climate impacts using the 100-year and the 20-year GWPs.

Over a 100-year time frame (Figure 39), LNG high-pressure injection dual fuel (HPDF) engines emitted 15% less life-cycle GHG emissions than MGO; LNG Low-pressure injection dual fuel (LPDF) slow-speed, two-stroke engines emitted 9% less life-cycle GHGs than MGO. LNG Low-pressure injection dual fuel (LPDF) medium speed, four-stroke engines, the most popular LNG engine technology currently, emitted 8% more lifecycle GHGs than MGO. These results assumed that upstream methane emissions are well-controlled.

As more LNG production shifts to shale gas, it is more difficult to control upstream methane emissions and recent evidence has shown that upstream methane leakage could be higher than previously expected. Furthermore, using low-pressure engines might result in unburnt methane escaping from the crankcase that had not previously been assessed. A scenario where the upstream methane leakage and the downstream methane slip are higher is shown in Figure 40.

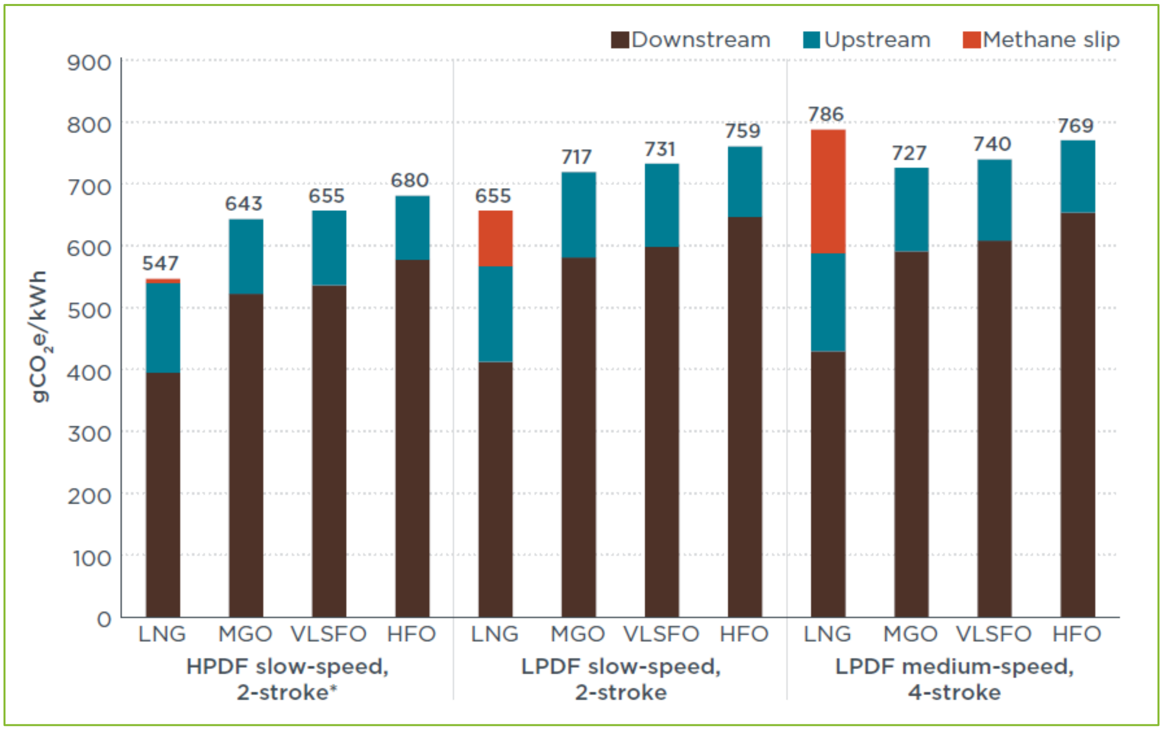


Figure 39. Life-cycle GHG emissions by engine and fuel type, 100-year GWP, low methane scenario

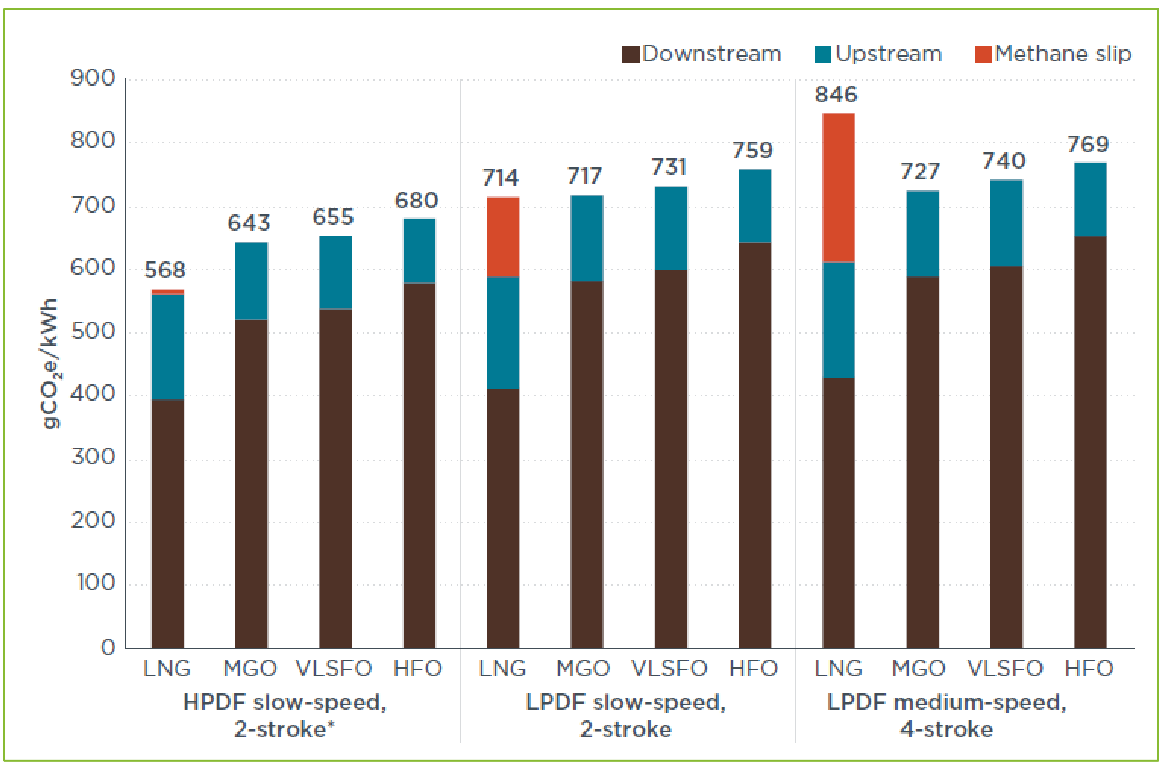


Figure 40. Life-cycle GHG emissions by engine and fuel type, 100-year GWP, high methane scenario

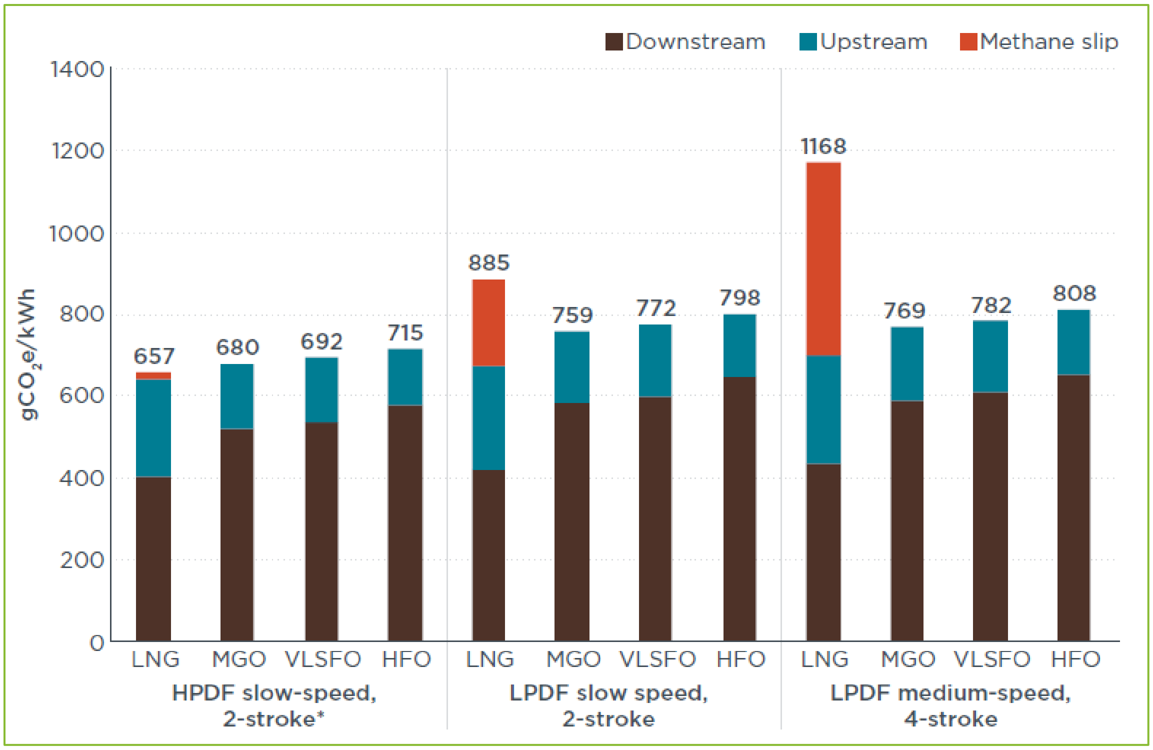


Figure 41. Life-cycle GHG emissions by engine and fuel type, 20-year GWP, low methane scenario

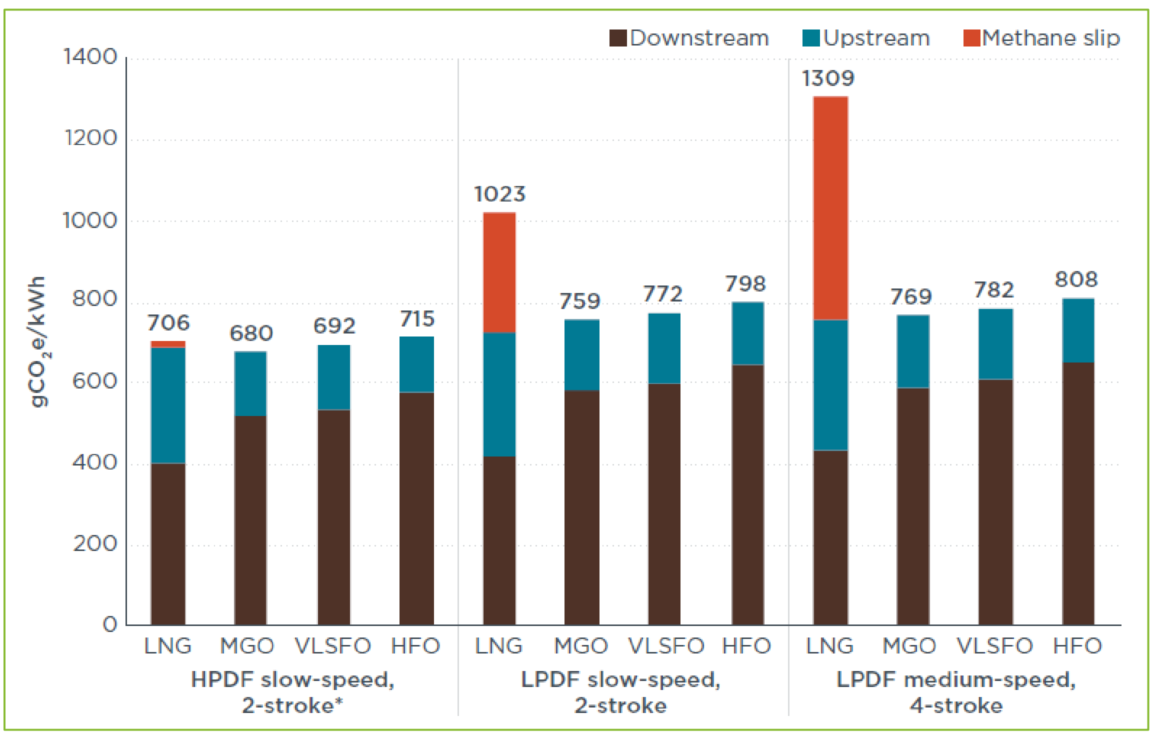


Figure 42. Life-cycle GHG emissions by engine and fuel type, 20-year GWP, high methane scenario

While most life-cycle assessments used the 100-year GWP, Pavlenko et al. also considered the short-term impacts of using LNG. This was because methane has an atmospheric lifetime of only 12.4 years (a fraction of the lifetime of CO2) but has a much larger impact on the climate in the near term. Given that methane has significant warming effects, it was argued that using the 20-year GWP better aligns with the urgent need to reduce GHGs, reflected in IMO's initial GHG strategy: "IMO remains committed to reducing GHG emissions from international shipping and, as a matter of urgency, aims to phase them out as soon as possible in this century". Using a 20-year GWP, the only engine type that had lower life-cycle emissions using LNG was the HPDF (Figure 41). The emissions savings were relatively small, only 3% lower than MGO. For the high methane scenario (Figure 42), the results showed that there was no climate benefit from using LNG, regardless of the engine technology.

For cruise ships, Pavlenko et al. further compared LNG and conventional fuels in both LPDF medium-speed, four-stroke engines (results presented above) and medium-speed, four-stroke marine diesel engines. The results for the 100-year GWP and the 20-year GWP are presented in Figure 43 and Figure 44 respectively. In all cases, LNG emitted more GHG than conventional fuels.

It was concluded that using LNG did not deliver the emissions reductions required by the IMO's initial GHG strategy, and that using it could worsen shipping's climate impacts. Continuous investment in LNG infrastructure on ships and fueling stations on shore might make it harder to transition to low-carbon and zero-carbon fuels in the future. Investing instead in energy-saving technologies, wind-assisted propulsion, zero emission fuels, batteries, and fuel cells would deliver both air quality and climate benefits.

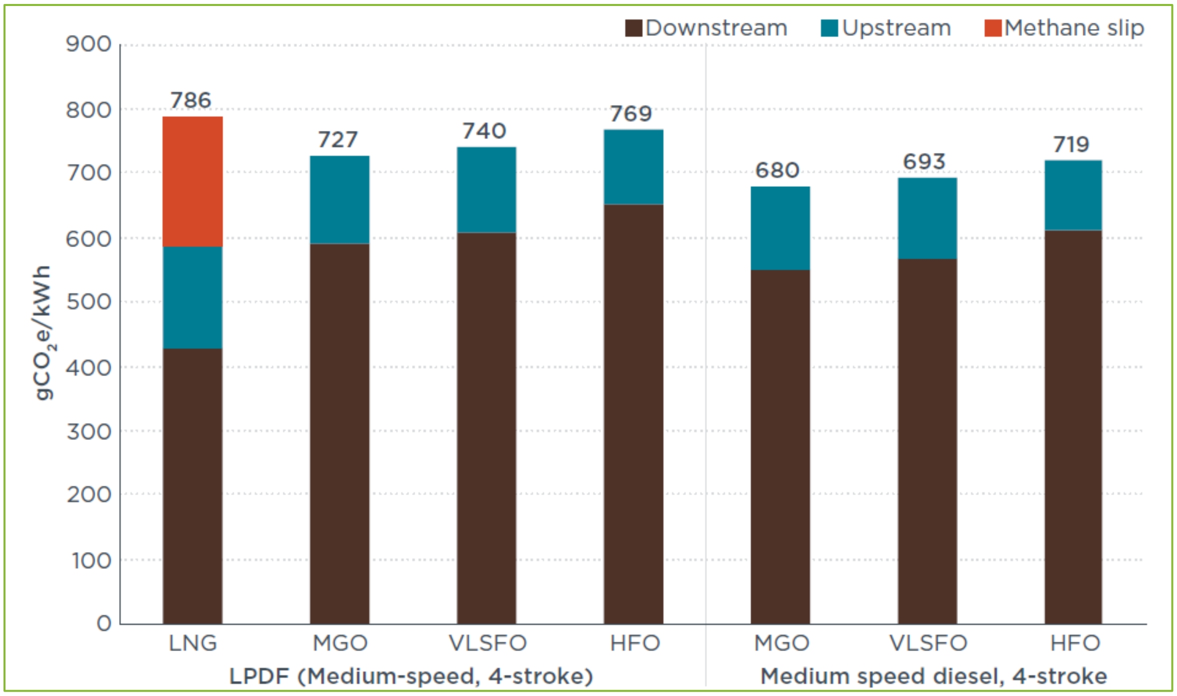


Figure 43. Life-cycle GHG emissions by fuel type for engines suitable for cruise ships, 100-year GWP

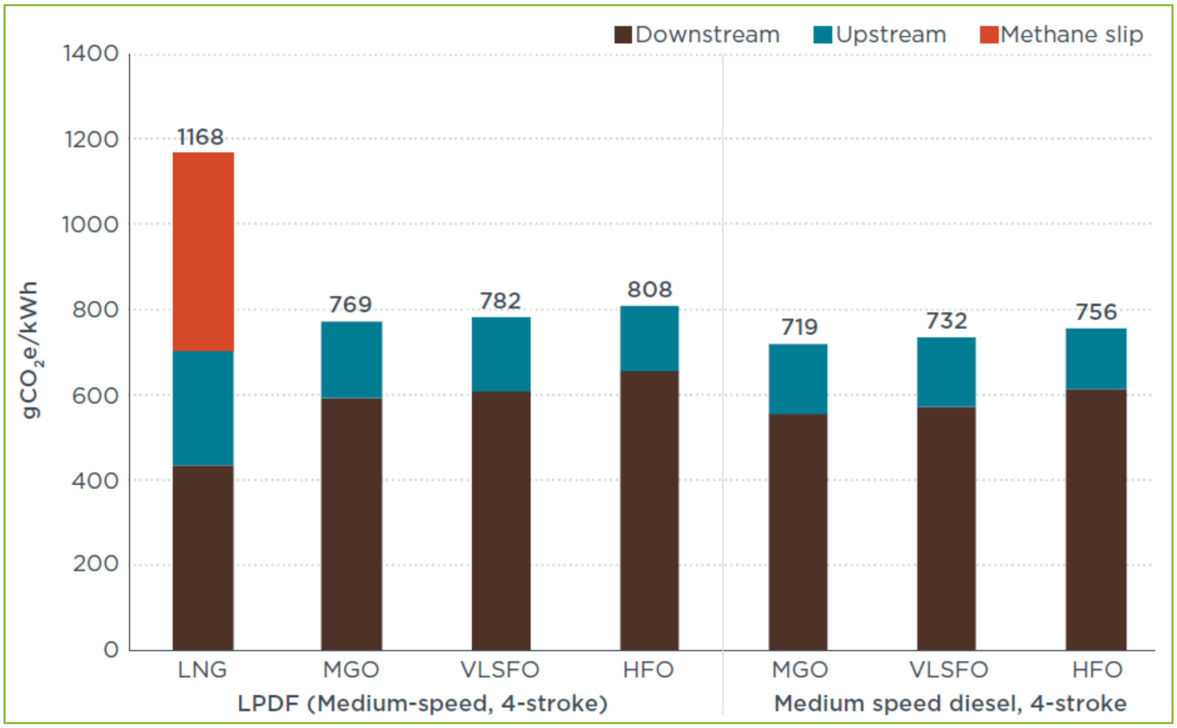


Figure 44. Life-cycle GHG emissions by fuel type for engines suitable for cruise ships, 20-year GWP

Lindstad and Rialland (2020) conducted a comprehensive study to establish comparable GHG estimates for well-to-wake (WTW) emissions for LNG and traditional fuels transparently. It was demonstrated that differences in input values and assumptions resulted in different GHG impacts in previous studies. The results also showed that increased use of dual-fuel (Otto) LNG engines (which were the current option for cruise vessels and other vessels using 4 stroke engines) would increase GHG emissions compared to conventional fuels (MGO, HFO & Scrubber, and VLSFO) (see Figure 44 and Figure 45). This highlighted a need to adopt shipping policies that could reduce the broader GHG emissions instead of CO2 only and include the well-to-tank emissions from fuels. If not, there could be many ships fulfilling all energy efficiency requirements but with GHG savings on paper only, while the real GHG emissions increased. It was also recommended that methane needed to be included in the IMO EEDI formula to reward LNG engine technologies that have nearly no methane slip (i.e., 2-stroke high-pressure dual-fuel (diesel) LNG engines) and to incentivize manufacturers of Otto LNG engines to minimize the uncombusted methane. High-pressure dual-fuel (diesel) 2-stroke LNG engines were already delivering 15% GHG reductions of WTW emissions for ships. To fully take advantage of LNG as a potential transition fuel, there is a need to develop 4-stroke dual-fuel (diesel) LNG engines.

The Clean Ship Coalition (CSC) (2019) made a submission to IMO to encourage the uptake of alternative low-carbon and zero-carbon fuels, including the development of lifecycle GHG guidelines. In its submission, CSC used AidaNOVA, a dual fuel LNG capable cruise ship as a practical example to illustrate the implications of engine methane slip on GHG emissions. Using AidaNOVA engine specifications, CSC estimated the most likely GHG footprint of AidaNOVA and compared it to the ship's hypothetical equivalent running on MGO (Figure 47). It showed that the engine technology chosen by AidaNOVA (a four-stroke low-pressure dual-fuel engine popular with cruise ships) using LNG resulted in more GHG emissions than using MGO.

CSC suggested that activities under the IMO GHG Strategy should focus on delivering short-term emission reductions in the existing fleet and speeding up the development of genuine low carbon fuels and the roll out of zero emission vessels, instead of engaging in a complicated and ultimately unproductive shift from one fossil fuel to another. MEPC was scheduled to discuss the submission in its sixth and seventh meetings of the Intersessional Working Group on Reduction of GHG Emissions from Ships, in November 2019 and March 2020, respectively.

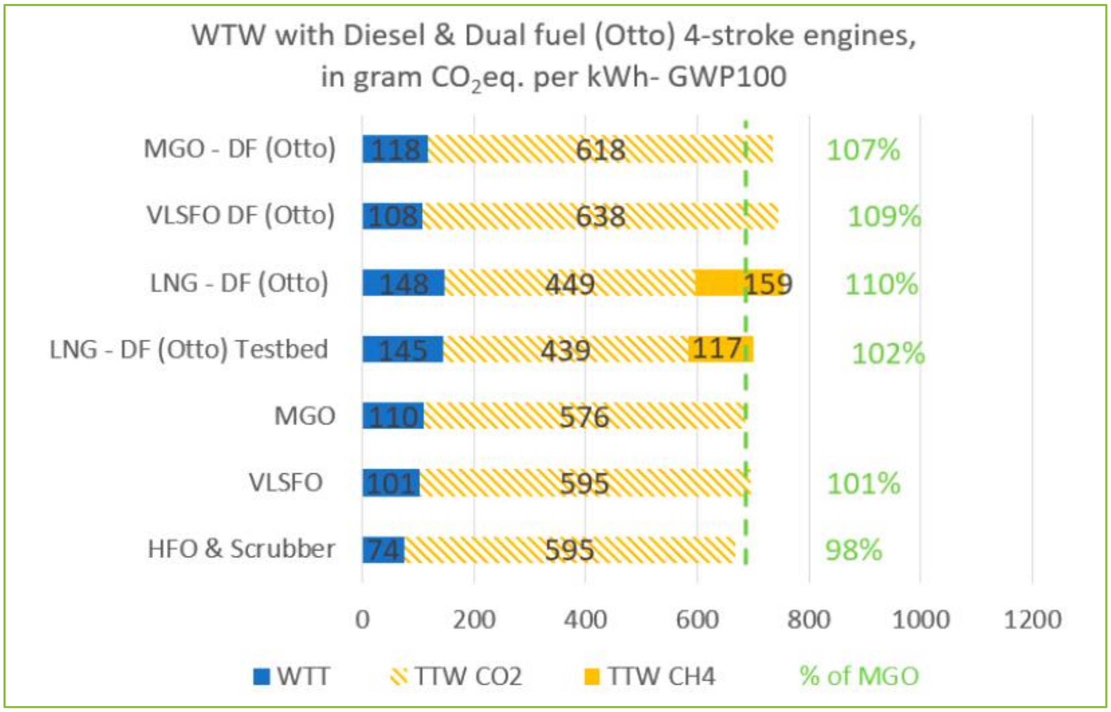


Figure 45. Well-to-wake (WTW) CO2eq emissions per kWh as a function of fuel and engine, GWP100

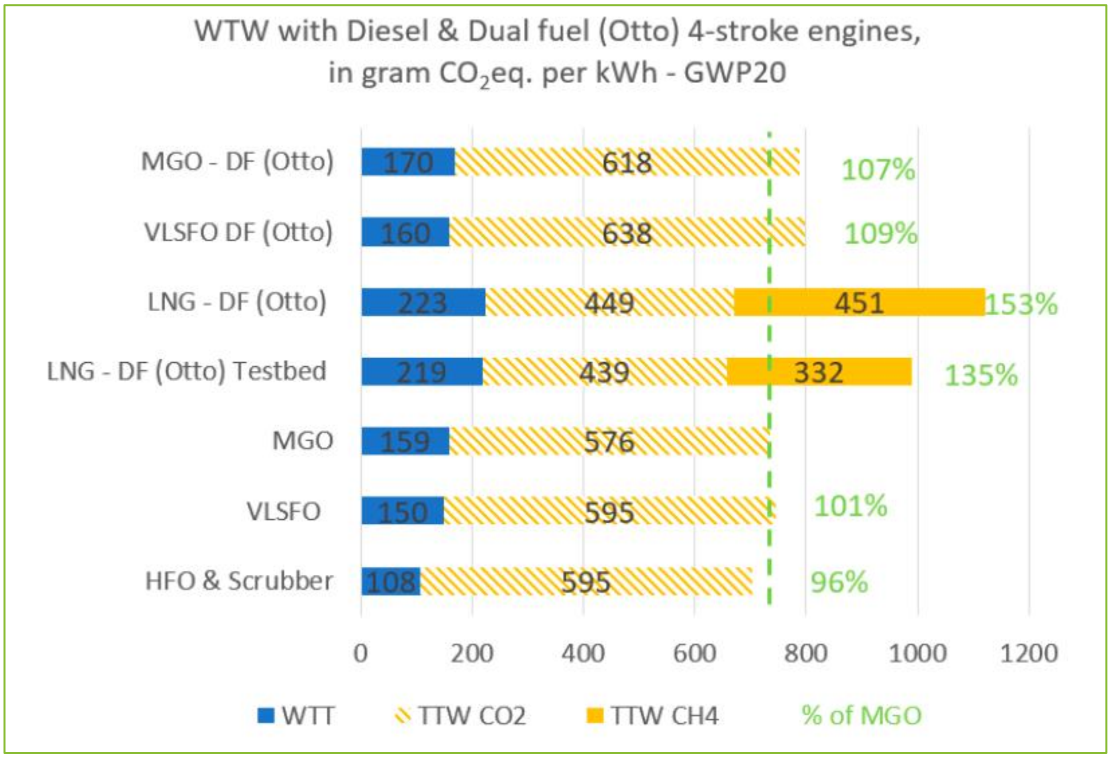
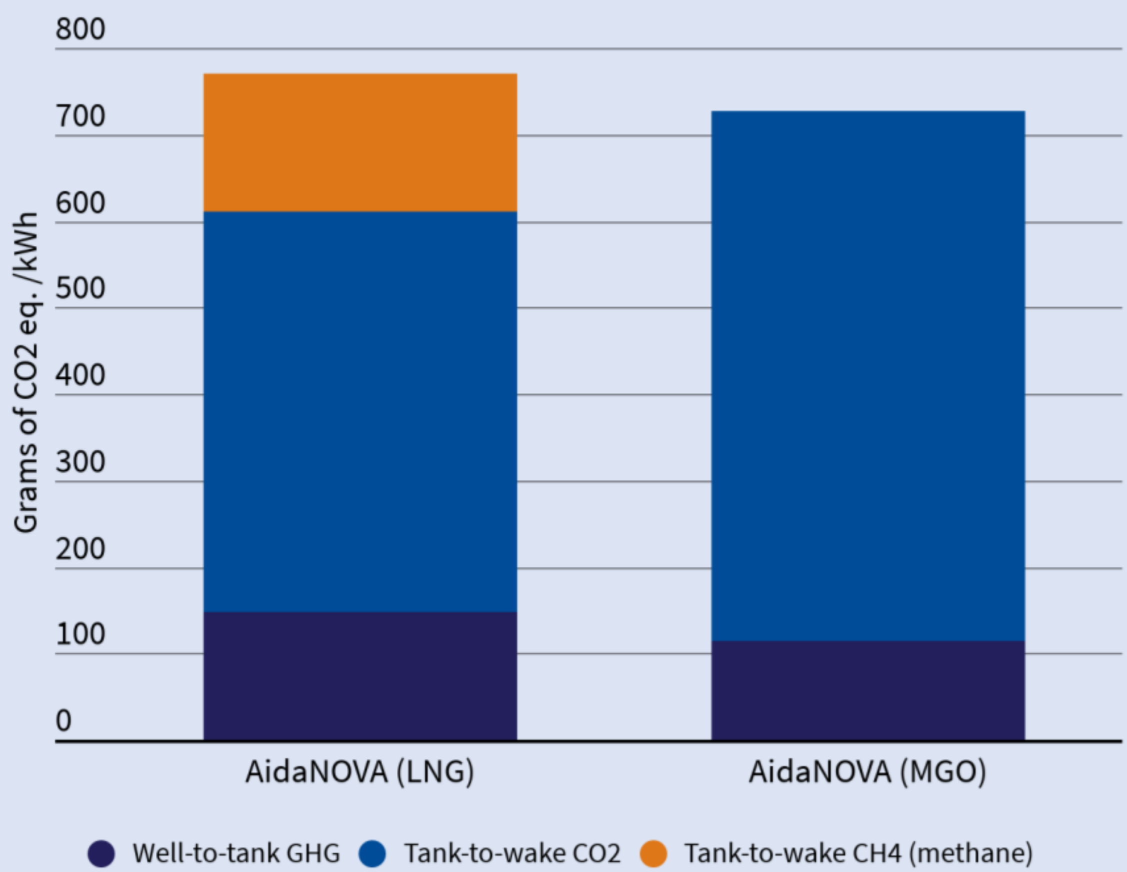


Figure 46. Well-to-wake (WTW) CO2eq emissions per kWh as a function of fuel and engine, GWP20



Source: values for the graph were taken from Well-to-Wake figures for 4-stroke (low pressure) dual-fuel engines using the global warming potential of methane of 100 years in the analysis from a short paper by Dr Elisabeth Lindstad (2019), chief scientist at SINTEF Ocean AS, Norway.

Figure 47. Comparison of CO2 equivalent emissions of dual fuel cruise ship AidaNova running on either LNG or MGO

Another report by the European Parliament Think Tank (2015) stated that measures proposed by IMO would only mitigate growth of the CO2 emissions but not lead to absolute emission reductions in the long run. Performance indicators such as CO2 emissions per tonne mile (e.g. EEDI) could inform the discussion on the challenges and ambition of a target. They also provided clear information to the stakeholders of the covered activities. However, they might also obscure a lag of ambition. If the growth of the activity data was stronger than the efficiency improvement of performance indicator, absolute emissions continued to grow despite an ambitious looking efficiency target (Figure 48). Moreover, to determine whether the global effort to reduce GHG emissions

<u>was sufficient to stay below 2°C, indexed targets needed to be transformed into absolute targets so that the global effort could be aggregated.</u>

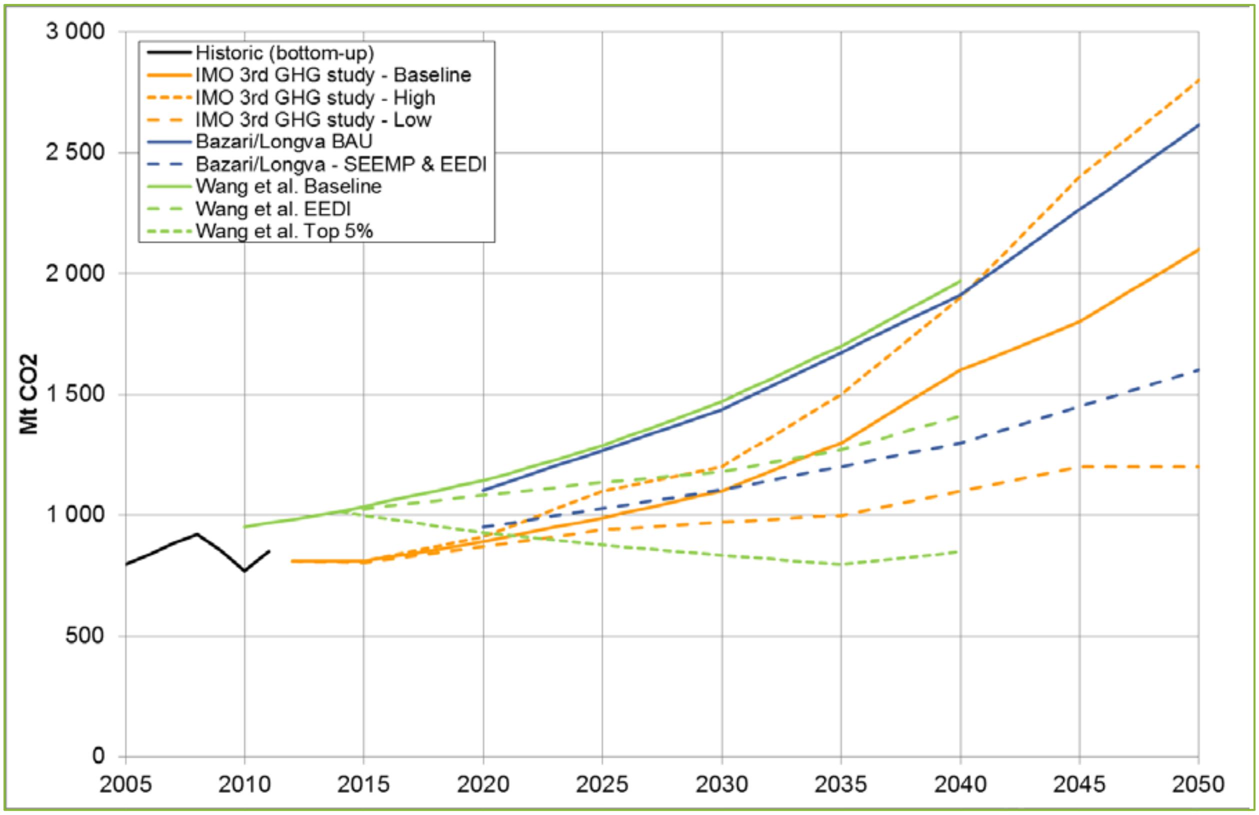


Figure 48. Emission projections for international maritime transport

Box 4: Summary of Recent Research on LNG as a Fuel for Shipping

Stenersen and Thonstad (2017) reported that the average methane emissions from all LNG engine types was 5.3 g/kWh energy produced. Lindstad and Bo (2018) demonstrated that this basically cancelled out the advantage of LNG in GHG emissions over conventional fuels.

For <u>existing vessels</u>, Lindstad et al. (2017) determined the best options to comply with IMO regulations to reduce sulphur emissions. The results showed that for vessels with the highest fuel consumption, HFO (with sulphur content up to 3.5%) with on-board exhaust gas scrubbing had the lowest cost while complying with IMO regulations. Distillates (diesel) with sulphur content less than 1.0% was an attractive option for smaller vessels. For all vessels, except for the largest fuel consumers, residual fuels desulphurised to less than 0.5% sulphur (e.g. LSHFO) were good abatement options. Retrofitting existing vessels for LNG was found to be too costly.

For new vessels, Lindstad et al. (2018) investigated the best options to meet IMO EEDI requirements. The results showed that LNG solutions were more expensive than HFO with scrubber and hybrid systems. The reductions in GHG emissions ranged from 5% with standard low-pressure dual fuel LNG technology to 20% with the best high-pressure LNG technology. The study also highlighted a critical shortcoming in EEDI, which only accounted for CO2 emissions and ignored the adverse impacts from well-to-wake emissions of other greenhouse gas (e.g. methane) that are much more potent than CO2.

Thinkstep (2019a) reported that Well-to-Wake emissions reduction benefits for LNG fuelled engines today compared with HFO fuelled ships were between 14% to 21% for 2-stroke slow speed engines, and between 7% to 15% for 4-stroke medium speed engines. If the global marine transport fleet for 2015 were to completely switch to LNG, there would be a 15% reduction in marine GHG emissions based on engine technology alone. The impact on climate change was assessed based on the100-year Global Warming Potential (GWP).

Lindstad (2019) conducted a critical review of the Thinkstep report. It was pointed out that the larger well-to-tank (WTT) emissions from production, processing and delivery of LNG through the supply chain and un-combusted methane from a ship's engine might more than nullify any GHG reduction benefits. Also, Thinkstep's report used higher thermal efficiency for LNG; low amounts of un-combusted methane from testbed data; a different conversion from gram of CO2 per MJ to gram of CO2 per kWh; and the selection of the 100-year GWP (instead of the 20-year GWP) gave more favourable results for LNG. After correcting the above using data collected by SINTEF Ocean and other research organizations, it was shown that the only LNG option that contributes to reducing GHG emissions is the 2–stroke high pressure dual fuel engine. For all other LNG options, the GHG emissions increased or were the same when compared to using MGO or HFO.

Lindstad (2019) argued for the use of the 20-year GWP because the warming impact of methane in the 20-year timeframe is 85 times larger than CO2 while its warming impact in 100-year timeframe is 28-34 times higher than CO2 and better reflected a need to rapidly reduce GHG emissions. Pavlenko et al. (2020) also considered the short-term impacts of using LNG. This is because methane has an atmospheric lifetime of only 12.4 years (a fraction of the lifetime of CO2) but has a much larger impact on the climate in the near term. Given that methane has significantly greater warming effects, it was argued that using the 20-year GWP better aligns with the urgent need to reduce GHGs, reflected in IMO's initial GHG strategy.

Thinkstep (2019b) published an addendum to address the main critiqued points of Lindstad (2019). Thinkstep insisted that the100-year GWP was the best practice partly because it was compulsory for the UNFCCC national GHG inventory reporting. Thinkstep argued that HFO should account for certain refinery emissions. In addition, Thinkstep insisted that their conversion method was justified because more specific engine efficiencies were used, and pilot fuel and urea use were considered. While Thinkstep supported the use of onboard measurement data Lindstad proposed instead of steady-state, testbed data, they insisted that IMO E2/E3 cycle was an accepted methodology in the absence of broadly measured data.

Assuming upstream methane emissions were well-controlled and using the 100-year GWP, Pavlenko et al. (2020) reported that LNG high-pressure injection dual fuel (HPDF) engines emitted 15% less life-cycle GHG emissions than MGO; and LNG Low-pressure injection dual fuel (LPDF) slow-speed, two-stroke engines emitted 9% less life-cycle GHGs than MGO. However, LNG Low-pressure injection dual fuel medium speed, four-stroke engines, the most popular LNG engine technology currently, emitted 8% more lifecycle GHGs than MGO. If the 20-year GWP was used, HPDF was the only engine type using LNG that had lower life-cycle emissions than MGO (3% lower).

As more LNG production shifts to shale gas, it is more difficult to control upstream methane emissions. If upstream methane emissions were not well controlled and using the 100-year GWP, only the HPDF engines emitted less life-cycle GHG emissions than MGO. If the 20-year GWP was used, there was no climate benefit from using LNG, regardless of the engine technology. It was concluded that using LNG did not deliver the emissions reductions required by the IMO's initial GHG strategy, and that using it could worsen the climate impacts from shipping.

For cruise ships, Pavlenko et al. (2020) compared LNG and conventional fuels in both LPDF medium-speed, four-stroke engines and medium-speed, four-stroke marine diesel engines. All the results for the 100-year GWP and the 20-year GWP showed that LNG emitted more GHG than conventional fuels. Similarly, Lindstad and Rialland (2020) showed that increased use of dual-fuel (Otto) LNG engines (which are the current option for cruise vessels and other vessels using 4 stroke engines) would increase GHG emissions compared to conventional fuels (MGO, HFO with Scrubber, and VLSFO). Using AidaNOVA engine specifications, the Clean Ship Coalition (2019) also showed that the engine technology chosen by AidaNOVA (a four-stroke low-pressure dual-fuel engine popular with cruise ships) using LNG resulted in more GHG emissions than using MGO.

Lindstad and Rialland (2020) pointed out that high-pressure dual-fuel (diesel) 2-stroke LNG engines were already delivering 15% GHG reductions of Well-to-Wake emissions for ships. To fully take advantage of LNG as a potential transition fuel (e.g. for ammonia when it is available), it was suggested that 4-stroke dual-fuel (diesel) LNG engines needed to be developed.

4.5.1.7 Low Sulphur Fuel

MARPOL Regulation 14 further lowered sulphur content on January 1, 2020 for ships operating outside ECAs. The ships using conventional fuels have three options for compliance:

1. for ships using scrubbers, Heavy Fuel Oil (HFO) or High Sulphur Fuel Oil (HSFO) with a maximum sulphur content 3.5% mass can continue to be used;
2. switch to Very Low Sulphur Fuel Oil (VLSFO) with maximum sulphur content 0.50% mass; or
3. switch to Marine Gas Oil (MGO) with maximum sulphur content 0.50% mass

Finland and Germany reported problems with future hybrid fuels with 0.5% sulphur content (e.g. VLSFO) during a black carbon measurement campaign in an IMO submission (Finland and Germany, 2019). Germany carried out the black carbon measurement campaign with two of the three recognized measurement methods (FSN and PAS) to analyse the impact of different fuel oil qualities on black carbon emissions. A black carbon emission analysis was carried out on future hybrid fuels with 0.50% sulphur content from different sources and different production processes, in comparison to two conventional fuels, HFO and MGO with ISO 8217 DMA designation, as reference, and a future synthetic Gas to Liquid (GtL) fuel, at varying engine ratings on a test bed.

The results showed that there was a high aromatic content in future low sulphur marine fuels. There was a clear trend for increasing black carbon emissions with increasing aromatic content (Figure 49). The increased black carbon emissions ranged from 10% to 85% when compared to HFO and ranged from 67% to 145% (a factor of 2.45) when compared to MGO with DMA designation. The highest black carbon emissions were generally detected at 75% and 25% engine load. The 0.50% sulphur fuel with 95% aromatic compounds showed the highest black carbon emissions at 25% load with 8 mg/Nm^3, followed by 75% load with 7 mg/Nm^3.

Since black carbon has a warming impact on climate over 4,000 times and over 1,000 times more than carbon dioxide per unit of mass in 20-year and 100-year timeframe, respectively, Finland and Germany proposed changes to the specification of marine fuels of the ISO 8217 petroleum standard to include aromatic content. This would enable a better qualification of marine fuels with respect to their environmental performance in terms of black carbon emissions and their ignition and combustion quality.

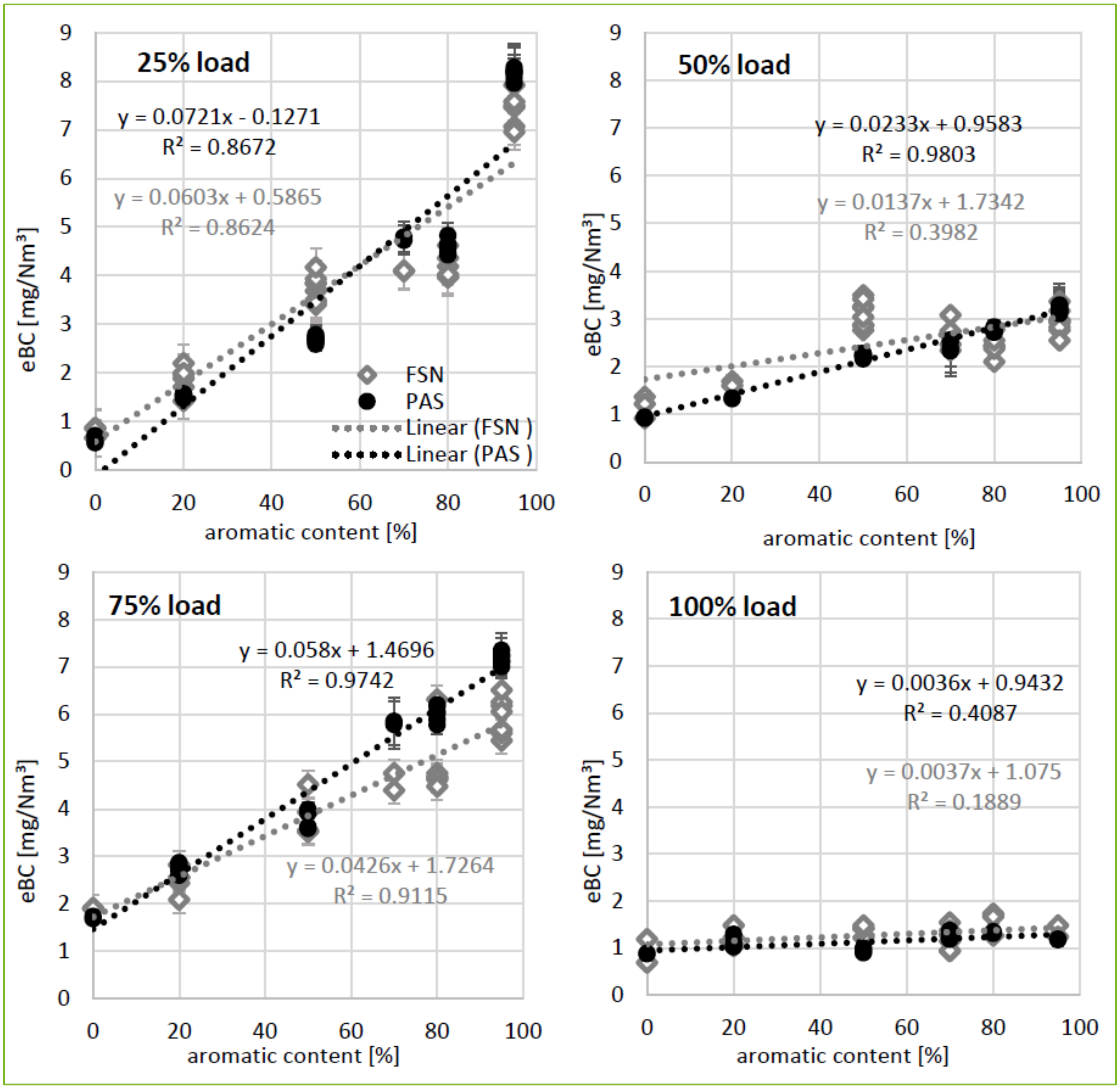


Figure 49. Black carbon emissions for 25, 50, 75 and 100% engine loads in relation to fuel aromatic content

4.5.2 Vessel Energy Efficiency / Saving Measures and Technologies

Besides fuel solutions, improving energy efficiency in ship design and operation are also important in reducing emissions. There are many energy saving measures and technologies. It is important to present the key categories of energy saving measures and example technologies under each category to show the broad range of possibilities and potential, as well as to ensure policy development does not focus on a few technologies only but consider a full range of technologies and measures available.

In Norway, research organizations such as SINTEF Ocean (formerly Marintek) and academic institutions (e.g. Norwegian University of Science and Technology) conduct research and development in many of the categories. However, a lot more research and development are still required.

In Figure 50, Wang and Lutsey (2013) show six categories of energy saving measures and example technologies. Improvements promoted by IMO for EEDI and improvements promoted by industry from practical experience are also reflected in Figure 50. A similar table of energy saving categories with example technologies is presented in Figure 51 and Figure 52 by Ballou (2013) to show IMO recommended measures for SEEMP.

Wang and Lutsey found that industry-leading ships are about twice as efficient as industry laggards across major ship types, due to new ships' technical efficiency improvements, operational speed practices, and ship size differences. For example, the top 5% of container ships have a carbon dioxide (CO2) emission intensity (i.e. emission rate per unit of cargo carried) that is 38% lower than industry-average container ships, whereas the bottom 5% have 48% higher CO2 emissions. Similar trend is seen between shipping industry leaders and laggards across the other major ship types (e.g. tankers, general cargo, bulk carriers).

An analysis by Wang & Lutsey (2013) indicated that by fully embracing the available technologies and best practices of the top 5% industry leaders of today, there was the potential to cut international shipping's CO2 emissions in half by 2040 even when business-as-usual freight movement doubles (Figure 48). This was achieved by using class-leading green technology (e.g. state-of-the-art diesel engines with electronic controls) and in-use operational measures (e.g. speed reduction) that industry leaders were already putting into practice. Among all the measures, the most important one to achieve such a level of efficiency was designing for and operating at lower speeds (Figure 49). The idea to fully utilize available technologies and best practice was also advocated by the European Parliament (2015) and Pavlenko et al. (2020). Lindstad and Bo (2018) had also called for using technologies to reduce hull resistance and Lindstad stated the need for more research into energy efficient technologies (Martin, 2019).

Area	Technology	Potential CO_2 and fuel use reduction	Improvements promoted by EEDI standards?	Improvements promoted from in-use efficiency policy?
Engine efficiency	Engine controls	0-1%	✓	✓
	Engine common rail	0-1%	✓	✓
	Waste heat recovery	6-8%	✓	✓
	Design speed reduction*	10-30%	✓	✓
Thrust efficiency	Propeller polishing	3-8%		✓
	Propeller upgrade	1-3%		✓
	Rudder	2-6%	✓	✓
Hydrodynamics	Hull cleaning	1-10%		✓
	Hull coating	1-5%		✓
	Water flow optimization	1-4%	✓	✓
Aerodynamics	Air lubrication	5-15%	✓	✓
	Wind engine	3-12%	✓	✓
	Kite	2-10%	✓	✓
Auxiliary power	Auxiliary engine efficiency	1-2%	✓	✓
	Efficient pumps, fans	0-1%	✓	✓
	Efficient lighting	0-1%	✓	✓
	Solar panels	0-3%	✓	✓
Operational	Weather routing	1-4%		✓
	Autopilot upgrade	1-3%		✓
	Operational speed reduction*	10-30%		✓

Notes: "✓" = promotion of the practice/technology; percents in the table are not strictly additive
* CO_2 and fuel reduction rate depends upon the rate of speed reduction and extent to which engine design modifications, controls, design rating//tuning are included

Figure 50. Examples of ship efficiency measures

Efficiency Improvement Strategy	MEPC.1/Circ. 683 Section	Comments
Fuel-efficient operations		
Improved voyage planning	4.2-4.3	This category addresses ship route optimization in planning and execution using available software tools. IMO offers guidelines for voyage planning in its resolution A.893(21) (25 Nov. 1999).
Weather routing	4.4	Weather routing is a less comprehensive method of route planning that allows ships to avoid adverse weather conditions. Some solutions, however, may increase fuel consumption.
Just-in-time	4.5-4.6	This category is related to the concept of "Virtual Arrival," whereby, through communication with the destination port, a ship may slow down and delay arrival to avoid port congestion.
Speed optimization	4.7-4.10	Speed optimization includes "slow steaming," but also considers the optimal speed for a given ship design, as well as gradual increases in speed when leaving port. Speed reduction can result in adverse consequences, including increased vibration, soot, and fuel consumption.
Optimized shaft power	4.11	Optimizing shaft power includes running at constant RPM and usage of electronic engine management systems rather than human intervention.
Optimized ship handling		
Optimized trim	4.12	Most ships are designed to operate most efficiently with a designated amount of cargo at a certain speed. Adjusting fore/aft trim can have a significant effect on fuel consumption for a given draft and speed. Trim effects may be less noticeable in heavy seas.
Optimized ballast	4.13-4.15	Ballast is used to adjust trim, and has a significant effect on steering and autopilot response. A ship's Ballast Water Management Plan must also be observed.
Optimized propeller and inflow	4.16-4.17	Improvements to propeller design and water inflow to the propeller can increase propulsive efficiency.
Optimized use of rudder and autopilot	4.18-4.20	Misadjusted or poorly designed automated heading and steering control systems can cause excessive fuel consumption due to added resistance and distance sailed off track.
Maintenance and logistics		
Hull maintenance	4.21-4.24	Hull maintenance includes cleaning, repairing, and painting of the hull to reduce roughness, and propeller cleaning and polishing.
Propulsion system	4.25-4.27	Efficient operation of the propulsion system can be improved by using automated electronic engine control and monitoring systems. Preventive maintenance and timely repairs of malfunctions are essential for efficient operation.
Waste heat recovery	4.28-4.29	Products are now available that use thermal heat losses from power plants and exhaust gas to generate electricity and/or additional propulsion.
Improved fleet management	4.30-4.31	Effective fleet management offers one of the largest potential improvements in ship operating efficiency. (IMO and others estimate potential fuel savings as high as 50%.) The guiding objectives are to maximize paid passages and minimize ballast voyages for the period.

Figure 51. IMO recommended measures for SEEMP.

Efficiency Improvement Strategy	MEPC.1/Circ. 683 Section	Comments
Improved cargo handling	4.32	Port efficiency is an important component of total ship efficiency. Delays at port due to congestion or inefficient usage of port facilities result in higher energy consumption as well as delayed departures. Efficient transfer to connecting transportation services (road, rail, etc.) should also be considered in the total efficiency calculation.
Energy management	4.33-4.34	This parameter addresses efficient use of shipboard electrical services. Thermal insulation and optimized locations for stowing refrigeration containers are factors in this measure.
Fuel type	4.35	Changing to some fuel types, for example, liquid natural gas (LNG), improves EEDI /EEOI because they produce lower carbon emissions per ton. Switching to higher viscosity bunker may reduce operating cost, although this does not improve EEOI. In either case, modifications to the power train may be necessary.
Other measures	4.36-4.39	This category includes new innovations in tracking fuel consumption, renewable energy resources, using shore power (cold ironing), and reducing hull friction (bubbles, etc.)

Figure 52. IMO recommended measures for SEEMP (continued)

Wang and Hon (2011) also compiled the marginal carbon dioxide abatement cost of these efficiency improvement technologies. Marginal abatement cost illustrated greenhouse gas (GHG) emission reductions from design standards, retrofit technologies, and operational measures that improved ship energy efficiency relative to their costs.

In Figure 53, efficiency measures were arranged from left to right according to increasing cost per tonne of CO2 averted. It was assumed that the measure with the lowest marginal abatement cost would be adopted first, followed by the one with the second lowest marginal abatement cost etc. The emission reduction potential of the remaining measures decreased, and the cost increased as each additional measure was implemented. The width of each bar represented the potential of the measure to reduce CO2 emissions from the world fleet. The height of each bar represented a weighted average marginal cost of avoiding one tonne of CO2 emissions through that measure, assuming that all measures to the left were already applied.

It is shown that propeller polishing had the lowest average marginal abatement cost, with moderate CO2 reduction potential. Speed reduction had the largest reduction potential, with moderate cost. Solar panels had the highest marginal abatement cost, with limited CO2 reduction potential.

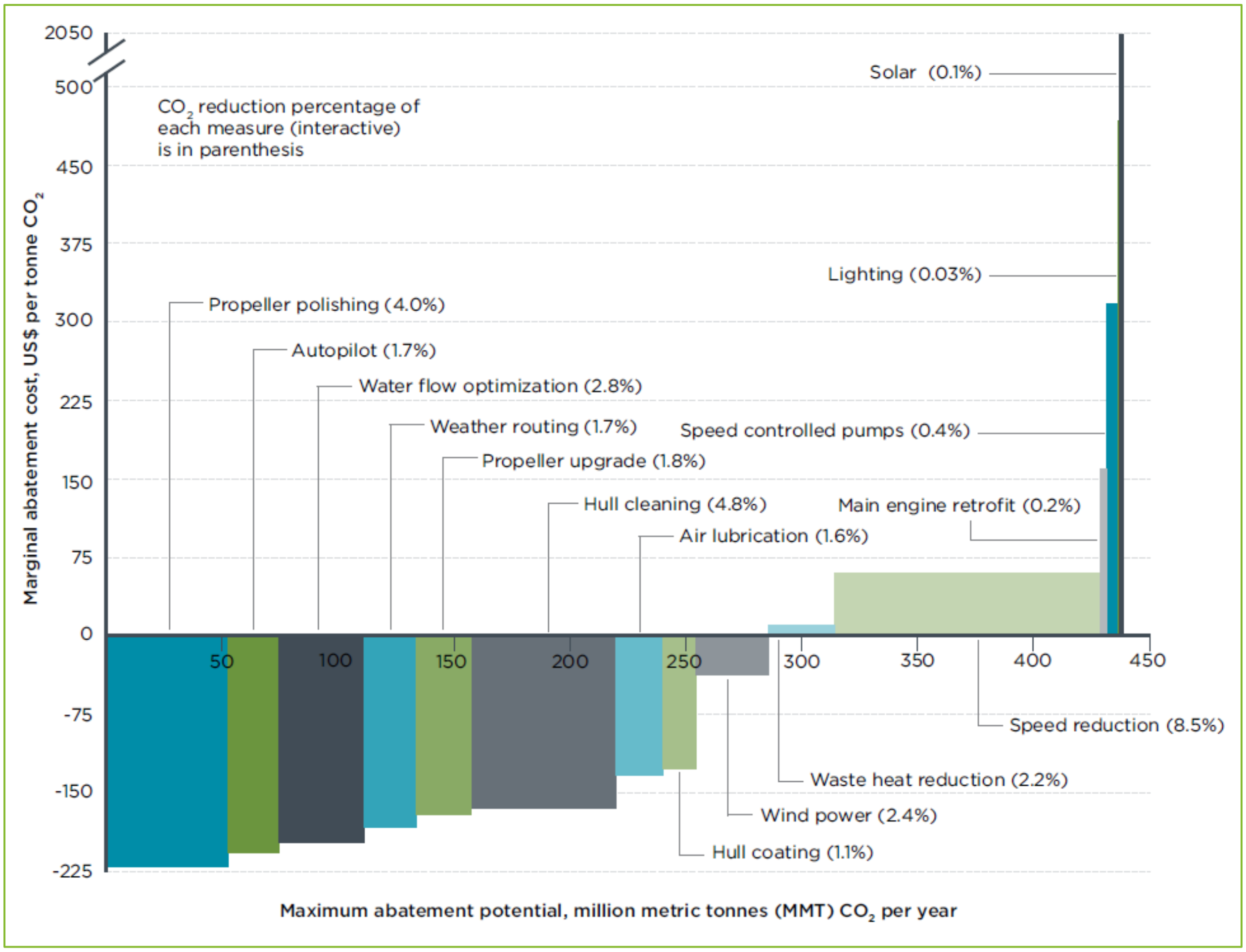


Figure 53. Marginal CO2 abatement costs of technologies

4.5.3 Autonomous Ships

With key benefits in energy and operational efficiency, autonomous ships will have various positive impacts on climate and the environment. Autonomous ships can have more aero- and hydrodynamic designs to minimize wind and water resistance. With no crew, there is no need for the deck house, crew accommodation, ventilation, heating and sewage systems etc. This will make the ship lighter, more energy efficient and consume less fuel, thus reducing operating and construction costs and facilitating new designs. It will be possible, for example, to electrify autonomous ships and operate them for longer distances using electric propulsion (Norwegian Ministry of Climate and Environment, 2019a).

In Norway, there are several pilot projects with autonomous technology (Appendix A). Vard is leading a pilot on autonomous load/unload solutions as part of an innovative fleet renewal program for low- and zero emission self-unloading ships. ASKO is developing autonomous, electric sea drones to transport cargo across fjords in a new multi-modal transportation system. Kongsberg is developing an autonomous, battery-powered cargo ship to establish a standardized and autonomous shipping and logistics concept for the global market.

The Norwegian government has been supporting the development of autonomous technology for shipping. For example, Enova provided grants of NOK 133 million for the construction of the *Yara Birkeland*, an autonomous electric container ship, and granted NOK 119 million for development of the AutoBarge design for the grocery wholesaler ASKO (Norwegian Ministry of Climate and Environment, 2019a).

Various Norwegian government departments are working to support autonomous shipping. The Ministry of Transport is amending the Pilotage Act to include autonomous navigation in coastal waters. The Norwegian Maritime Authority is involved in all projects related to autonomous ships and the certification of these ships. The Norwegian Coastal Administration assesses possible test beds for autonomous ships on an ongoing basis. The Maritime Authority and the Coastal Administration are both partnering with industry (Norwegian Ministry of Climate and Environment, 2019a).

In addition, the Norwegian Maritime Authority and the Norwegian Coastal Administration are working actively with IMO on autonomous ships. Norway also established a Forum for Autonomous Ships, which is an important arena for individuals and organizations who are interested in autonomous ships to exchange information and develop partnerships.

4.5.4 Onshore Power

Onshore power is electricity from land, replacing power production from the ship's own machinery (which typically runs on diesel) when docked. Since 98% of electricity in Norway is generated from renewable energy, onshore power is clean, renewable energy. Typically, onshore power meets just a limited percentage of the ship's energy requirements (lighting, heating, galleys, etc.) (City of Oslo, 2018).

For most existing vessels, upgrade of retrofit is required for onshore power if the ship's electrical system must meet the entire demand when docked. Aboard the ship, equipment includes transformers, distribution systems, control panels and junction boxes, cable reels and coupling devices, and frequency converters. On the shore side, extensive equipment is required to provide enough power to ships when docked, including a high-voltage network, transformers, control panels and junction boxes, frequency converters, cable reels and coupling devices.

Several standards have been developed for high and low-voltage systems as follows:

- IEC/IEEE 80005-1 High Voltage Shore Connection Systems – General requirements;
- IEC/IEEE 80005-2 High voltage shore connection (HVSC) systems – Communication interface description; and
- IEC/IEEE 80005-3 Utility connections in port – Part 3: Low Voltage Shore Connection (LVSC) Systems – General requirements

4.5.5 NRC Observations and Recommendations

1. The latest research publications on LNG and low sulphur fuel have highlighted the following important issues:

    a. There is a critical shortcoming in IMO EEDI and SEEMP, which narrowly focuses on carbon dioxide emissions and ignores other emissions such as methane that have much greater adverse impacts on global warming (e.g. warming impact of methane is 85 times larger than carbon dioxide in a 20-year timeframe). Due to this shortcoming, many LNG ships are meeting the energy efficiency requirements despite significant methane emissions from upstream (from production, processing and delivery of LNG through the supply chain) and unburnt methane (methane slip). Several studies documented in this report have demonstrated that some LNG technology ultimately fails to reduce GHG emissions.

    b. Policies focusing too narrowly on individual pollutants, such as carbon dioxide, NOx, sulphur, (e.g. IMO CO2 reduction targets for 2050, Phase 3 requirements of EEDI, NOx Tier 3 reductions and 2020 sulphur caps) may result in the shipping industry meeting all the regulatory requirements and still fall short on improving environmental impacts (e.g. the black carbon emissions from low sulphur fuels have a warming impact over 4,000 times more than carbon dioxide in a 20-year timeframe). Countries must urge IMO to act immediately to consider the entire lifecycle of emissions from each type of fuel and ensure it includes all greenhouse gas emissions in its maritime emissions reduction strategy.

c. The 20-year Global Warming Potential may be a better indicator of the global warming impacts of greenhouse gas emissions from shipping than the 100-year Global Warming Potential. Besides the arguments presented by different authors above, it should also be recognized that if governments, industry and IMO are not measuring the right things in the short-term (e.g. the more potent emissions like methane and black carbon) and focus on long-term measurement only, it is likely that the world will miss the short-term environmental targets. If we are not doing the right things in the short-term, we will not know what the right things are to do in the long-term and we may not have a second chance.

d. There are many technologies besides batteries, scrubbers, LNG, low sulphur fuel, onshore power etc. that can contribute to the reduction of greenhouse gas emissions. Research and development into technologies to improve hydrodynamics (e.g. reduce hull resistance through hull cleaning and coating), operational efficiency (e.g. reduce design speed), aerodynamics (e.g. use of wind power), thrust efficiency (e.g. propeller redesign), energy efficiency (e.g. engine derating) and auxiliary power (e.g. solar power) that can help to reduce GHG emissions must not be neglected.

e. The latest research on LNG methane emissions and low sulphur fuel black carbon emissions were published recently in or after the second half of 2019. The market will digest this new information and reflect decisions in large capital investments, such as new builds of vessels, down the road. This means, new builds statistics with zero- or low-emission technologies (e.g. LNG) published to date (e.g. Figure 1) may not be representative of the adoption rate of these technologies in the future and there may be significant changes in capital investment statistics.

2. In reviewing the two key Norwegian action plans – the Norwegian government's action plan for green shipping (Norwegian Ministry of Climate and Environment, 2019a) and Port of Oslo's action plan to become a zero-emission port (City of Oslo,

2018), it became apparent that the Norwegian government and the Port of Oslo are primarily focusing on a small number of technologies. These technologies are vessel zero- and low-emission fuels (battery-electric, battery-hybrid, hydrogen, ammonia, LNG, biodiesel and biogas), onshore power and autonomous ships.

Energy efficiency measures were mentioned briefly in the Norwegian government's action plan for green shipping but there was no detailed description on what action Norway has taken or will take. Energy efficiency measures were not mentioned in the action plan for the Port of Oslo, except for speed reduction. On the other hand, Norwegian research organization, SINTEF Ocean (formerly Marintek) is clear that there needs to be more research into energy efficient technologies (including hullforms and propulsion), increased focus on sustainable energy sources to reduce the use of carbon- and non-carbon-based fuels and development of wind assisted propulsion technologies, high-efficiency hullforms, weather-routing systems etc. (Martin, 2019). That view is shared by Pavlenko et al. (2020) and the European Parliament (2015). In addition, Equinor included requirements to implement energy efficiency measures in its long-term contracts with suppliers.

3. For Canada, it is important that policies related to the reduction of greenhouse gas emissions for shipping set ambitious SMART goals; use all available technologies and best practices to achieve emission targets cost effectively; support continuous research and development; develop strong innovation clusters to foster innovation and gain competitive advantage; create synergy with government, industry and academics collaborating on projects; the development of green technology to economic development, job growth and export opportunities; fund pilot projects to encourage entrepreneurship and risk taking; incorporate requirements of green solutions in public procurements; provide appropriate incentives for industry to embrace new green solutions; partner with industry to develop scale-up strategies for new green solutions; and continuously learn from the success of one market segment and replicate it in other market segments.

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6 Appendix A: Green Shipping Programme Pilots

Logistics 2030

Today's logistics infrastructure for general cargo in Norway is built on the road transport's premises with most goods transported from Europe passing through Eastern Norway, independent of final destination. A new national logistics - and terminal structure, that facilitates transition from truck transport via Eastern Norway to direct maritime transport to the entire country, is more sustainable. Direct maritime transport both ways between Europe and the West, and between Europe and the East of Norway, will reduce costs and GHG emissions and improve the cargo flow balance.

Consequently, the goal of the study is to develop a knowledge base and plan that can help realize this sustainable logistics and terminal structure. At the end of the project, customers will be able to test a new sea-based logistics structure between Norway and Europe. The test will be realized over the course of 3-4 years, followed by large scale implementation resulting in significant cargo transfer from road to sea in 5-10 years.

Pilot owner: ASKO

Participants: Flowchange, Seatrans, DFDS, Grieg Star, Hydro, Norske Havner, Stavanger Havn, Klima- og miljødepartementet, Oslo kommune/Oslo Havn, Bergen Havn, Flora kommune, Universitetet i Sørøst-Norge (USN), SINTEF, Menon, The Norwegian Coastal Administration, Norwegian Maritime Authority, Enova and DNV GL

Status: The project was launched in March 2019 and is in the closing stages of mapping cargo volumes and trade patterns between Norway and Europe. Phone interviews with approximately 50 companies in addition to 20 in-depth interviews have been conducted. The results will be used to identify and evaluate national customer volumes that are suited for direct sea-based distribution to Norway from central warehouses or consolidation terminals in Europe in combination with export cargo. Further project work includes mapping of current transport offering and sketching a proposed sea-based logistics structure for 2030.

Maritime transport of raw building material and grain

Large volumes of raw building material and grain are transported on relatively small bulk carriers along the coast. This fleet is characterized by high age, low renewal rate and fossil driven propulsion systems.

Through this pilot HeidelbergCement and Felleskjøpet Agri want to evaluate the feasibility of combining two cargo owners' logistics between the east and the west of Norway, under the hypothesis that the total goods flow combined with long-term chartering contracts can make it possible to realize a zero-emission bulk carrier.

Pilot owner: HeidelbergCement and Felleskjøpet Agri

Participants: ABB, Enchandia, Flowchange, Gasnor, Grieg Star, Hordaland Fylkeskommune, Hyon, Kongsberg Maritime, The Norwegian Coastal Administration, Kystrederiene, Norwegian Maritime Authority, SINTEF, Vard and DNV GL

Status: The pilot was initiated in March 2019. Analyses of historical shipments have revealed a significant potential for coordination and co-utilization of vessels. A requirements specification for the logistics solution with zero emission ships is under development. Possible zero-emission solutions, green contract regimes and cost-benefit analysis are being evaluated.

Fleet renewal, next generation coastal bulk carrier

The small-sized bulk – and general cargo fleet used for domestic coastal transport has an average age of approximately 30 years. There is a need for green fleet renewal in order to sustain this transport in the future.

Vard's goal with this pilot is to establish an innovative fleet renewal program for low- and zero-emission self-unloading ships, based on electric transmission and autonomous load/unload solutions, and designed for the market needs up to 2040.

Pilot owner: Vard

Participants: ABB, Enchandia, Flowchange, Gasnor, Grieg Star, Felleskjøpet Agri, HeidelbergCement, Hyon, Kongsberg Maritime, The Norwegian Coastal Administration, Kystrederiene, Norwegian Maritime Authority, SINTEF and DNV GL

Status: The pilot was started in April 2019. The ship segment is mapped, concept development is initiated, logistics system is evaluated and a roadmap for evaluation and weighing of measures is established. Current phase is focused on design development.

Port transition barometer

Ports are central for maritime transport's competitiveness and for cargo transfer from road to sea, both as logistics, business and energy hubs. Ports can influence the development of these aspects through transparent and targeted measures.

Through this pilot Norwegian Ports Association wants to promote cargo transfer from road to sea in Norwegian ports, in a bid to reduce GHG emissions in the transport sector and the traffic intensity on roads, and accelerate the development of zero-emission ports (green ports). A measurement system (port barometer) will be developed, which through a port index can document the ports' facilitation of cargo transfer and measure the effects in terms of increased volumes at quay and reduced emissions. Further, the pilot should facilitate identification and sharing of best port practices and identify and develop measures for increased green cargo transport through the ports.

Pilot owner: Norske Havner (Norwegian Ports Association)

Participants: Selected member ports, ship owners/cargo owners, The Norwegian Coastal Administration and DNV GL

Status: The pilot was initiated in August 2019.

Hydro(gen)ship

Can a hydrogen fuelled vessel be financially competitive? If so, it could potentially be a game-changer in the maritime industry as the first zero emission bulk vessel in the world!

Hydro Aluminium has regular aluminium shipments to the ARA-area from their production site in Sognefjord (Norway). At the same time, Hydro's Energy department has the means to produce Hydrogen in the same area as the loading port. The Pilot's intention is to establish if a H2 driven bulk carrier is feasible (including H2 production) and where the gaps lie compared with a conventional vessel, as they are operated today.

Pilot owner: Hydro

Participants: ABB, Enchandia, Flora Municipality, Flowchange, Gasnor, Hordaland municipality, Hydro Energi, Hyon, Kongsberg Maritime, Norwegian Maritime Directorate, SINTEF, Vard, Wärtsilä, ZEM, DNV GL

Status: The pilot was initiated March 2019. Work groups have been established to cover the different tasks to be assessed.

Multimodal transport system with autonomous sea drones

There is a need for cost efficient multimodal transport of cargo over short distances to reduce road traffic and eliminate emissions.

The pilot develops a commercially and technically realizable zero-emission concept, where autonomous, electrical and flexible sea drones transport across fjords and short distances, and in combination with electrical trucks constitute a cost-efficient door-to-door transport system. Flexibility includes transport of different cargos; ro/ro, container and bulk.

Pilot owner: ASKO

Participants: Kongsberg Maritime, Naval Dynamics, Norwegian Maritime Authority, The Norwegian Coastal Administration, ABB, Enova and DNV GL

Status: The project is currently developing the concept with focus on the sea drone including propulsion and electrical system, cargo loading/unloading including the berth/terminal and business and technical risk analysis.

Hydrogen by the sea

This pilot will work to develop knowledge and understanding needed for the successful introduction of zero emission shipping and how hydrogen can best contribute to this target. The pilot will investigate how (and where) to develop a maritime hydrogen infrastructure based on the real demands in shipping. The key focus areas are Norwegian coastal shipping and short sea shipping in the North Sea.

Pilot owner: Equinor

Participants: Gasnor, Port of Stavanger, Østensjø Rederi, Hyon, Flora municipality, Norwegian Shipowners' Association, Seatrans, Norwegian Maritime Authority, DNV GL

Status: The pilot was initiated early in 2018. Initial case studies to explore how to synchronize supply and demand are under way.

Environmental Port Index (EPI)

The largest Norwegian cruise ports have developed the Environmental Port Index (EPI) - a methodology for quantifying and reporting ships environmental performance in ports. By rewarding green ships, Norwegian ports expect to attract "best in class" ships to Norwegian ports. The idea is to offer incentives for investing in green technologies as well as to increase the barriers for the more polluting ships. For port areas, this will lead to a significant reduction of ship emissions and impacts.

This pilot will contribute to the introduction of EPI as a common standard for ships in Norwegian ports (and elsewhere). In its initial phase the project is focusing on cruise ships but it will eventually include other classes of ships too.

Pilot owner: Port Bergen

Participants: Port of Oslo, Port of Flora, Menon, Norske Havner, KS Bedrift, The Norwegian Coastal Administration, DNV GL

Status: An AIS-based (Automatic Identification System) emission inventory for cruise ships in Norwegian ports has been established. It has so far been used to calculate environmental damage cost (e.g. overall, selected ports, per port call). The project has also estimated potential annual cost savings and emission reductions for green cruise ships (case ships), assuming globally uptake of standards differentiating on environmental performance in ports.

Green financing solutions

The green shift in coastal shipping is dependent on use of innovative environmental technologies. Improved access to capital and financing of new technical solutions will accelerate the shift.

The pilot aims to develop and test attractive financing alternatives and structures that support new and future technical solutions, with involvement from both the public and private sector.

Pilot owner: Danske Bank

Participants: Swedbank, Kystrederiene, GIEK, Enova, ABB, Hydro, Asko, Innovasjon Norge, Hyon, ZEM, Ship Owner Assoc., Seatrans, Torghatten, NOx-fund, DNV GL

Status: Pilot just established (June 2018).

Green smart vessel

The ongoing digitalization of onboard systems gives new possibilities for ship owners to optimize operations. The pilot "Green smart vessels" is focusing on the methodology behind establishing secure data systems onboard and ashore to achieve reductions in fuel consumption and emissions.

Pilot owner: Østensjø Rederi

Participants: Teekay, Statoil, ABB, DNV GL

Status: The pilot contains three scenarios describing the chain of information flow from the vessel, combining vessel data with shore-based systems, and how to share information with third parties. The first scenario is in progress (June 2018).

Plug-in hybrid fishing vessels

Fiskebåt (The Norwegian Fishing Vessel Owners' Association) aims to reduce greenhouse gas emissions from the fishing fleet by at least 40 percent. The pilot is conducting a technical survey of possible low and zero emission solutions for fishing vessels. It is a challenge that the fleet consists of very different vessels with different operating patterns.

Pilot owner: Fiskebåt

Participants: Corvus, Flora municipality, Norwegian Maritime Authority, ZEM, DNV GL.

Status: Fiskebåt has contributed with operational data for different vessels. Plug-in hybrid solutions with batteries as well as LNG and biofuel have been assessed for the different ship types. The goal is to link a chosen solution to a newbuilding project by 2020. The pilot study has recommended a study investigating barriers and possible solutions for an effective green shift, to be carried out.

Sea-based transport system for fresh fish

The rapidly growing aquaculture industry needs a sustainable alternative to road-based transport to reduce emissions, accidents and road wear.

The pilot develops a commercially and technically realizable concept for transporting fresh fish from central Norway to Europe. The pilot is an important learning project for socioeconomic analyses for all partners in the programme.

Pilot owner: Kystrederiene

Participants: Marine Harvest, Salmar, ABB, Menon, Norwegian Maritime Authority, DNV GL

Status: The project has shown that the concept is realistic for profitable ocean-based transport from central Norway to Europe to meet market needs. Results show great socioeconomic benefits. The solution is already realized using existing ships and shipping lines in the first phase, and then with new, climate-friendly hybrid ships in the following phase.

Biodiesel-powered plug-in hybrid ferry

Sustainable biodiesel provides low greenhouse gas emissions. The Torghatten pilot investigates the possibilities for building a ferry running exclusively on sustainable biodiesel. The pilot assesses sustainability issues, NOx emissions, as well as price and availability of biodiesel.

Pilot owner: Torghatten

Participants: ABB, Corvus, Echandia, Energy Norway, Gasnor, Goodfuels, Norwegian Maritime Authority, DNV GL

Status: MF Hornstind was completed in 2017. However, lack of reliability in biodiesel supply and high price means that biodiesel does not appear to be a valid alternative during the remaining contract period in Nordland. The ferry is also built to be able to go battery hybrid with marine gas oil, or fully electric for future tenders with zero and low emission requirements.

Hydrogen powered passenger boat

Hydrogen is the only zero emission fuel alternative for energy-demanding and long distances. Flora municipality, together with the local business community, has initiated a project for a hydrogen-powered fast boat for 100 passengers on the Florø - Måløy route. The pilot is developing the ship design while analyzing the feasibility, investments and operating costs, payback period and environmental benefits.

Pilot owner: Municipality of Flora

Participants: Maritime Association of Sogn and Fjordane, Kongsberg, ABB, Corvus, Echandia, KS Business, Statoil, Norwegian Maritime Authority, DNV GL

Status: Sogn and Fjordane County Municipality have a crucial role in the realization of the pilot by demanding a zero-emission solution through innovative procurement (e.g. a development contract). The goal is to have the fast boat in operation from 2021.

Autonomous battery-powered container ship

The pilot investigates how a new ship type, a battery-powered unmanned ship with zero emissions, can contribute to moving cargo from road to sea. The idea is based on DNV GL’s autonomous concept vessel, ReVolt. The ambition is to establish a standardized and autonomous shipping and logistics concept for the global market.

Pilot owner: Kongsberg

Participants: Port of Stavanger, Seatrans, Kystverket, Norwegian Maritime Authority, DNV GL

Status: Through this pilot, Kongsberg has developed competence which has been utilized in the Yara Birkeland autonomous ship, with automated cargo handling. The implementation of the pilot through Yara Birkeland will show that the concept is realizable and sustainable. After testing in 2018/19, a fully autonomous solution between Herøya-Brevik-Larvik will be in place by 2020.

Battery hybrid shuttle tanker

This pilot investigates how the use of batteries and utilization of vapor from the oil cargo can improve a shuttle tanker's operation and reduce fuel costs, while significantly reducing emissions of climate and environmental gases.

Pilot owner: Teekay

Participants: Statoil, Kongsberg, ABB, Gasnor / Shell, Norwegian Maritime Authority, Maritime Battery Forum, DNV GL

Status: Teekay has four shuttle tankers under construction. Completion in 2019 and 2020.

Hybrid aquaculture vessel

Using LNG in combination with batteries can make vessels serving the aquaculture industry more energy efficient and can significantly reduce emissions. The pilot examines which hybrid propulsion system works best to reduce emissions and operating costs, as well as ensuring safe operation at the cages.

Pilot owner: ABB/Kystrederiene

Participants: Egil Ulvan Rederi, ZEM, Kongsberg, GMC, DNV GL

Status: Egil Ulvan Rederi is building the world's first plug-in hybrid cargo vessel, which also serves the fish farming industry. This is a highly advanced and environmentally innovative new build based on the Cargo Ferry Pilot and the Aquaculture Pilot under the Green Shipping Programme. Completion in 2020.

Green port

By analyzing energy consumption and offering liquid natural gas and electrical power to ships, ports can become green energy and logistics hubs. This pilot explores electric-powered port vehicles and cranes, smart efficiency-enhancing electronic goods and transportation management, as well as the use of plug-in charging stations for shore power, all-electric and hybrid ships.

Pilot owner:Port of Stavanger;

Participants: GMC, ABB, Kystrederiene, ZEM, Statoil, Kongsberg, Kystverket, DNV GL

Status: Port of Stavanger has achieved major reductions in emissions and costs by making climate and environment a central part of its business strategy. The port has become a showcase for other ports and is continuing to work for improvements. Port of Stavanger is today among the world’s largest bunkering ports for LNG-powered ships.

7 Appendix B: Norwegian Policy Recommendations

Greening the fleet: A technological innovation system (TIS) analysis of hydrogen, battery electric, liquefied biogas, and biodiesel in the maritime sector (Steen et al., 2019)

(from authors with SINTEF, Lund University and Norwegian University of Science and Technology)

7.1 General Policy Recommendations

- Support variety: The different Technological Innovation Systems (TIS) (e.g. hydrogen TIS, LBG TIS etc.) have advantages and disadvantages that make them suitable for different segments (e.g. cargo ship, ferries etc.) within the Norwegian Maritime Shipping Sector (MSS). The technologies presented in this report differ considerably in their maturation and implementation. Apart from biodiesel, they can all be regarded as being in early phases of development. Given the immense variety in ships and vessels (and hence energy needs), it is important that different Low- and Zero Carbon (LoZeC) technologies are supported.

- Beware of competition between emerging technologies: Although not covered explicitly in this report, emerging TISs often compete for market shares and scarce resources. A policy challenge is to support various LoZeCs simultaneously, for example by ensuring that niche market opportunities exist for different technological solutions.

- Make choices: LoZeC technologies can be implemented in pure or hybrid forms. Given the abundance of cheap, renewable electricity in Norway, there is considerable potential for the expansion of battery electric and hydrogen. Although we refrain from making clear recommendations on which energy solutions to choose for which market segments, it appears that further development and uptake of hydrogen could be supported by focusing on this energy solution for high-speed ferries.

- R&D support: It is highly recommended that policies continue to support R&D, which is needed in both upstream and downstream dimensions of the different TIS. This includes supporting Norwegian participation in EU R&D networks.

- Financial support: As suggested in the report on the maritime sector to the expert committee on green competitiveness (Grønt Kystfartsprogram, 2016), financial support (e.g. in the form of favourable loans or guarantee schemes) is needed in order to reduce risks associated with investing in ships with new energy solutions.

- Cluster and networking support: The existing maritime clusters (e.g. NCE Maritime CleanTech) appear to be an important locus of innovation activities related to LoZeC solutions. Support for cluster and networking initiatives should be continued and strengthened.

- Increase the cost of fossil fuels: In order to create economic incentives to make implementation of LoZeC technologies attractive to shipowners and public procurers, fossil fuel subsidies should be removed. The implementation of a CO2 tax would incentivize fuel savings. Incomes from the CO2 tax, as well as the public money currently spent on subventions of marine diesel, should assist the implementation of LoZeC technologies, for example through a LoZeC bonus or a CO2 fund similar to NOx-fondet.

- Harbour fees: The implementation of differentiated harbour fees depending on individual ships' emissions (e.g. reduced harbour fees for ships with low emissions) can create further economic incentives for the introduction of alternative LoZeC solutions. However, there may be a need for national coordination and harmonization of harbour fees and other economic instruments between different ports, to avoid both complexity and inter-port competition (i.e. ports competing by charging low fees to attract customers).

- Licenses to operate: In both the petroleum and aquaculture sectors, licenses to operate should include GHG emission-level requirements for maritime transport (e.g. supply ships, workboats, and feed carriers).

- Provide support-seeking assistance: A number of our interviewees reported that accessing the existing support measures (e.g. from Enova and Innovasjon Norge) was sometimes challenging. This applied especially to shipowners with limited administrative capacity, typically in segments such as fishing and freight. We recommend considering whether 'application assistance' could be provided to facilitate access to these funds for a broader group of actors.

- Increase the number of development contracts: The development contracts resulting in the first battery electric ferry and the first hydrogen ferry have been very important for the development of these LoZeC technologies. We recommend increasing the number of development contracts. However, in order to mitigate economic risks, increased financial support within the development contracts should be considered.

- Public procurement as a tool: In the passenger ferry segment, public procurement has been of central importance to facilitating the development and uptake of various LoZeC technologies and LNG. Through public procurement (i.e. by requiring low- or carbon-free transport of goods), public actors can stimulate a transition also in other segments, such as freight.

- Maintain clear direction: It is of central importance to keep and further sharpen climate policies and emissions regulations, both on the national level and the international level. As a global frontrunner within sustainable shipping, Norway should continue lobbying the IMO and other international actors for stricter emission regulations and targets for maritime transport.

7.2 Biodiesel TIS-Specific Recommendations

Since all functions for the biodiesel TIS are judged as weak, several types of policy actions would be needed to strengthen the TIS. Given that it is possible to use biodiesel in conventional diesel engines, the best incentive for increased use of this alternative fuel would be to subsidize the high price. Financing the subvention could be done by removing the subvention of marine diesel. However, given the considerable concerns about biodiesel availability and sustainability (with current production methods), as well as the fact that it may prolong the use of fossil fuels, our recommendation is to not focus policy support on biodiesel within the MSS per se. However, support for continued R&D on new ways of producing biodiesel would be beneficial.

7.3 Liquified Biogas (LBG) TIS-Specific Recommendations

Overall, the LBG TIS is currently not very strong, as all functions apart from direction of search are assessed as weak. The main measure recommended for implementation in order to strengthen the entire TIS is to support resource mobilization through increased public funding. Support is needed for the production of LBG, construction of bunker infrastructure, and for the building of gas-powered ships. Parallel to developing infrastructure for fuel production and distribution, it is important to stimulate market formation. This could also be done via LBG-dedicated (localized) pilot projects that include upstream LBG production. Apart from resource mobilization, this would strengthen knowledge development and diffusion and entrepreneurial experimentation. Furthermore, to support market uptake, LBG could be subsidized to the extent that it would match the market price for LNG.

Maintaining a clear direction of search is crucial in order to succeed in strengthening the remaining functions. Therefore, our recommendation is to reinforce the direction of search by implementing policies aimed at increased use of LBG within the MSS. Initially, the targets for LBG-LNG mixes should be established

7.4 Battery Electric TIS-Specific Recommendations

Although there has been a rapid expansion of battery electric technology in the passenger segment in recent years, the battery electric TIS is still in need of further support. The main system strengths of the battery electric TIS is its high legitimacy, clear direction of search, strong market formation and resource mobilization, as well as the diverse entrepreneurial experimentation. These functions provide the foundation for the success of large-scale implementation of BE storage systems in the Norwegian MSS. In order to preserve these functions' strengths, it is of central importance to maintain funding possibilities and innovation support. This in turn is important to ensure continued uptake of battery electric also in other market segments (e.g. fishing and freight). The measure would also strengthen knowledge development and diffusion, which is currently assessed as intermediate, as one of the identified system weaknesses is the continued need for development and upscaling of technology.

To strengthen knowledge development and diffusion further, we recommend the implementation of policies aimed at more cooperation between the battery electric and hydrogen TISs, in order to create further synergies between the two technologies, which would also strengthen the development of positive externalities. This could be done through, for example, dedicated R&D and pilot programmes that encompass both technologies. We have also identified a need for education of ship personnel regarding maintenance and operation of battery electric systems. Education could strengthen the knowledge development and diffusion and the development of positive externalities, as it would build up experience that could be shared within the TIS. Ensuring access to standardized charging infrastructure would further strengthen the development of positive externalities and increase the process of legitimation of the BE TIS. This would require that current issues related to electricity grid development and upgrading are addressed.

7.5 Hydrogen TIS-Specific Recommendations

Hydrogen appears to be a promising alternative for several segments in the future and is one of few feasible options for larger vessels. Considering the immaturity of the technology and its maritime applications, it is important to increase resource mobilisation to create possibilities for knowledge development and diffusion and for entrepreneurial experimentation, which in turn would strengthen legitimation and create market formation. We recommend that the resource mobilisation should be strengthened through increasing public funding of hydrogen ship technology by prioritizing hydrogen technology within the public funding programmes. To achieve a rapid introduction of hydrogen propulsion, it is important that funding is offered to hydrogen production, the building of infrastructure, and the development of maritime applications and construction of ships.

To strengthen further the currently intermediate functions of knowledge development and diffusion and entrepreneurial experimentation, we strongly recommend that further development contracts should be awarded in the passenger segment, especially for high-speed ferries. In addition, to continue the improvement in the regulatory framework, especially regarding safety aspects, it is crucial to increase the process of legitimation within development contracts. It is especially important to achieve a classification of hydrogen ships, to avoid the costs of constructing a hydrogen vessel as an ‘alternative design’, which is Sjøfartsdirektoratet’s current classification. This, in combination with the development contracts, would also strengthen market formation.

To initiate market formation, we recommend that initially the use of grey hydrogen should be permitted in order to increase available volumes rapidly. However, to avoid unnecessary use of natural gas-based hydrogen without carbon capture and storage (CCS), and to encourage further the sustainable production of hydrogen, a time limit on the use of grey hydrogen should be implemented. Given limited fuel availability, we also recommend starting the implementation of hydrogen in segments in which the impact on emission reductions will be substantial, notably passenger vessels.

Along with the implementation of hydrogen ship technology, there will be a need for education of on-board personnel regarding the maintenance and operation of the new systems. In addition, universities and maritime schools should update their curricula to include the operation of hydrogen ships. Apart from creating knowledge development and diffusion, education would also strengthen the development of positive externalities, as it would build up human capital. With regard to the battery electric TIS, we recommend the implementation of policies aimed at more cooperation between the battery electric and hydrogen TISs, in order to create further synergies between the two technologies, which would also strengthen the development of positive externalities.

8 Appendix C: Additional Research Information

López-Aparicio et al. (2017) used ship call activity data to develop an emission inventory for the Port of Oslo that identified the main contributing harbour activities, including different operational modes of shipping, land traffic and cargo handling. Development of detailed emission inventories is essential for the design of effective measures to reduce emissions, and for providing boundary conditions for air dispersion models.

The study evaluated the implementation of onshore power, speed reduction zone and increased use of LNG by all domestic ferries[3] as measures to reduce emissions. It also considered emissions from harbour vessels (e.g. domestic ferries, tugboats) and oceangoing vessels. The study was complemented by the analysis of SO2 measured data from Oslo in combination with meteorological conditions to assess the potential impact of shipping emissions on urban air quality.

The vessels were divided into two groups in the study - oceangoing vessels and harbour vessels. Oceangoing vessels consisted of bulk carriers, ro-ro vessels (including car carriers), container vessels, cruises, international ferries, general cargo and oil/chemical tankers. In 2013, the Port of Oslo had around 3000 calls or registers of arrivals, with the international ferries (34.25%), followed by general cargo (22.20%) and container vessels (14.95%). Emissions from oceangoing vessels were classified into categories by the operational modes (cruising, manoeuvring, and at berth).

The harbour vessels consist of commercial fishing boats, domestic ferries, supply vessels, tugboats, and workboats, among others that mainly operate within the port area. Domestic ferries operate year-round, with higher activity in the spring and summer, while other harbour vessels mainly operate in summer.

The land activities considered were vehicle traffic, including the contribution from light, medium and heavy-duty vehicles, and the cargo handling equipment, which consists of forklifts, cranes, reach stackers, and terminal tractors.

The emission inventory developed estimated the emission of air pollutants (NOx, PM10, SO2) and greenhouse gases (GHGs; CO2, CH4, N2O) from shipping and land activities

[3] On 28 September 2016, case 260, Oslo City Council adopted a ten-point strategy for the use of electric (instead of LNG) ferries in the Oslofjord and shore power (City of Oslo, 2018)

in the port. The estimated emissions by vessel type, traffic and cargo handling equipment are shown in Table 24 and Figure 54.

Table 24. Emission (ton) by vessel type, traffic and cargo handling equipment for the Port of Oslo in 2013

Vessels/sector	NO_x	PM_{10}	SO_2	CO_2	CH_4	N_2O	CO_2-eq
Bulk carrier	10.10	0.15	2.71	461.58	0.00	0.02	468.14
RO-RO	19.93	0.31	5.43	946.83	0.01	0.04	960.43
Container	59.13	0.99	16.17	2806.72	0.02	0.13	2846.12
Cruise	164.41	3.49	58.69	10741.32	0.06	0.45	10881.70
International ferry	264.89	6.36	91.19	17223.79	0.09	0.72	17449.67
General cargo	28.60	0.43	7.90	1371.41	0.01	0.06	1390.70
Oil/chemical tankers	42.27	0.65	12.35	2115.54	0.01	0.09	2144.95
Commercial fishing	0.30	0.01	0.20	30.42	0.00	0.00	30.77
Domestic ferry	79.41	3.41	48.86	10241.14	1.38	0.31	10364.97
Recreational	4.55	0.20	2.84	461.25	0.06	0.01	466.66
Supply vessels	1.82	0.08	1.07	184.40	0.02	0.01	186.56
Tug - push boat	6.38	0.28	3.75	646.89	0.08	0.02	654.47
Work boats	5.74	0.25	3.38	582.26	0.08	0.02	589.09
Other vessels	8.80	0.39	5.50	893.29	0.12	0.03	903.77
Trafikk	22.15	0.58	0.01	2043.99	0.04	0.03	2054.73
Cargo handling equipment	40.89	0.45	0.00	5538.06	0.05	0.10	5571.33
Total	759.37	18.03	260.04	56288.88	2.03	2.04	56964.05

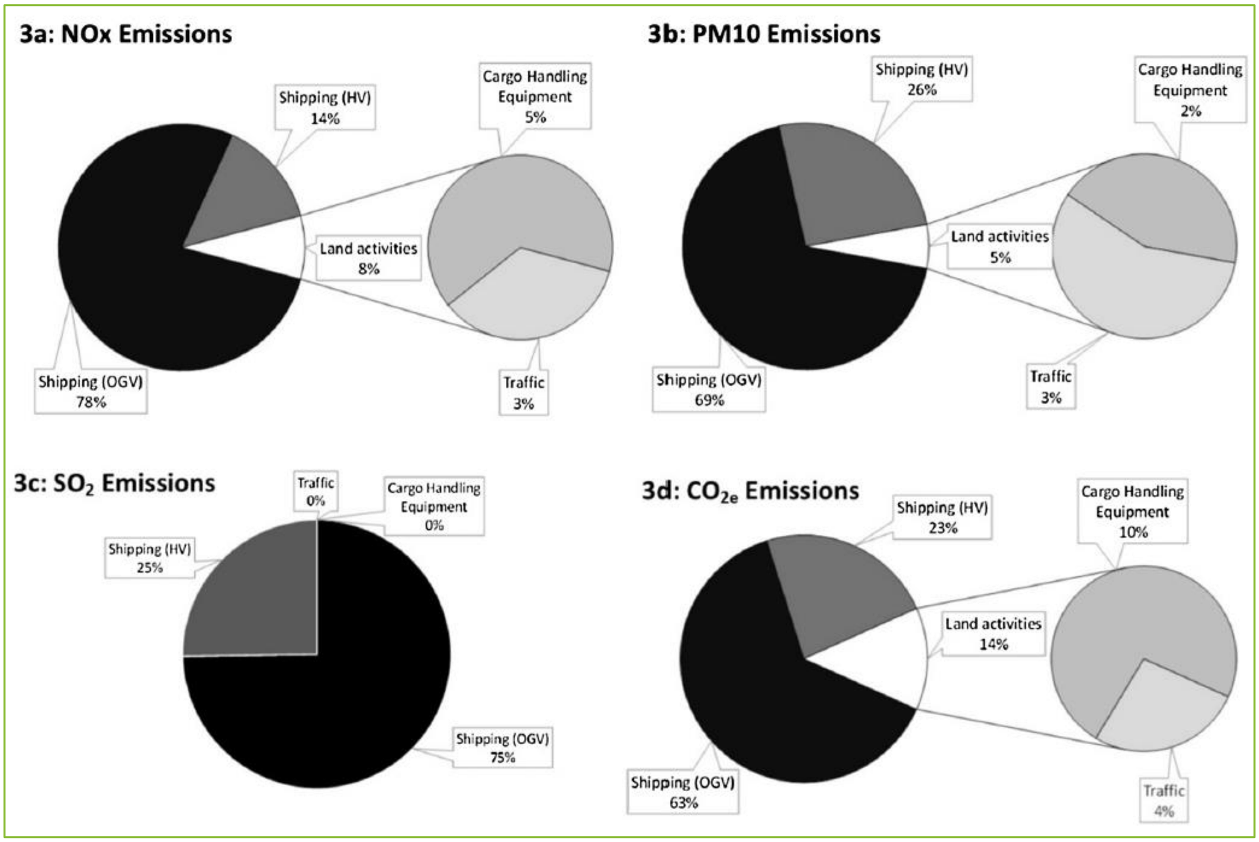

Figure 54. Emission contribution by sector in the Port of Oslo (2013)

Harbour vessels (HV)   Oceangoing vessels (OGV)

It was observed that emissions from ships, especially oceangoing vessels, were the main emission contributors in the Port of Oslo. Oceangoing vessels accounted for 63 to 78% of the total NOx, PM10, SO2 and CO2 emissions. The main contributors among oceangoing vessels were international ferries, cruises and container vessels while the main contributors to emissions among harbour vessels were domestic ferries.

The 2020 scenario accounted for (i) the expected increase in maritime traffic; (ii) compliance with a new regulation regarding sulphur content in ship fuel (<0.1%); and (iii) implementation of various mitigation measures. The mitigation measures included implementation of onshore power for selected oceangoing vessels, the establishment of a speed reduction zone at 12 knots and the increased use of LNG by all domestic ferries. The projected 2020 emissions by vessel type, traffic and cargo handling equipment are shown in Table 25.

Table 25. Projected emission (ton) by vessel type, traffic and cargo handling equipment for the Port of Oslo in 2020

Vessels/sector	NO_x	PM_{10}	SO_2	CO_2	CH_4	N_2O	CO_2-eq
Bulk carrier	11.14	0.14	0.30	502.91	0.00	0.02	510.15
RO-RO	26.37	0.35	0.71	1232.15	0.01	0.06	1250.14
Container	70.78	0.92	1.92	3269.38	0.02	0.15	3316.55
Cruise	190.98	3.20	6.76	11391.90	0.07	0.52	11554.96
International ferry	299.89	5.01	10.25	17600.03	0.11	0.82	17855.74
General cargo	35.67	0.47	0.98	1665.59	0.01	0.08	1689.65
Oil/chemical tankers	45.99	0.63	1.33	2240.04	0.01	0.10	2272.05
Commercial fishing	0.30	0.01	0.00	30.42	0.00	0.00	30.77
Domestic ferry	89.89	3.32	1.03	11592.97	1.56	0.35	11733.15
Recreational	5.15	0.20	0.06	522.14	0.07	0.02	528.26
Supply vessels	2.04	0.08	0.02	207.33	0.03	0.01	209.76
Tug - push boat	7.41	0.28	0.09	751.42	0.10	0.02	760.23
Work boats	6.45	0.24	0.08	654.70	0.09	0.02	662.37
Other vessels	9.97	0.38	0.12	1011.21	0.13	0.03	1023.06
Traffic	17.74	0.61	0.02	2369.67	0.05	0.12	2408.04
Cargo handling equipment	8.30	0.52	0.00	6429.69	0.06	0.04	6442.39
Total	828.07	16.36	23.66	61471.53	2.30	2.35	62247.27

The results showed that compliance with regulation provided a reduction of 90% and 10% in SO2 and PM10 emissions respectively. Onshore power in combination with a speed reduction zone provided reductions of up to 15% in NOx and CO2 emissions by 2020 compared with 2013, and further reductions of up to 23% NOx and 17% CO2 emissions if the use of LNG were extended to all domestic ferries.

McArthur and Osland (2013) examined emissions from ships in the Port of Bergen, which is Norway's largest port in terms of cruise passengers and fourth measured by gross tonnage. The port is situated in the inner urban area of Bergen, which is located on the west coast of Norway, has a population of around 260,000 and is the country's second largest city. Bergen has experienced air quality problems that are exacerbated by local topography resulting in temperature inversions. The study estimated the monetary values of emissions from ships at berth to make their impact, such as local health problems, damaging environment and vegetation, more apparent.

The study accounted for the ship, the call, the time spent at berth, the power of the auxiliary engine, the load factor for the ship when hotelling, the emission factor of the pollutants. The pollution generated by the combustion of fuel depended on a variety of factors e.g. the type of fuel, the sulphur content of the fuel and the type of engine. For cruise ships, the energy requirements were calculated based on the number of passengers.

Table 26. Estimated emissions (ton) by vessel type when hoteling in the Port of Bergen in 2010

Vessel type	NO_x	NMVOC	SO_2	PM_{10}	$PM_{2.5}$	CO_2
Tankers	82.52	3.71	2.41	1.08	1.03	4898.64
Bulk	42.23	1.90	1.24	0.55	0.53	2506.94
Other cargo	143.13	6.43	4.19	1.88	1.78	8496.65
Passenger	97.31	4.37	2.85	1.28	1.21	5776.39
Cruise	129.61	5.83	3.79	1.70	1.61	7694.34
Offshore	77.22	3.47	2.26	1.01	0.96	4583.88
Tug/salvage	3.82	0.17	0.11	0.05	0.05	226.63
Fishing	28.37	1.28	0.83	0.37	0.35	1684.27
Specialised/support	1.76	0.08	0.05	0.02	0.02	104.32
Other	57.54	2.59	1.68	0.75	0.72	3416.01
Total	663.49	29.82	19.41	8.70	8.26	39,387

Table 27. Annual monetary cost of emissions from ships at berth in the Port of Bergen

	MAG	CA	CAFE	BeTa
$SO_{2/x}$		0.86	0.99	3.95
NO_x	137.66	60.89	26.46	27.55
PM_{10}	26.17	7.01		
$PM_{2.5}$			1.95	8.06
(NM)VOCs		2.74	0.26	0.62
CO_2	8.38	8.38	8.38	8.38
Total (m NOK)	172.20	79.86	38.02	48.56
Total (m EUR)	21.53	9.98	4.75	6.07

Notes: figures are given in million 2011 NOK.
Source: MAG: Magnussen et al. (2010). CA: Coastal Administration (Kystverket, 2007). CAFE: Holland et al. (2005). BeTa: Holland and Watkiss (2002).

The annual monetary cost of emissions from ships while at berth is shown in Table 27. The study used unit cost estimates (NOK per ton) for pollutants in different studies, adjusted to 2011 value using consumer price index and multiplied by the estimated emissions of pollutants in Table 26 to obtain the annual monetary cost. The two Norwegian estimates were provided in the MAG and CA columns. They represented the lower- and upper-bound of the environmental costs. The estimates in the MAG column were specific to Bergen and included particulate matter and NOx presented problems that caused poor air quality in the city. CA figures referred to maritime transport at sea; CAFE referred to the lower-bound estimates; and BeTa estimates used EU-15 averages and were adjusted for the size of Bergen. The results showed that the estimated cost of emissions annually was between NOK 80 and NOK 172. In Table 28, the emissions from the Port of Bergen were compared to those of other selected ports in the world.

Table 28. In-port emissions estimates (ton per year) of selected ports

Port	Year	Calls	SO_2	NO_x	CO_2	PM
Rotterdam[a]	2000	26,766	2903	3917	347,434	218
Rotterdam[a]	2005	27,845	3233	4400	397,007	245
Copenhagen[b]	2001	5729	43.6	346		
Køge[b]	2001	543	10.6	29		
Elsinore[b]	2001	45,226	0.8	46		
Piraeus[c]	2009	10,488	722	1790		99
Aberdeen[d]	2004	≈8000	52	376	36,720	14
Kaohsiung[e]	2010	16,042	589	501	34,531	122
Bergen	2010	19,912	19.4	664	39,387	8.7

Notes: figures for the port of Piraeus refers to passenger and cruise ships. The NO_x figure for Aberdeen applies to NO_2. PM refers to PM_{10} except in the case of Piraeus, where it refers to $PM_{2.5}$.

[a] Hulskotte and Denier van der Gon (2010).

[b] Saxe and Larsen (2004).

[c] Tzannatos (2010).

[d] Marr et al. (2007).

[e] Berechman and Tseng (2012).

Simonsen et al. (2019) used AIS data to track emissions of 81 cruise ships entering Norwegian waters in 2017, and assessed the amount of pollutants emitted at sea and in ports. It comprised a total of 549 trips since several cruise ships engaged in multiple trips to Norway, Technical information of the cruise ships were obtained from SeaWeb database and used in a model that estimated emissions in time and space. The model was based on installed power. It considered fuel consumption and fuel type for pollutants including CO2, NOx, and PM2.5 but did not consider SOx. Ships were assumed to consume MDO and emission factors were used for different pollutants.

Most of the cruise ships sailing Norwegian waters in 2017 were smaller, with 31% falling into the category of up to 25,000 GT, and only 7% representing very large ships in excess of 125,000 GT. The smaller ships were usually older, as 80% of the smallest ships<25,000 GT were built before 2000, while all ships with>125,000 GT were built after 2000. The cruise ships burned an estimated 129,798 ton of fuel in Norwegian waters (Table 29), out of this 18,975 ton (14.6%) in port (Table 30). This corresponded to emissions of 416,132 ton CO2, 7,184 ton NOx and 132 ton PM2.5 in Norwegian waters. In terms of CO2 emissions, the cruise ships emissions in Norwegian waters represented about 1% of global CO2 emissions from cruise ships (35 M ton). In-port emissions were 1,042 ton NOx and 19.1 ton PM2.5. Oslo, Bergen and Stavanger were the cities with the highest amounts of pollutants (Figure 55).

Table 29. Ship sizes, and emissions of pollutants in total and per nautical mile, 2017

Gross tonnage	Nautical miles	Total fuel use (at sea and in port) (t)	CO_2 (t)	NO_x (t)	$PM_{2.5}$ (t)	Fuel use per nmi (kg)[a]	CO_2 per nmi (kg)[a]	NO_x per nmi (kg)[a]	$PM_{2.5}$ per nmi (kg)[a]
up to 25,000	172,186	13,075	41,919	773	13	75.9	243.4	4.5	0.08
25,000–50,000	141,270	24,692	79,164	1416	25	174.8	560.4	10	0.18
50,000–75,000	64,449	16,891	54,151	925	17	262.1	840.2	14.3	0.27
75,000–100,000	84,325	28,128	90,178	1518	29	333.6	1069.4	18	0.34
100,000–125,000	41,933	24,043	77,083	1365	25	573.4	1838.2	32.5	0.58
125,000–200,000	36,770	22,969	73,637	1188	23	624.6	2002.6	32.3	0.64
∅*	–	–	–	–	–	240	769	13.3	0.24

[a] Weighted average, considering distance sailed.

Table 30. Ship sizes, fuel consumption in port and emissions, 2017

Gross tonnage	Number of ships	Hours in port	Fuel in port per hour (kg) **	NO_x in port per hour(kg) (kg)**	$PM_{2.5}$ in port per hour (kg) **
up to 25,000	25	15,088	73	4.4	0.07
25,000–50,000	22	5363	736	41.3	0.75
50,000–75,000	11	2719	1130	61.9	1.15
75,000–100,000	11	2785	1506	81.1	1.54
100,000–125,000	6	1311	2680	152.0	2.73
125,000–200,000	6	1117	3046	157.8	3.11
∅[a]	–		677	37.2	0.69

[a] Weighted average, considering hours in port.

A simulation on the effects of speed reduction was also conducted. It showed that if ship speed were reduced by 2 knots, total fuel consumption would decline to 108,573 ton from 129,798 ton. The emissions were reduced to 348,085 ton CO2 (from 416,132 ton), 6,003 ton NOx (from 7,184 ton), and 111 ton PM2.5 (from 132 ton). Thus, <u>a modest speed reduction will significantly reduce fuel consumption and emissions by about 16%.</u>

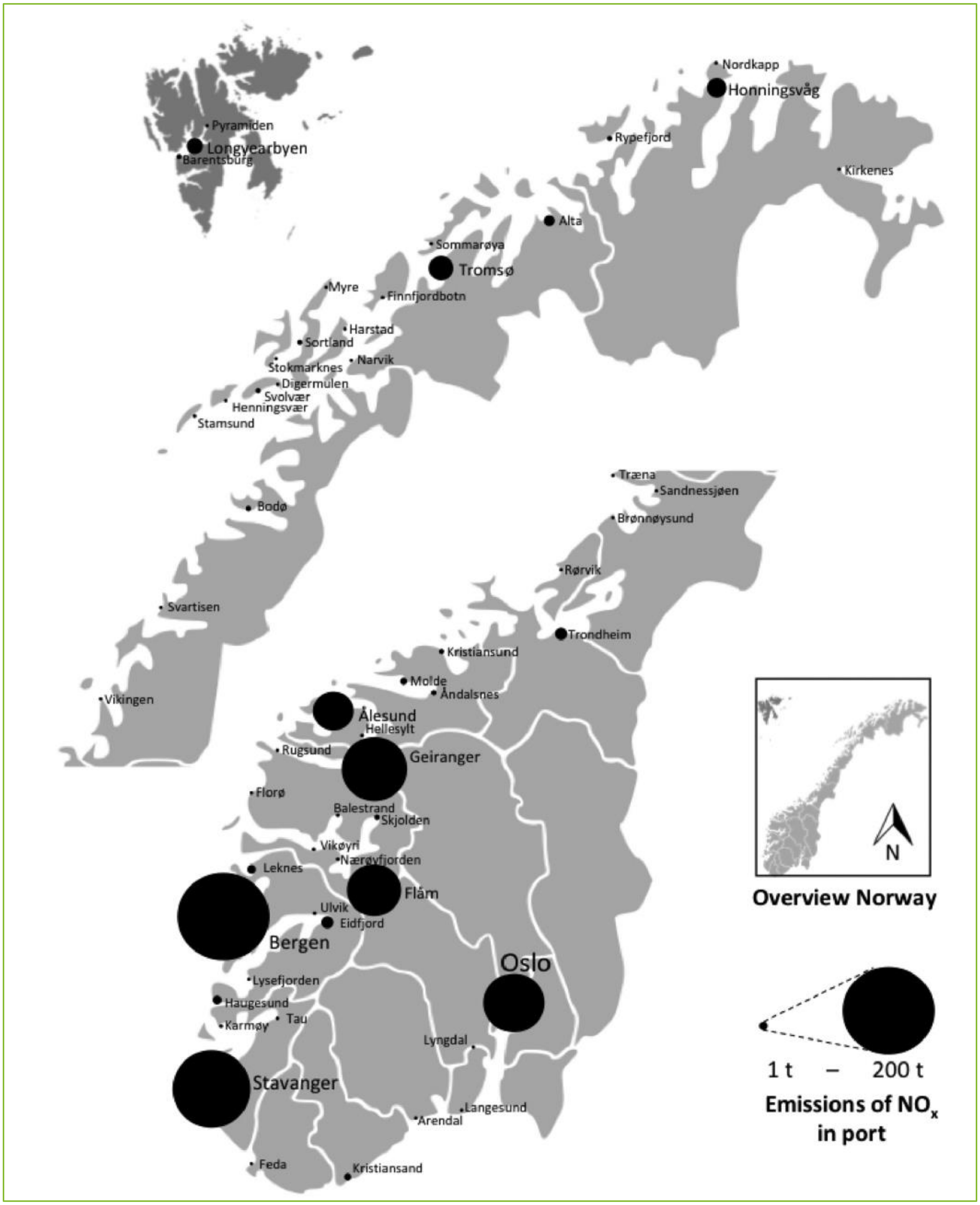

Figure 55. Geographical distribution of emissions of NOx by port, in 2017

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