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Environmental assessment of LNG tankers for Furetank

Emissions to air and external costs

Commissioned by Furetank

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1 Introduction

This report outlines estimates of benefit for society through reduced external costs for air pollutants and climate gases from new technologies used in new LNG ships that are delivered to Furetank. External cost is a concept used by environmental economists to capture negative impacts of consumption and production that are not included (compensated for) in the price of the goods or services produced. Environmental degradation and human health impacts from air pollution are typical examples of external costs.

Within this study the external costs are compared for the new ships in relation to alternative ships that merely fulfil the regulations, i.e., ships running on marine gas oil (MGO). In this report a planned new product tanker with LNG engines for Furetank is analysed and compared with an existing tanker running on MGO. Further, the new ship is more fuel efficient than the old ship.

In this report we first present the emission reduction following the use of the analysed ships and then the calculated external costs following from these changes.

2 Calculating emissions

In order to calculate the emissions from the different ships data was collected from the ship-owners. It should be emphasised that the new ship is not in operation and thus many of the parameter values are based on specifications and assumptions. Data was collected on fuel consumption (specific for the engines or predicted yearly values), fuel types, engine details, emission factors and planned traffic patterns. Other parameter values were taken from the literature. Emissions calculated were nitrogen oxides (NO_X), sulphur dioxide (SO_2), particulate matter (PM) and climate gases (carbon dioxide, CO_2, methane, CH_4 and nitrous oxide, N_2O). The climate gases are presented as CO_2-equivalents.

A number of parameter values used in the calculations are presented in Table 1.

Table 1. Common data used in the emissions calculations

Parameter	Unit	Value	Reference
CO_2 equivalent for CH_4	-	25	IPCC (2013)
CO_2 equivalent for N_2O	-	298	IPCC (2013)
C-content MGO	-	0.867	Brynolf (2014)
C-content LNG	-	0.746	Brynolf (2014)
S-content MGO	ppm	1000	Maximum allowed value
S-content LNG	ppm	5	Brynolf (2014)
Heat content LNG	MJ/kg	48	Brynolf (2014)
Heat content MGO	MJ/kg	43	Brynolf (2014)

2.1 The ship

The new product tanker is a LNG fueled ship which will be used in the Baltic and North Seas. The ship has a dual fuel main engine and MGO fueled auxiliary engines. It is compared with an existing ship of approximately the same size. This reference ship runs on gas oil and ECA oil and shows higher fuel consumption relative the new ship. This is due to improvements in design for the new ship. The data used in the calculations can be found in Table 2. The reference ship has a few percent smaller cargo capacity than the new ship and the data was therefore adjusted to represent the same volume of cargo (i.e. the transport work is the same in both cases).

Table 2. Data used in the emission calculations

Parameter	Unit	Value		Reference
		LNG ship	Alt ship	
MGO consumption	tonnes/year	254	901	ship-owner/ship designer
ECA-oil consumption	tonnes/year	0	3528	ship-owner/ship designer
LNG consumption	tonnes/year	1828	0	ship-owner/ship designer
SFC LNG ME	g/kWh	148	-	engine maker
SFC MGO ME	g/kWh	2	190	engine maker
EFNO_x ME	g/kWh	1.2	12	engine maker
SFC AE	g/kWh	208	220	engine maker
EFNO_x AE	g/kWh	2.3	9.9	engine maker
EF$PM_{2.5}$ ME	g/kWh	0.01	0.4	ship-owner/Cooper (2004)
EF$PM_{2.5}$ AE	g/kWh	0.4	0.4	Cooper (2004)
EF CH_4 ME	g/kWh	4.15	0.004	ship-owner/Cooper (2004)
EF CH_4 AE	g/kWh	0.004	0.004	Cooper (2004)

The resulting yearly emissions can be found in Table 3.

Table 3. Resulting annual emissions and fuel use.

Results	LNG ship	Alt. Ship	Unit
CO_2 eqv	7040	14000	tonne
SO_2	0.527	8.860	tonne
NO_x	22.5	311	tonne
$PM_{2.5}$	1.46	11.1	tonne
Fuel use	99	190	TJ

3 Calculations of environmental and health impacts and external costs

Since the models used for the analysis are relatively coarse, and the environmental and human health impacts from air pollutants are seen only as a result of emissions much larger than from a single ship, we upscaled the emissions from the individual ships. The impacts from air pollution can rarely be assigned to one single point source of emissions, but the burden sharing of total air pollution impacts can easily be distributed among the sources following their relative contribution to the concentrations in the air. In other words, environmental and health impacts from the emissions of one single ship are impossible to verify, but the environmental and health impacts from all the ships in the North and Baltic sea are verifiable, and one single ship's contribution to this impact is proportional to its relative share of emissions. In this study we scaled up the calculated annual emissions with a factor 10 000 prior to introducing the emissions into the models.

The different emissions for the sea regions cause different human health impacts. With the online[1] version of the GAINS model (Amann, 2011) we calculated population weighted $PM_{2.5}$-exposure and exposure to ground-level ozone (SOMO35 metric[2]) for each European country that would follow from the shipping emissions. The $PM_{2.5}$ concentration in ambient air is caused by primary $PM_{2.5}$ emissions, but also by emissions of NO_X and SO_2 since these form secondary $PM_{2.5}$ during their residence time in the air. Ground-level ozone formation is directly affected by NO_x (and VOC) concentrations.

Country-specific data on population-weighted calculated exposure to $PM_{2.5}$ and ground-level ozone were then applied in the Swedish version of the economic valuation tool ARP (Holland, 2013) for further calculation of health impacts and monetary valuation of the same. After having calculated the total monetized health impact of the scenarios, the values were scaled down by a factor 10 000 in order to get an impact corresponding to the actual emissions from the ships. Furthermore, the economic valuation of health impacts was complemented with economic valuation of reduced CO_2 emissions and crop losses in the affected regions.

The health impact with highest monetary value is avoided mortality (fatality), which is valued by either estimating the Value of Statistical Life (VSL) or the Value Of Life Year lost (VOLY). The estimated economic value of these varies in the literature and between methods. The values can also differ between VOLY and VSL due to differences in how many life years that are assumed to be lost when a fatality occurs. We therefore included low, mid and high values in this study (Table 4). Low values implies that the valuation of avoided mortality is based on the median VOLY estimate from Desaigues (2011); mid values implies that we've used the median VSL estimate from Friedrich (2004) and Hurley (2005); high values implies that we've used the mean VSL value from OECD (2012). Table 4 presents the values for VSL and VOLY used in the monetization of health impacts.

[1] http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1

[2] The SOMO35 metric quantifies the yearly sum of the daily maximum 8-hour ozone concentrations exceeding a 35 ppb (70 µg/m³) threshold

The health impacts from air pollution are specified by the use of exposure-response functions, and in our analysis we used values from the WHO/EU Health Risks of air pollution in Europe (HRAPIE) project (Henschel 2013, Holland 2014b, Heroux 2015).

To avoid risk of double-counting health effects from $PM_{2.5}$ and ground-level ozone, chronic mortality from ozone exposure was not included in the valuation. This approach was used in the Cost-Benefit Analysis of Final Policy Scenarios for the EU Clean Air Package (Holland 2014a).

Table 4. Economic value of VOLY and VSL used in this analys.

End point	Impact	Valuation (€$_{2010}$)	Data source
Mortality from long term exposure (All ages) median VOLY	Life years lost	44 708	Desaigues, 2011.
Mortality from long term exposure (All ages) median VOLY	Life years lost	64 491	Friedrich, 2004, Hurley, 2005
Mortality from long term exposure (All ages) mean VOLY	Life years lost	155 025	Friedrich, 2004, Hurley, 2005
Mortality from long term exposure (30yr +) deaths median VSL	Premature deaths	1 218 293	Friedrich, 2004, Hurley, 2005
Mortality from long term exposure (30yr +) deaths mean VSL	Premature deaths	2 481 294	Friedrich, 2004, Hurley, 2005
Mortality from long term exposure (30yr +) deaths mean VSL	Premature deaths	3 129 560	OECD, 2012
Infant Mortality (0-1yr) median VSL	Premature deaths	1 827 440	Friedrich, 2004, Hurley, 2005
Infant Mortality (0-1yr) mean VSL	Premature deaths	3 721 941	Friedrich, 2004, Hurley, 2005
Infant Mortality (0-1yr) mean VSL	Premature deaths	4 694 340	Friedrich, 2004, Hurley, 2005, OECD, 2012.

There are a number of additional health impacts from air pollution, such as bronchitis, cardio-vascular and pulmonary diseases, as well as restricted activity, but since the economic impact of these are smaller than the impact of avoided mortality they have been omitted from the table above.

Crop damage is valued per tonne of NO_X emissions from each sea region. NO_X is one of the substances needed for the formation of ground-level ozone, which in turn causes damage to crops. The economic valuation of these damages is based on aggregated market prices for a number of crops. NO_X emissions from the Baltic Sea are associated with crop damages corresponding to ~146 €$_{2010}$ / tonne NO_X, while NO_X emissions from the North Sea are associated with crop damages corresponding to ~35 €$_{2010}$ / tonne NO_X (Holland, 2011).

Furthermore, the use of LNG is associated with reduced CO_2 emissions that also have a monetary value. Using economic values from the EU ETS market and the Handbook on External Costs of Transport (Korzhenevych, 2014) a range of external costs of CO_2 can be estimated. The economic values analyzed for CO_2 are listed in Table 5.

Table 5. Economic values per tonne of CO_2 emission used in this analysis.

Economic value of CO_2		Unit	Source
Low	6.6	$€_{2010}$/tonne CO_2	Current (Sept. 2017) EU ETS market price[3] converted to $€_{2010}$ with GDP-deflator[4]
Mid	90	$€_{2010}$/tonne CO_2	EC Update on Handbook on External Costs for Transport (2014), central value
High	168	$€_{2010}$/tonne CO_2	EC Update on Handbook on External Costs for Transport (2014), high-end value

Thus, by using the same monetary values for human health and crop damage impacts as used by the European Commission, but updated to $€_{2010}$ exchange rate, significant reductions in external costs due to health impact improvements and reduced crop damages are found for all cases. When values for external costs of CO_2 emissions are added, the monetized effect is further increased. This monetary benefit is a total of the benefits for all European countries affected by reduced emissions in the Baltic Sea and in the North Sea for a single ship of the types considered. These values are understatements of the external costs associated with our cases since the actual ship routes are located in densely populated areas while the GAINS model results deliver results for a sea region average emission reduction.

Below (Table 6) we present the difference in external costs between a high emission ship and an LNG-fueled ship using the emission data in Table 3. This difference in external costs is equal to benefits for the European societies from reduced emissions.

The new LNG-fueled ship is compared with the performance of a similar existing ship running on MGO. The changes in external costs are calculated for a ship operating 90% of the time in sulphur emission control areas and of this 60% of the time in the North Sea and 40% in the Baltic Sea.

Table 6. Annual economic values of reduced health impacts and crop losses associated with the LNG ship when compared to the alternative ship.

	Difference in external costs* (thousand $€_{2010}$/year) -
	LNG ship vs. Alt ship
Human Health, low	757
Human Health, mid	1598
Human Health, high	3708
CO_2, low	42
CO_2, mid	570
CO_2, high	1064
Crop damage	21
Total, central (low-high)	***2200 (820-4800)***

[3] http://www.nasdaqomx.com/transactions/markets/commodities, as of 2017-09-09

[4] http://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=teina110

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Appendix 1. A short note on the method used in the calculations

In this study we have used the Impact Pathway Approach to calculate the external costs of the air pollutions from ships. The Impact Pathway Approach is presented in (Bickel and Friedrich 2005) and a summarizing figure is seen below:

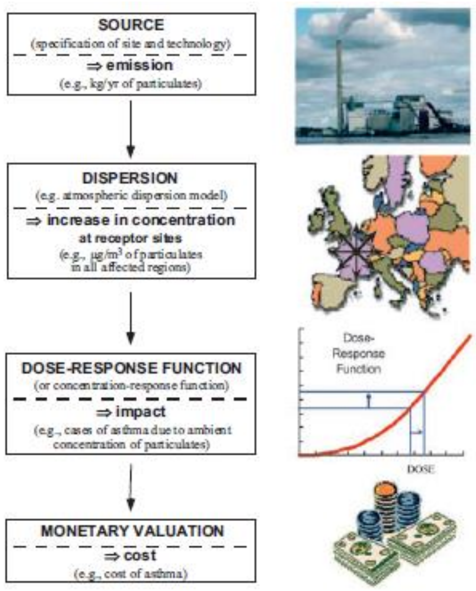

Figure 1: The main steps of an impact pathway analysis (Bickel and Friedrich 2005)

In this study, the emission levels are calculated using the information available from the ship-owners. The air pollution emissions from a single ship are upscaled so as to correspond to an entire fleet of ships, and the emissions are introduced into the GAINS model. The GAINS model is then used to calculate emission dispersion and concentration at receptor sites. The ARP model, and the dose-response functions within, is then using the results from the GAINS model to calculate the impact on human health and the monetary values of these impacts. We then add on monetary valuations of impacts on crop production and on climate change outside of the models.

Reference to the appendix:

Bickel, P. and R. Friedrich (2005). ExternE Externalities of Energy - Methodology 2005 update.

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