Addendum

Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel

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Background

Transport and Environment (T&E), a European campaign group on clean transport, published a statement from Dr. Elizabeth Lindstad (Scientist, SINTEF Ocean AS) in June 2019, outlining that an "increased use of LNG might not reduce maritime GHG emissions at all".

In this statement, Dr. Lindstad raises several issues with the methodology of thinkstep's analysis and - based on the SINTEF engine measurements - argues that in most cases that LNG's GHG footprint will actually be worse than that of MGO. T&E published this letter in order "to raise public and industry awareness of the dangers of a large-scale shift to LNG in the maritime sector."

As author of the thinkstep analysis "Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel," published in April 2019 we want to take the opportunity to comment on Dr. Lindstad's main critiqued points, in particular on three points:

1) Well-to-Tank calculations of Heavy Fuel Oil (HFO)
2) Engine efficiencies
3) Methane emissions

Introduction

First of all, we want to thank Dr. Lindstad for her critique and to express our respect for her on-going work at SINTEF. An open and transparent debate is key to capturing the full complexity of the shipping industry, evaluating the different engine technologies and thereby contribute to an environmentally friendly development of the maritime industry. As we stated in the report, our study is prepared to support open and transparent communication with external stakeholders, such as investors, ship owners, operators, governmental organisations, NGOs and regulators. The study is intended to provide objective and transparent information about the benefits as well as the remaining barriers to LNG as a marine fuel.

We agree on some points raised in Dr. Lindstad's critique, such as the fact that many studies have been performed over the last years demonstrating different Greenhouse Gas (GHG) impacts from the use of LNG as a marine fuel. This was also one of the reasons why the two associations SEA\LNG and SGMF, with their 160 members, commissioned this study to resolve the existing uncertainties in the overall life cycle GHG emissions of LNG as a marine fuel.

We also fully agree that the selection of the environmental impact method, like the Global Warming Potential with a 20 or 100-year timeframe, is essential for the results and for deriving objective conclusions. This is transparently addressed in our report (see section 3.3). Beyond distinguishing between 20 and 100-year timeframes, we used the IPCC Assessment Report 4 and 5 characterisation factors to calculate the GWP_{20} and GWP_{100} results. We also showed the results of other methods, like the Global Temperature Potential (GTP), in the report (see section 6.8). In summary, there are many metrics available to quantify climate change that are discussed by scientists, but GWP_{100} is considered the best practice and default metric, in part because it is compulsory for UNFCC national GHG inventory reporting.

Well-to-Tank Calculations of Heavy Fuel Oil (HFO)

While Dr. Lindstad accepted our calculated Well-to-Tank (WtT) values for LNG with 18.5 grams of CO_2-eq per MJ and MGO (14.4 grams of CO_2-eq per MJ) in terms of order of magnitude as well as relative difference, she challenged the HFO value of 13.5 gram of CO_2-eq per MJ. This is surprising, since thinkstep used the same calculation method for both refinery fuels, HFO and MGO.

The various steps of the fuel supply chain, from crude oil production to crude oil transport and refining, all contribute to the GHG inventories for both fuels. Dr. Lindstad challenged the GHG results of the refining step.

Therefore, it may be helpful to elaborate further on the refinery part. One has to keep in mind that refineries are complex. Almost all refinery unit processes are multi-output processes, i.e., they have several outputs, to which the related refinery GHG emissions need to be allocated. In thinkstep's refinery model, we allocate using physical metrics by following the ISO 14040/44 standard, namely energy and mass. Thus, we analyse each refinery product through the refinery by passing a refinery unit process, and we allocate the emissions associated with the energy and material consumption of this refinery unit process to the corresponding output of this process. Since most of the refinery products pass a sequence of refinery unit processes, the information of the GHG intensity is stored as a "virtual" backpack. In simplified terms that means that, the longer the way through the refinery and hence the more unit processes a single refinery product passes, the larger the backpack, and hence the higher the GHG intensity for this product. We consider differences in value between high and low calorific products (e.g., MGO vs. HFO) by their energy content expressed as lower heating value. For details on the allocation and backpack principle as it is applied in the GaBi LCA databases[1] see: http://www.gabi-software.com/fileadmin/Documents/The_GaBi_Refinery_Model_2018.pdf.

As mentioned, we calculate the GHG inventory of all refinery products, including HFO and MGO, using the same transparent and comprehensive approach, leading to 13.5 and 14.4 grams of CO_2-eq per MJ respectively.

To bring the HFO value of 13.5 grams of CO_2-eq per MJ into perspective, values for HFO, between 9 - 17 grams of CO_2-eq per MJ can be commonly found. Hence, the 13.5 grams of CO_2-eq per MJ are well in the acknowledged range and are neither on the upper nor the lower end. So, for example, the Verbeek 2015 study ("LNG for trucks and ships: fact analysis TNO Report 2014 R11668) cited by Dr. Lindstad outlines equally 14.2 grams of CO_2-eq per MJ for MGO and 14.2 grams of CO_2-eq per MJ for HFO.

Following the suggestion and assuming HFO is produced without any environmental impact at the refinery (i.e., considering HFO as refinery GHG emissions free), appears to be a highly unusual approach not yet encountered in any scientific literature.

We scrutinise Dr. Lindstad's statement that "the HFO share of the energy consumption is next to zero" at existing refineries. This would imply that HFO is not considered as product, in turn implying that the market value of HFO is US$ = 0 (or even negative if refiners want to get rid of it), a claim that represents neither the current nor the likely future market situation. If HFO were not a valuable product (i.e. impacting emissions at the refinery), one could conclude that one should use HFO, because it can be produced without any refinery emission. A clearly misleading conclusion.

In general, when it comes to allocation in refining there is no simple right or wrong answer. It is more important that a study documents the method used and that that method is comprehensive and fits the study's purpose. Again, considering HFO as "refinery GHG emissions free" is highly unusual. As mentioned, the data sources used in our study are documented, and the allocation method is

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[1] GaBi is an LCA software and one of the largest consistent LCA databases on the market. The databases offer >10,000 LCA datasets (all compliant with ISO 14040/44 standards in the ILCD data format of the European Commission), based on collected primary data during thinkstep global work with companies, associations and public bodies including all relevant industry sectors. The datasets are updated annually.

described well and applied in all our LCA refinery datasets, which have been used by more than 2000+ LCA practitioners worldwide for more than 30 years.

In summary, we believe that allocating in a comprehensive, transparent and systematic way is the best approach for addressing allocation in refining. By taking physical properties into account, considering that there are more valued, higher calorific products (e.g., MGO) and less valued, lower calorific values (e.g., HFO), in combination with the applied “backpack principle,” we are using an established, fair approach, without giving an advantage or disadvantage to one product or the other. We further believe that as long as HFO is considered a product – that it has a positive market value – HFO should be accountable for certain refinery emissions.

Engine Efficiencies

We based our calculations for the Well-to-Tank GHG emissions per kWh brake power on the fuel consumption values of engines and the Well-to-Tank GHG emissions per MJ fuel input. In that way we considered pilot fuel and urea usage for the Tier III operations. We chose Tier III NO_X limits for the comparison according to the defined scope of the study, because it is the most onerous regulation (the direction in which regulation is likely to move) and reflects the future character of the study (investments in vessels are likely to last for the next 20-30 years). In addition, we also calculated the less strict Tier II NO_X limit results, presenting them in the report as well.

To give clarity on the calculation, we explain the conversion method using 2-stroke slow speed (SS) diesel dual fuel (DF) engines (in line with Dr. Lindstad’s statement).

The Well-to-Tank GHG emissions per MJ fuel input and the lower heating values of the fuels are shown in the following table (all numbers are documented in the report, section 3.2 and Annex B).

	MGO	LNG	Unit
Well-to-Tank GHG emissions	14.4	18.5	g CO_2-eq/ MJ
Lower Heating Value (LHV)	42.7	49.2	MJ/kg

The fuel consumption and urea usage are (all numbers are documented in the report, section 5.2):

	MGO engine 2-stroke SS Diesel DF	LNG engine 2-stroke SS Diesel DF	Unit
LNG fuel consumption	-	141.3	g LNG / kWh
MGO fuel consumption	174.0	6.4 (pilot)	g MGO / kWh
32.5% urea solution use	20.6	-	g Urea s. / kWh

By using the following formula (= Fuel consumption * LHV * Well-to-Tank GHG emissions / 1000), the Well-to-Tank GHG emissions per kWh brake power are calculated and shown together with the Tank-to-Wake and Well-to-Wake results:

	MGO engine 2-stroke SS Diesel DF	LNG engine 2-stroke SS Diesel DF	Unit
Well-to-Tank LNG	-	128.3	g CO_2-eq / kWh
Well-to-Tank MGO	106.8	3.9 (pilot)	g CO_2-eq / kWh
Well-to-Tank Urea	13.9*	-	g CO_2-eq / kWh
Sub-Total Well-to-Tank	**121**	**132**	**g CO_2-eq / kWh**
Tank-to-Wake	565	417	g CO_2-eq / kWh
TOTAL Well-to-Wake	**686**	**549**	**g CO_2-eq / kWh**

* Value derived from thinkstep’s GaBi LCA databases 2019

Note, for 2-stroke slow speed Diesel-DF LNG engines an exhaust gas recirculation (EGR) systems was considered.

Considering the main and pilot fuel used, we calculated the thermal efficiencies with 48.5% for the MGO 2-stroke slow speed Diesel-DF engine and for the LNG 2-stroke slow speed Diesel-DF engine with 49.8%.

We believe that the conversion method we selected is suitable to show the GHG emissions of the Tier III operation according to the scope of the study. In summary, and in contrast to Dr. Lindstad's approach:

1. We used more specific engine efficiencies (for MGO = 48.5 % and for LNG = 49.8% incl. MGO pilot fuel) instead of using a default efficiency of 48% for both.
2. We considered pilot fuel.
3. We considered urea use.

All three aspects are contributing to the difference in GHG emission results of the thinkstep study, compared with Mrs. Lindstad's calculations.

Methane Emissions

We can confirm that we used test-bed fuel consumption and emission data and have chosen the IMO E2/E3 cycle to estimate the un-combusted methane emissions of reciprocating engines across the different load points.

To recap, we collected the fuel consumption and methane emission data in brake power specific units (kWh) per individual engines and per engine load point (we considered four different engine loads: 25%, 50%, 75% and 100%). For each engine technology distinguished, we averaged the individual data points collected from each engine manufacturer (OEM) for the different engine load points, resulting in one average value for each load point. For reciprocating engines, we then weighted the load points according to the IMO E2/E3 cycle. Each of the OEMs provided between 1-3 representative datasets, each representing consumption and emission data for one individual engine out of their portfolio. In total, we collected and evaluated 39 engine specific datasets from Caterpiller MaK, Caterpillar Solar Turbines, GE, MAN, MTU (Rolls Royce), WinGD, and Wärtsilä.

Without a doubt, methane emissions of LNG vessels depend on the engine load point of operation. They are higher at lower engine load points and lowest at higher engine load points. For completeness, engine efficiencies also dependant on the load point. We took both into account in the study by using the IMO E2/E3 cycle. It considers defined weighting factors between the different engine load points.

We agree that you can observe ship operation at lower load points (compared to the IMO E2/E3 cycle) today when you look at the world fleet. Some people may identify these lower load points as resulting from weak freight markets, while others - and this may be more important - may see it as a result of optimising engine operations for cost by trying to save fuel and hence operating at high engine efficiencies.

Indeed, based on the data collected, 2-stroke slow speed engines running on oil-based fuel have their lowest fuel consumption at a load point of around 60-65%. In response about the world fleet being not operated close to the IMO E2/E3 cycle, it is also important to mention that today more than 90% of the marine fuel consumed is oil-based, namely HFO and MGO, again, with a minimum fuel consumption at load points around 60-65%.

When analysing LNG, the situation is different. 2-stroke slow speed engines running on LNG have their lowest fuel consumption at load points between 65-80%. That is, they tend to have a lower fuel consumption at higher load points compared with HFO/MGO fuelled engines.

To complete the picture, all 4-stroke medium speed engines (i.e., HFO/MGO and LNG fuelled engines) have their lowest fuel consumption at load points between 80-90% based on the data we collected.

As a consequence, we believe that HFO/MGO fuelled engines may be operated at different load points compared with LNG fuelled engines. Ship operators may act based on fuel cost sensitivity (i.e., they will try to minimise fuel costs) and may operate at high engine efficiencies - for HFO/MGO at load points between 60-65%, for LNG at higher load point between 65-80%. This behaviour will also support the IMO ambition to reduce GHG emissions by 50% by 2050 compared with 2008 values.

Running LNG fuelled engines on low load points would be neither environmentally friendly nor economically beneficial, and hence we see it as critical to extrapolate today's load profile into the future. Running LNG engines on higher load points also helps to reduce the global warming effect resulting from methane slip as these emissions are lower at higher engine loads.

It was agreed among the participating association members that the IMO E2/E3 cycle is an accepted, standardised methodology, which is repeatable and reproducible and hence should be used in the study. If such a cycle needs to be generally modified (e.g., to better reflect reality) is a different discussion and beyond the scope of this study. In such a case, anyone could have questioned any weighting factors that we randomly modified, de-compromising the work. To rely on a defined standard brings the advantage not only having a standardised methodology, but also to gain consistent and, as said, repeatable results.

In addition, different ship applications, itineraries, weather conditions, etc. may also have a large influence on the operation of the engines and result in different load profiles from those considered by the IMO E2/E3 cycle. These influences are an additional reason to rely on a defined standard.

We fully support the idea of using onboard measurement data instead of steady-state, test-bed data for the combustion of the fuels. We clearly stated the recommendation in the report to "develop technologies to enable making on-board measurements looking at transient (real life) operation. This would help to better understand real time fuel consumption and the amount and significance of methane slip" (see section 9.2). As we further outlined in the report, "transient, onboard measurement data from ship operation can further increase the quality of the study" (see section 9.1).

It is also clear that onboard measurements would lead to different results compared to the usage of test-bed data, and hence we continue to encourage the shipping industry to work on this aspect further.

To our knowledge, as of yet, there are no comprehensive onboard measurement campaigns that analyse GHG emissions (and other pollutants) from 2- and 4-stroke engines, with a focus on deep sea shipping, that represent more than 70% of global shipping operations. SINTEF, for instance, has performed and published onboard measurements on 4-stroke engines in coastal operations in the North Sea, a great starting point. However, for now "only" 4-stroke engines in coastal operation are covered, representing only a minor share of global shipping, since, as mentioned, the majority of the fuel combusted by the shipping sector is the deep-sea shipping space where 2-stroke engines are used.

To obtain good data from onboard measurements, the shipping industry has to work on it to a) define measurements standards, b) perform measurements, c) publish the results and d) update them on a regular basis.

We are convinced that more solid information about real-time fuel consumption and emissions data will help support fact-based decision-making and will help the industry to succeed sustainably.

This commentary is intended as a reply to Dr. Elizabeth Lindstad's critique to make our approach more transparent and comprehensible. It is also intended to explain the results of the study, which we believe we carried out with comprehensive data using a calculation methodology that adheres to the most current scientific standards.

Summary

Dr. Lindstad raised several issues with the methodology applied by thinkstep in its analysis: “Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel.”

We believe that as long as HFO is considered a product with a positive market value, HFO should be accountable for certain refinery emissions and should not be considered as “free of any refinery GHG emissions.” We also believe that the fuel conversion method we selected is suitable to show the GHG emissions of the Tier III operation according to the scope of the study. Therefore, the consideration of specific engine efficiencies, instead of using a default efficiency for both, LNG and MGO, the consideration of pilot fuel (compared with not considering it) and the consideration of the urea solution (compared with not considering it) are best practice. The IMO E2/E3 cycle is an accepted, standardised methodology, which is repeatable and reproducible, and hence - especially with the absence of broadly measured data - an appropriate approach to quantify the GHG emissions, including methane, of vessel engines. Running LNG fuelled engines on low load points would be neither environmentally friendly nor economically beneficial.

Finally, we fully support the idea of using onboard measurement data instead of steady-state, test-bed data for the combustion of the fuels and, hence, encourage the maritime industry to work towards this.