Climate, Costs and Operational Effectiveness: Reduction of Greenhouse Gas Emissions in the Norwegian Armed Forces

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ABSTRACT

Tackling climate change is of strategic importance to NATO. Well-informed decision support analysis about possible climate measures and consequences will determine how well NATO handles this challenge. The merging of environmental science and military operational analysis will enable nations and the alliance to make well-informed decisions, with the potential of reducing both greenhouse gas emissions and costs, and improve operational effectiveness.

The Norwegian Ministry of Defence has tasked The Norwegian Defence Research Establishment (FFI) with studying the potential for reduction of greenhouse gas emissions in the Norwegian Armed Forces within the boundaries set by the military requirements.

We have modelled the future emissions from the Norwegian Armed Forces and quantified the emission reductions and costs of seven measures. In total, these measures have the potential to reduce the greenhouse gas emissions with 15–30 % relative to the baseline for future emissions, with a mean estimate of 22 %. In addition, we have identified several equally important measures for which the emission reduction can be difficult to quantify.

The military platforms of the Armed Forces have a long service life. Investing in energy inefficient solutions now will generate emissions and costs for many years into the future. We therefore recommend that emission projections get a more prominent role in acquisition decisions and the long-term defence planning process.

1.0 INTRODUCTION

The activities of the Norwegian Armed Forces have several negative effects on the environment. Some of these effects are inevitable, given the nature of the tasks of the Armed Forces. The environmental impacts are surveilled continuously and reported annually. Emission of greenhouse gases from the defence sector has gotten increased attention internationally and nationally, and the Norwegian Ministry of Defence has tasked The Norwegian Defence Research Establishment (FFI) with studying the potential for reduction of greenhouse gas emissions in the Norwegian Armed Forces.

The aim of this paper is to model this potential, within the boundaries set by the military requirements. This study does not contain a complete list of possible environmental measures in the defence sector. We have prioritized areas where the current knowledge is lacking. We have also considered the emission effect of a newly proposed alternative concept for maritime warfare. This should not be understood as an emission reduction measure, it is a measure to increase capability and reduce costs. However, we wish to demonstrate the emission consequence of such a concept, and use it as an example of how technology can be used to achieve more climate efficient solutions also in the defence sector.

In the present chapter we will briefly discuss climate change and the possible consequences for the

Norwegian Armed Forces. In the following chapters we will account for our analytical methods and data, results and conclusions.

1.1 Climate change

The greenhouse effect is a natural process which is necessary to support life on earth as we know it. Carbon dioxide (CO_2) and other greenhouse gases absorbs infrared radiation from the earth's surface, reemitting part of this back to the lower atmospheric layers and the earth's surface, and thus trapping some of the incoming energy from the sun in the atmosphere. Increasing concentration of greenhouse gases thus increases the temperature of the earth's surface and atmosphere.

The observed temperature increase since the industrial revolution can be attributed to changes in the global carbon cycle. The global carbon cycle can be understood as a series of carbon reservoirs, where carbon flows between the reservoirs. The cycle can be divided into a rapid domain and a slow domain. The rapid domain includes exchange of carbon between the atmosphere, the ocean, surface sediments in the ocean, vegetation on land, in the soil and fresh water. This cycle operates on a scale of years to decades and centuries. The slow domain includes reservoirs in rocks and sediments, and operates on a scale of at least 10.000 years or more (typically hundreds of millions of years). Carbon exchange between the rapid and slow domain includes relatively small exchanges, and happens by volcanic eruptions, weathering, erosion and sedimentation. This natural exchange between the slow and rapid domain has been relatively stable the last decades.

The extraction and burning of fossil fuels represents a significant movement of carbon from the slow to the rapid domain, increasing the amount of CO_2 in the atmosphere and thus increasing the earth's surface temperature [1]. In addition to this, changes in the rapid carbon domain and nitrogen cycle caused by intensive agriculture, forestry, deforestation and other land use changes further contributes to climate change, and this accounts for 23 % of anthropogenic greenhouse gas emissions [2].

1.2 Consequences for the Norwegian Armed Forces

The causal relationship between armed conflict and climate change is still uncertain. As an example, risk of conflict can increase as a consequence of reduced food production. Oppositely, natural disasters and extreme weather events can weaken military capabilities and make people, militaries and governments prioritize this over armed conflict. It's expected that climate change will increase migration which can increase the risk of conflict. Other factors, such as lacking socio-economic development is likely more important, but in a 2 °C or warmer scenario the likelihood of conflict might increase [3].

Some expected developments which will influence the Norwegian Armed Forces, are [4]:

- Increased need for humanitarian operations.
- Increased sea level and frequent extreme weather events can impact coastal bases and damage facilities.
- Changes to the operational planning process to take the consequences of climate change into account.
- Increased external pressure on militaries to minimize environmental impacts.
- Protection of environmental targets might be a possible future military operation scenario.
- The strategic importance of the Arctic will increase due to melting sea ice.

1.3 Research question

Given the importance of addressing climate change, all sectors, including the military sector, need to examine how they can reduce their greenhouse gas emissions. A Norwegian report, Climate Cure 2030 [5], has examined how Norway can reduce its greenhouse gas emissions by 50 % by 2030.[1] However, this report did not consider measures for military vessels and aircraft. Military vessels and aircraft account for 85 % of the direct emissions (scope 1[2]) from the Norwegian Armed Forces [6], therefore this is the main focus in the present paper.

Since the Norwegian Armed Forces are vital to national and societal security, it is important that potential climate mitigation measures do not reduce the capabilities of the Armed Forces. Capability reducing measures are not considered further in this paper. The research question in this paper is therefore:

> *How can the Norwegian Armed Forces reduce greenhouse gas emission, and maintain or improve capability? And at what cost or savings?*

1.4 Delimitations

We have not considered measures concerning buildings, facilities and infrastructure. The reason for this is twofold: The Norwegian Defence Estates Agency already has a strong focus on this, and the emissions from energy use in buildings in Norway are relatively low due to a high share of renewable energy.

We do not look at measures concerning administrative vehicles since this is a less military specific problem, and civilian measures apply to them.

2.0 ANALYTICAL METHODS

In order to measure the effects and costs of possible climate mitigation measures we need a baseline for future emissions and costs to measure against. Once this baseline is established possible measures have to be identified. The emission reduction effects and costs of the measures can then be modelled and compared to the baseline. The measures can be analysed individually or combined.

2.1 Establishing a baseline for future emissions

FFI monitors and reports annually the environmental impact of the Norwegian Armed Forces, including greenhouse gas emissions in accordance with the greenhouse gas (GHG) protocol [6]. Merging this database with detailed information of the current long-term plan for the force structure, we are able to model the future emissions of the Norwegian Armed Forces. For instance, one needs to take into account the operating hours of new weapon systems and their hourly fuel use, which will combine to produce the total emissions from this system.

All costs should be measured relatively to the future cost of the force structure. FFI has a designated team devoted to model this future cost, and thus we have detailed information of the baseline cost for the force structure [7].

The modelled baseline for the future emissions from the Norwegian Armed Forces, in accordance to the current long-term plan, can be seen in figure 1-1.

[1] In the non-ETS (Emission Trading System) sector.

[2] The GHG Protocol Corporate Standard classifies a company's GHG emissions into three 'scopes'. Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions.

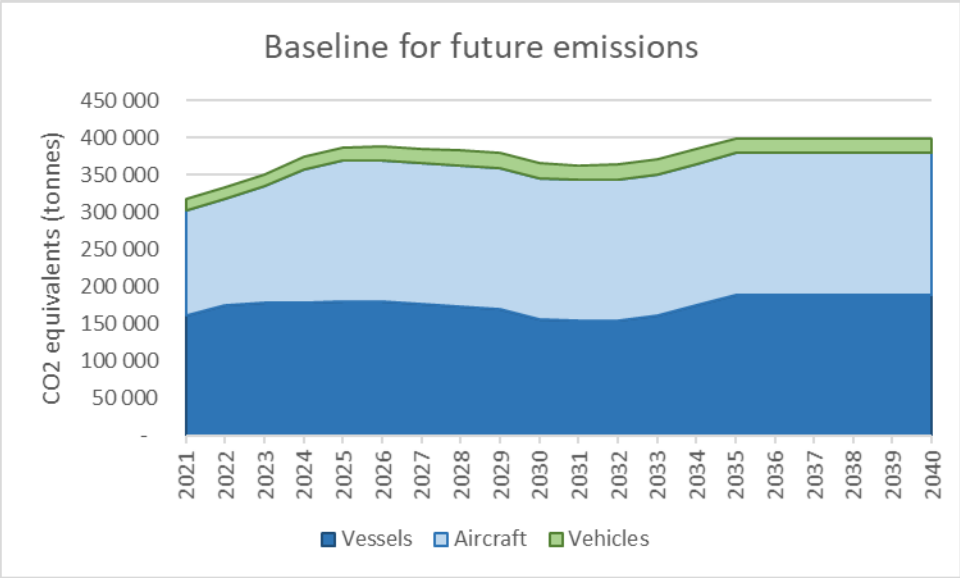

Figure 1-1: The modelled baseline for future emissions from the Norwegian Armed Forces in accordance to the current long-term plan.

2.2 Identifying possible measures

To identify possible climate mitigation measures we started the process with a brainstorming session. Further mitigation measures were identified searching through the national and international literature. The last procedure was a systematic review of the capabilities of the Norwegian Armed Forces, where we asked the question "Can this capability be provided by an alternative and more climate friendly technology?" In many cases the answers were "no" due to the operational requirements. However, some of the maritime capabilities currently handled by frigates might be solved by other means using modern technology in the future. Such maritime structures, utilizing modern sensor and communication technology together with long range precision weapons and a more flexible vessel structure has recently been studied by Hansen and Dahlmo [8] and found to have greater capability and lower costs than the baseline structure (which consists of new frigates). We have calculated the climate emissions of such a solution and included it in our list of measures, even though such a measure should not be understood as a climate measure. However, it represents an interesting case study where modern technology is utilized for greater capability and lower costs, and at the same time is producing lower emissions.

After this process we went through a selection process, asking the questions:

- Will this measure negatively impact capability?
- Will this measure/technology be eligible for application in the foreseeable future?
- Is the infrastructure to support this measure/technology sufficient?
- Can we quantify the emission reduction and cost of this measure?

If the answer is "No" to the first question, and "Yes" to the others, the measure is included in the list of measures. After this selection process we were left with seven quantifiable emission reduction measures, which are included in the results. In addition, five measures were deemed important enough to mention and discuss, even though we were not able to quantify the emission reduction and costs.

2.3 Modelling of single measures

Using the short list of measures produced in the previous section one can model the emission reduction and cost of each measure individually. The cost analysis uses standard cost analysis methodology. Modelling of emission reduction is done on a case-by-case basis.

We have used two main methods for modelling the emission reduction: Percentage reduction and bottom-up modelling. For instance for energy efficiency measures in surface vessels we model a percentage range of fuel consumption reduction based on available values from the literature. For the new maritime force structure/concept we model the emissions from this new structure bottom-up, and subtract the emissions of the parts of the structure it replaces.

As far as possible, we try to take lifecycle and indirect emissions into account. This is especially important in the case of biofuels, where there is a large range of outcomes depending on the system boundaries for the calculation.

2.4 Modelling combined measures

Once the measures are modelled individually the next step is to combine them to get the total potential for emission reduction. However, since some of the measure addresses the same sources of emissions, one needs to take care to not double count the emission reductions. Also, not all measures are compatible with one another. For instance, the measure where new surface vessels for the Coast Guard switches to a natural gas propulsion system is not compatible with the new concept for maritime warfare. This is because the concept involves acquisition of a standardized class of vessels serving both the Coast Guard and Royal Norwegian Navy, and therefore needs to adhere to NATO's single fuel policy [9].

This illustrates the fact that the measures have to be considered for compatibility. This should be done pairwise so all possible incompatibilities are addressed. Once the incompatibilities are established, one can combine measures into maximal groups of compatible measures. (The measures that do not have any incompatibilities go in all the groups.) In our case, we ended up with two groups of measures.

In order to avoid double counting of emission reductions the measures have to be put in order and recalculated.

If uncertainty is included in the modelling of measures, this can also be included in the combined measure calculation. One approach to this is to use cumulative uncertainty. For the first measure in the group, use a three-point estimate for the emission reduction. For the next measure in the group, combine the low estimate of the measure with the low estimate of the first measure, and the high estimate of the measure with the high estimate of the first measure. The mean estimate of the second measure is combined with the mean estimate of the first estimate. Continue like this for all the measures in the group, and repeat for all groups.

For all groups this has now produced a three-point estimate of the total emission reduction. Keep in mind that when combining uncertainties in this way, the probabilities of the high and low estimates of the combinations are not the same as the probabilities of the individual three-point estimates, (in fact they are very much lower,) due to the combination of probabilities.

3.0 RESULTS

The measures we identified and modelled for the Norwegian Armed Forces are the following:

- Advanced biofuels

- Battery hybridization of surface vessels
- Energy efficiency measure of surface vessels
- Increased use of simulator systems
- An alternative replacement for the Nornen class Coast Guard vessels
- A new concept for maritime warfare
- Liquid natural gas (LNG) on Coast Guard vessels

3.1 Results of individual measures

3.1.1 Measure 1 – Advanced biofuels

This measure involves gradually increasing the amount of advanced biofuels in to the fuel mix of the Norwegian Armed Forces. Two types of advanced biofuels are used in this measure: Hydrotreated vegetable oil (HVO)[3] and liquefied biogas (LBG).

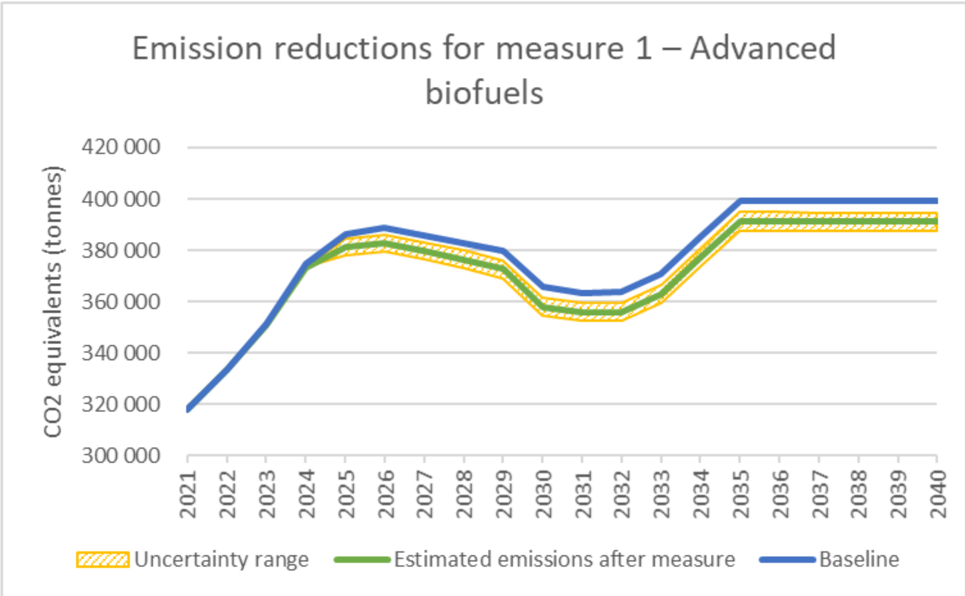

Figure 3-1: The modelled estimated emissions from the Norwegian Armed Forces after measure 1 – Advanced biofuels including uncertainty.

This measure will cost the Norwegian Armed Forces between 0.1 and 4 million euros annually (more than the baseline), depending on the percentage of biofuels in the mix, the price development and the future CO_2-tax in Norway (biofuels are exempt from CO_2-tax).

This measure does not influence operational effectiveness.

3.1.2 Measure 2 – Battery hybridization of surface vessels

This measure involves the instalment of batteries on a suitable range of surface vessels during their mid-life update (MLU) or when new vessels are acquired.

[3] The term HVO is also used for other hydrotreated raw materials such as animal fats. The two terms HEFA (*hydroprocessed esters and fatty acids*) and HVO are often used interchangeably.

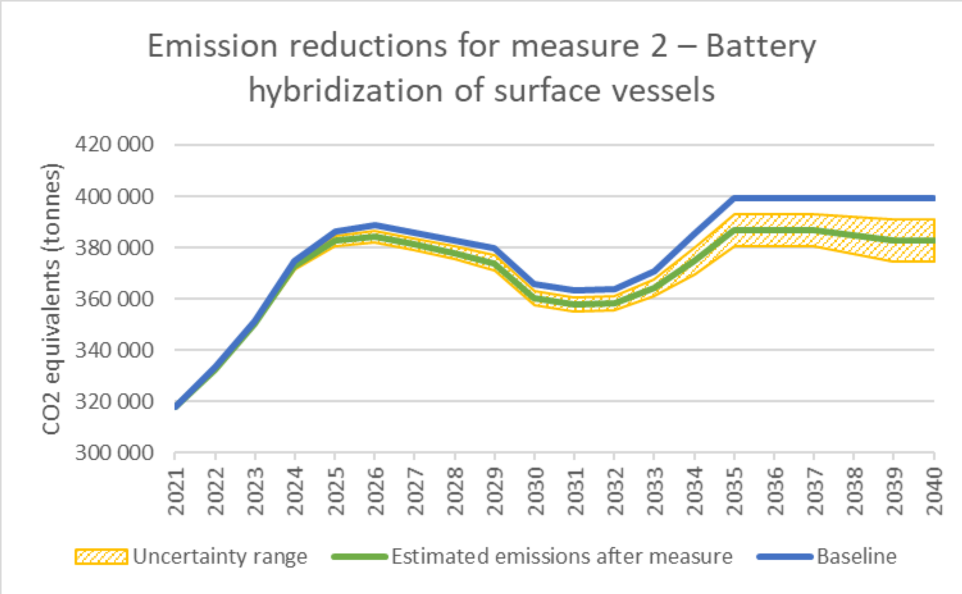

Figure 3-2: The modelled estimated emissions from the Norwegian Armed Forces after measure 2 – Battery hybridization of surface vessels, including uncertainty.

The cost analysis of this measure shows that it is likely, but not certain, that this measure will reduce the total costs of the Norwegian Armed Forces, in a life-cycle view. The cost estimate is sensitive to the effectiveness of the batteries (how much fuel consumption is reduced), investment and installation costs of the batteries and future fuel prices and carbon tax. The amount of fuel reduction varies with operational patterns, where the savings are greater e.g. for dynamic positioning than for long-range patrol. For vessels that are involved in operations requiring a lot of dynamic position this measure is likely to reduce costs already today. Given the fast development in battery technology we assess that this measure will likely be a cost saving measure for other vessels as well in the future.

This measure will have a positive impact on operational effectiveness overall. The batteries causes the engines to operate at more optimal speed. This leads to reduced need for maintenance and a lower signature. The reduction of fuel consumption also increases the range of the vessels. The batteries will however occupy some space and add some weight to the vessel. Also, batteries introduces a potential challenge for the security aspect on the vessel, and this has to be addressed.

3.1.3 Measure 3 – Energy efficiency measures on surface vessels

There are many energy efficiency measures which can be applied to surface vessels to reduce fuel consumption and emissions. Examples of such measures are hull coating, waste heat recovery and propulsion efficiency devices. There are too many of these measures to consider them individually in the present paper, hence we have grouped them together, and present our estimates of the total fuel savings. These estimates are based on our assessment of the literature and the feasibility of the various measures. We assume that these efficiency measures are implemented during MLU or when new vessels are acquired.

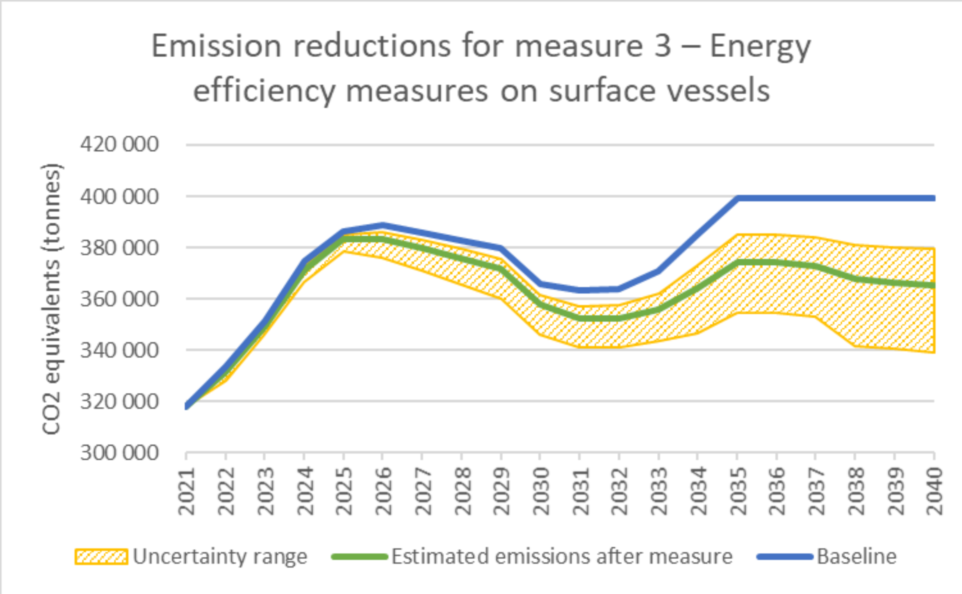

Figure 3-3: The modelled estimated emissions from the Norwegian Armed Forces after measure 3 – Energy efficiency measures on surface vessels, including uncertainty.

Since this measure is a collection of a wide variety of measures, each measure will have a different cost-to-benefit ratio. However, we expect that many of these measures will introduce cost savings for the Norwegian Armed Forces.

All of these measures reduces fuel consumption and thus increases range. Many of the measures will also impact the signature of the vessels in a positive way. Overall these measure will therefore increase the operational effectiveness of the vessels.

3.1.4 Increased use of simulator systems

This measure includes acquisition of full mission simulator systems for NH90 helicopters and P-8 maritime patrol aircrafts, and increased utilization of the frigate simulator already in use by the Royal Norwegian Navy. These simulator systems are then used to replace a percentage of the live training, reducing fuel consumption and emissions.

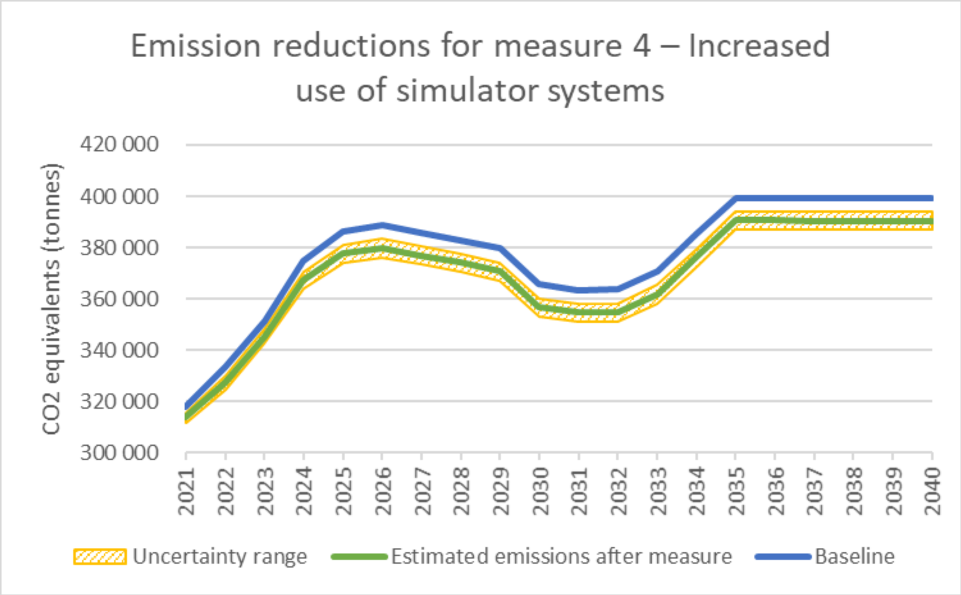

Figure 3-4: The modelled estimated emissions from the Norwegian Armed Forces after measure 4 – Increased use of simulator systems, including uncertainty.

The preliminary cost analysis from the NH90 acquisition shows that the NH90 simulator will introduce cost savings for the Norwegian Armed Forces in a life-cycle view/perspective. Based on experience and cost analysis of other air systems (NH90, F-35) we assess that it is likely that the P-8 simulator also introduces cost savings, although this has not been properly cost estimated yet. Increased utilization of the frigate simulator will introduce further cost savings.

The simulator systems allows for effective training and a high number of repetitions of manoeuvres and procedures that are either expensive or impractical to do live. It also allows for greater secrecy of training scenarios. Therefore this measure will impact operational effectiveness positively.

3.1.5 Measure 5 – An alternative replacement for the Nornen class Coast Guard vessels

In the current long-term plan the Nornen class Coast Guard vessels are expected to be replaced by much larger surface vessels. Since the size of a vessel is the driving factor for fuel consumption and emissions, we propose to replace this class with a new class of vessels of roughly the same size as the current class.

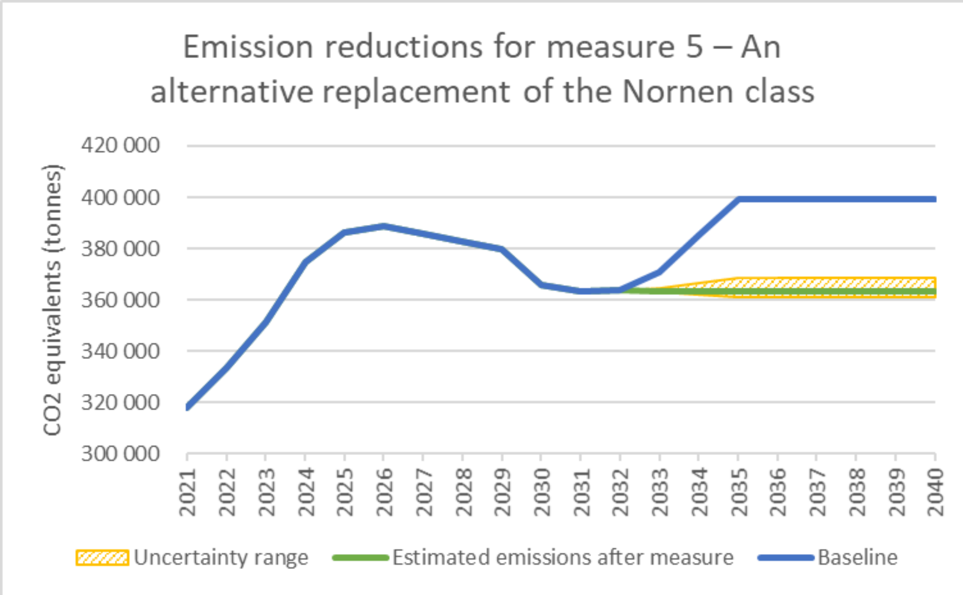

Figure 3-5: The modelled estimated emissions from the Norwegian Armed Forces after measure 5 – An alternative replacement for the Nornen class Coast Guard vessels, including uncertainty.

This measure will introduce cost savings for the Norwegian Armed Forces, as smaller vessels are cheaper in acquisition and operating costs.

We do not expect that size alone will impact the operational effectiveness of these Coast Guard vessels.

3.1.6 Measure 6 – A new concept for maritime warfare

This measure involves introducing a new concept for maritime warfare and a new force structure to fulfil this concept, as described in [8]. In shorthand, maritime surface vessels and coast guard vessels are replaced by a new structure, composed of:

- A new class of standardized surface vessels,
- several small force protection vessels,
- autonomous unmanned surface vessels (USVs) equipped with a small vertical-take-of-and-landing (VTOL) unmanned aerial vehicles (UAVs) (for anti-submarine warfare (ASW)),
- land based long-range precision naval strike systems,
- satellite systems,
- underwater sensor systems, and
- sea mines.

The new class of standardized surface vessels are modular and can be equipped with various equipment delivering a variety of capabilities which can be tailored for different operations.

As mentioned in section 2.2, this measure should not be understood as an emission reduction measure, but primarily a measure addressing operational capability and costs, with lower emissions as a positive “byproduct”. This measure represents a case where utilization of modern technology allows for greater capability, lower costs and lower emissions.

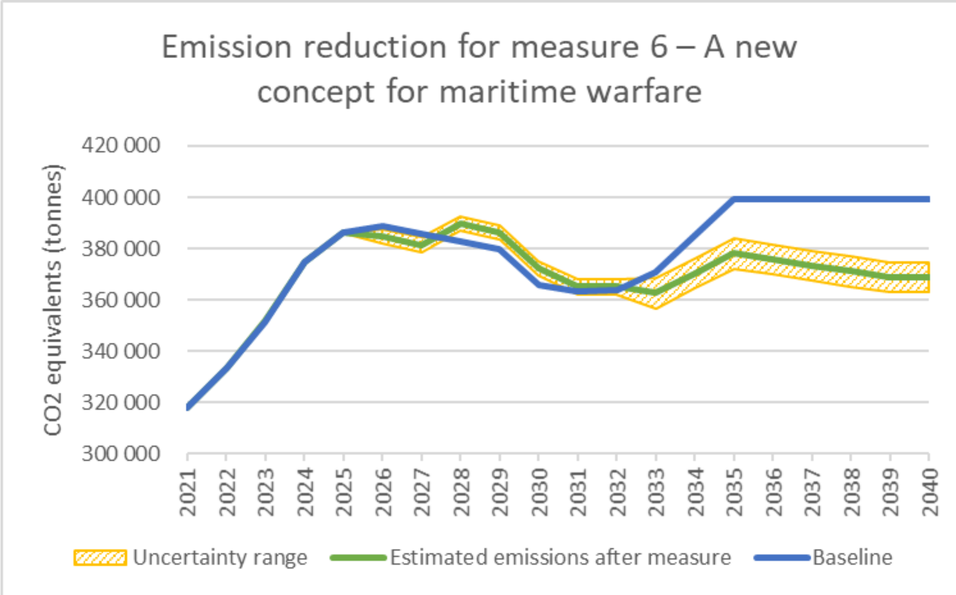

Figure 3-6: The modelled estimated emissions from the Norwegian Armed Forces after measure 6 – A new concept for maritime warfare, including uncertainty.

As shown in [8], this measure will introduce cost savings for the Norwegian Armed Forces and increase the operational effectiveness.

3.1.7 Measure 7 – LNG on Coast Guard Vessels

This measure involves choosing LNG propulsion systems for new Coast Guard Vessels.

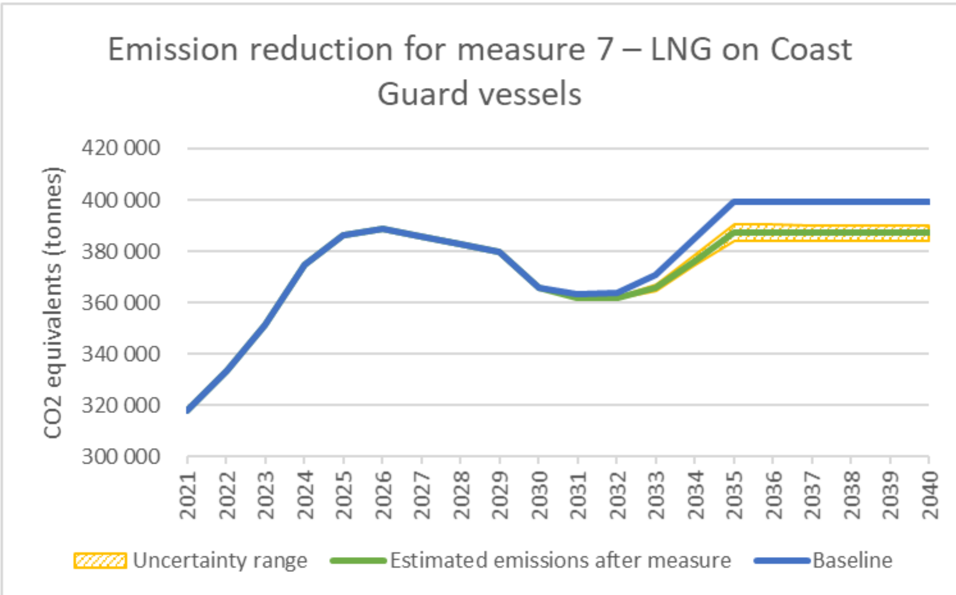

Figure 3-7: The modelled estimated emissions from the Norwegian Armed Forces after measure 7 – LNG on Coast Guard vessels, including uncertainty.

LNG propulsion systems are more expensive in the acquisition phase than traditional diesel electric engines. However, in the life-cycle perspective, it introduces cost savings due to lower operating costs.

The fuel infrastructure for LNG is not as good as for traditional marine gas oil (MGO), but this is expected to be much better by 2030. No other impacts are expected of this measure with regards to operational effectiveness.

3.2 Results of combined measures

As mention in section 2.4, not all measures are compatible. We have put together two packages of compatible measures and calculated the total emission reduction in these cases using the methods described in section 2.4.

3.2.1 Total emission reductions for package of measure 1

This package of measures consists of the following measures (calculated in the following order):

- Measure 6 – A new concept for maritime warfare
- Measure 2 – Battery hybridization of surface vessels
- Measure 3 – Energy efficiency measures on surface vessels
- Measure 4 – Increased use of simulator systems
- Measure 1 – Advanced biofuels

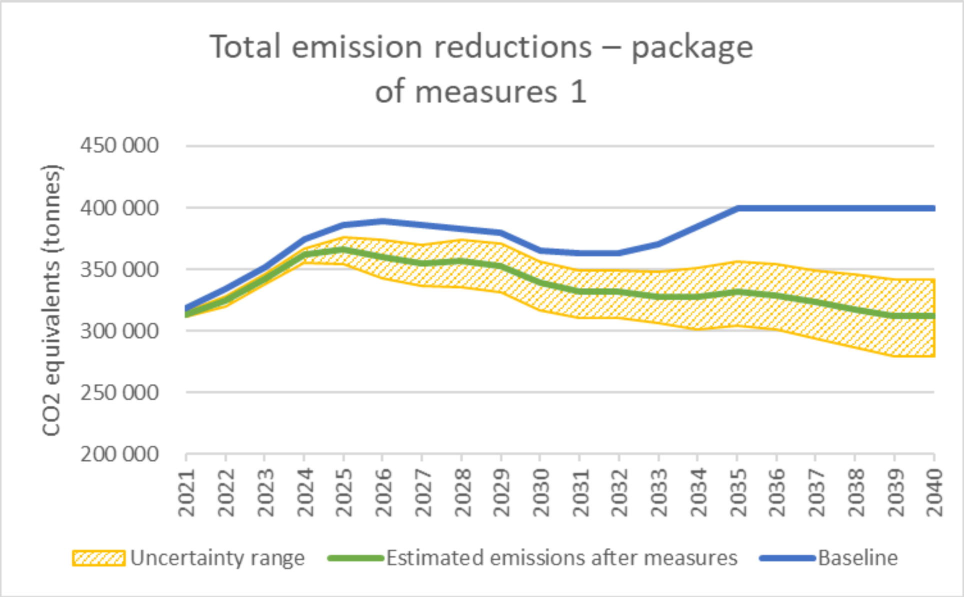

Figure 3-8: The modelled total emissions from the Norwegian Armed Forces after all measures in the first package of measures, including uncertainty.

Figure 3-8 shows the total emissions and emission reduction for package of measures 1. The emission reductions are relatively insignificant the first years, and gradually increases from 2025 as the measures start to take effect. By 2040, the annual emissions are reduced between 15–30 % relative to the baseline, with a mean estimate of approximately 22 %.

3.2.1 Total emission reductions for package of measures 2

This series consists of the following measures (calculated in the following order):

- Measure 5 – Alternative replacement of the Nornen class Coast Guard vessels
- Measure 7 – LNG on Coast Guard vessels
- Measure 2 – Battery hybridization of surface vessels
- Measure 3 – Energy efficiency measures on surface vessels
- Measure 4 – Increased use of simulator systems
- Measure 1 – Advanced biofuels

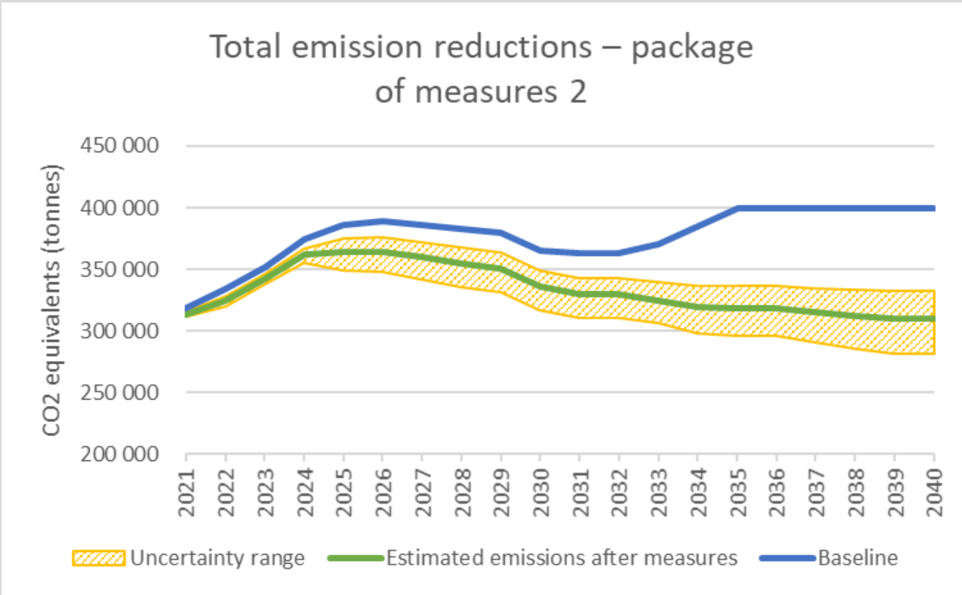

Figure 3-9: The modelled total emissions from the Norwegian Armed Forces after all measures in the second package of measures, including uncertainty.

Figure 3-9 shows the total emissions and emission reduction for package of measures 2. The emission reductions are relatively insignificant the first years, and gradually increases from 2025 as the measures start to take effect. By 2040, the annual emissions are reduced between 17–30 % relative to the baseline, with a mean estimate of approximately 22 %.

3.3 Other/non-quantifiable measures

In addition to these seven measures, five measures were identified as important enough to describe even though we could not model the effect of these measures. These measures were:

- Integrated environmental management
- Green acquisitions
- Reduction of food waste
- Climate friendly food choices
- Reduced (air) travel

3.3.1 Integrated environmental management

The environmental management in the defence sector in Norway is currently conducted only up to a certain level, and it is not integrated with top-level management and with strategic planning [10]. It is at these decision levels the choices with the highest environmental impacts are decided. Therefore, environmental management needs to be integrated with these processes.

3.3.2 Green procurement practices

The defence sector has substantial buying power. According to an organizational life-cycle analysis, upstream emissions outside the organization accounts for 68 % of the total emissions from the Norwegian defence sector [11]. Therefore, adopting green procurement practices can be a substantial and effective way to reduce indirect emissions.

3.3.3 Reduction of food waste

Previous estimates of food waste from the Norwegian Armed Forces are very uncertain [12]. In the literature, reduction of food waste is often shown to be a cost-efficient measure to reduce indirect emissions [5]. We assess that this is likely to be the case for the Norwegian Armed Forces as well. Better data needs to be collected and monitored as this measure is implemented.

3.3.4 Climate friendly food choices

Different foods have different environmental impact. It is well documented that grains, fruits, vegetables and legumes have considerably lower environmental impact than meat and dairy [13-16] and that production emissions outweigh transportation emissions [14, 15].

“Meatless Monday” was tested in parts of the Norwegian Armed Forces in 2014 [17, 18]. The test was not a success, but many lessons were learned. Using the knowledge obtained in this test could change the outcome of future tests and lead to a significant reduction of indirect emissions.

3.3.5 Reduced (air) travel

The defence sector has significant emissions from business travel activity, and air travel is the most prominent source of these emissions. The Covid-19 pandemic caused almost a 50 % reduction of air travel in 2020, after years of steady increase [6]. The increased utilization and familiarization of digital meeting platforms will enable the defence sector to considerably reduce travel activity in general, and air travel specifically, to a much lower level than before the Covid-19 pandemic. This will also reduce travel costs.

3.4 Discussion of results

As shown in section 2.2, without any measures the emissions from the Norwegian Armed Forces might increase as much as 25 % by 2040. This is due to a combination of increased activity and acquisition of new military systems with higher fuel consumption (such as F-35, P-8, AW101 and new Coast Guard vessels). Implementing the measures described in this paper will reduce emissions relative to this baseline scenario, but are not likely to reduce the emissions well below the 2020 level.

In a military setting, there are currently few alternatives to the internal combustion engine. Especially for aircrafts where the force-to-weight-ratio is a determining factor.

There is not enough sustainable biofuel currently available to replace the current consumption of fossil fuels. That means that everywhere where there are alternative technologies, societies needs to make this technological switch. The military sector represents a special case where not all these technological switches are viable. In a future where this technological shift has taken place, biofuels might be a sustainable alternative for the military systems dependent on the internal combustion engine. In today's biofuel market there is a risk of carbon leakage [19-21]. It is essential that sustainability requirements are addressed across nations and sectors for all biomass products (not limited to biofuels) to avoid carbon leakage.

4.0 CONCLUSION

In this paper we have modelled a baseline for future emissions from the Norwegian Armed Forces based on the current long-term plan. We have modelled and assessed seven emission reduction measures with regards to emission reductions, costs and operational effectiveness.

The use of advanced biofuels are the only measure that with relative certainty will increase the costs for the Norwegian Armed Forces. In the current market situation, there is a serious risk that increased use of biofuels could lead to carbon leakage, reducing the effect of this measure. In the long term, where emission free technologies largely have replaced the internal combustion engine, biofuels might be a sustainable alternative for the military systems dependent on the internal combustion engine.

Battery hybridization, energy efficiency measures on surface vessels, use of simulator systems, an alternative replacement of the Nornen class vessels, a new concept for maritime vessels, and LNG on Coast Guard vessels, are measures that either are cost saving already today, or are likely to be cost saving in the future (in a life-cycle perspective). Most of these measures will also increase operational effectiveness.

In total these measures have the potential to reduce the emissions from The Norwegian Armed Forces by 15–25 % in 2040, relative to the baseline emissions, with a mean estimate of 22 %.

Military systems have a long service life. Investing in energy inefficient solutions today will generate emissions and costs for many years into the future. We therefore recommend that emission projections get a more prominent role in acquisition decisions and the long-term defence planning process.

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