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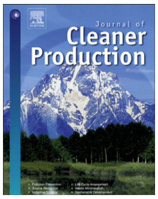

Assessing life cycle greenhouse gas emissions in the Norwegian defence sector for climate change mitigation

Magnus Sparrevik [a], [b], *, Simon Utstøl [c]

[a] Department of Industrial Economics and Technology Management, Norwegian University of Technology, Trondheim, Norway
[b] Norwegian Defence Estates Agency, Oslo, Norway
[c] Norwegian Defence Research Establishment, Kjeller, Norway

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ABSTRACT

The military sector is an important global player in terms of monetary expenditure and resource use. However, reporting of military greenhouse gas emissions is often embedded into other activities and quantitative estimations are scarce. This paper assesses the life cycle greenhouse gas emissions from the Norwegian defence sector from an organisational perspective. The total annual emissions add up to 0.8 million tonnes of CO_2 equivalents, corresponding to approximately 1.1% of the national emissions from Norwegian consumption. The results show that upstream activities are the main contributors to emission (68%), with only 32% allocated to the reporting organisation. From a management perspective, this distinction is important since these emissions may be mitigated through green procurement practices, in contrast to direct emissions that require operational reductions.

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1. Introduction

World military expenditure is estimated to have reached $1739 billion, representing 2.2 percent of the global gross domestic product (GDP), in 2017 (Tian et al., 2018). The military sector and defence industry are therefore major global players, using considerable resources and subsequently affecting the environment. Even though the environmental impact of military activities has been discussed and debated for centuries, few documented studies of the sector's environmental impact exist and most are connected to biodiversity and land use (Hanson, 2018; Lawrence et al., 2015; Nuttall et al., 2017; Vertegaal, 1989; Zentelis et al., 2017). Indirect correlations between military energy use, especially fossil fuel use, and greenhouse gas (GHG) emissions have been discussed previously (Bildirici, 2017; Clark et al., 2010; Nuttall et al., 2017), but quantitative estimations are scarce. According to the Kyoto protocol and, subsequently, the Paris agreement, emissions from military activities are to be included in the national emissions inventory if they are accrued within national borders. Reporting of overseas activities or impacts of warfare is not required. The emissions from military activities are often embedded into other activities, such as energy production, transportation, and industrial activities, or taken out of the reporting (Michaelowa and Koch, 2001). A few studies on sector-specific calculations of greenhouse gas emissions in the UK and Australia have been found, indicating that defence activities contribute to approximately 1% of the annual emissions of greenhouse gases in these countries (Bailey, 2009; Wood and Dey, 2009). Figures from the US are within the same range, varying from 25.4 million tonnes annually from direct fuel consumption (Belcher et al., 2019) to 172 million tonnes including electricity use and upstream emissions (Liska and Perrin, 2010). This is equivalent to 0.5–3.3% of the total US emissions in 2017 (EIA, 2019).

Emissions from fossil fuel and from energy production (often referred as scope 1 and 2) are compulsory to report according to the ISO 14 064 greenhouse gas reporting standard (Weng and Boehmer, 2006), since they can be directly connected to the reporting organisation. However, it is likely that multiple impacts may also arise from indirect emissions originating from both upstream and downstream in the value chain (scope 3), which are only partly influenced by the reporting organisation. Indirect emissions may occur in all life cycle stages and their contribution to the overall life cycle emissions may be substantial (Hertwich and Wood, 2018;

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* Corresponding author. Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim, Norway.
E-mail address: magnus.sparrevik@ntnu.no (M. Sparrevik).

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Hertwich and Peters, 2009), especially for large procuring organisations such as the military sector (Huang et al., 2009).

The concept of organisational life cycle assessments (O-LCA), proposed by the UNEP/SETAC initiative (Martínez-Blanco et al., 2015a), encompasses the aspects of life cycle and multiple impacts from an organisational perspective, and may be used to better assess the total impact of GHG from the military sector. Although LCA for procurement of defence material has been discussed in part (Hochschorner and Finnveden, 2006; Liska and Perrin, 2010), information about the wider life cycle impact from military activities is practically non-existent in the present scientific literature. This paper is, to our knowledge, the first advance in the field in many years, and the first to conduct a complete analysis evaluating production, operational, and end-of-life greenhouse gas emissions using the basics of the O-LCA framework. The research outlined in this paper applies an organisational perspective to assess life cycle GHG emissions for the Norwegian defence sector in order to evaluate climate-change mitigation strategies.

The paper is organised as follows. First, we discuss the O-LCA framework and how it may be adapted to the defence sector. Next, we analyse the GHG emissions of the Norwegian defence sector from an organisational perspective. Considering the findings, we discuss the impact of the results with a special focus on measures for greenhouse gas reduction. Finally, we draw conclusions, discuss benefits and limitations, and suggest a direction for future research.

2. Materials and methods

2.1. Main elements of O-LCA

In contrast to traditional LCA, which focuses on assessing the life cycle impacts of products or services, the O-LCA takes a much broader organisational perspective. As defined by UNEP/SETAC (Martínez-Blanco et al., 2015b), ‘O-LCA uses a life cycle perspective to compile and evaluate the inputs, outputs and potential environmental impacts of the activities associated with an organisation and the provision of its product portfolio’. Most of the differences from product LCA lie in how results are reported, how system boundaries are defined, and how data is collected. When setting the scope of the analysis, it is necessary to clearly define the reporting unit organisation, the outflow or portfolio which is used, and system boundaries consistent with all direct and indirect activities affected by the organisation’s activity (Martínez-Blanco and Finkbeiner, 2018). Data collection in O-LCA may be comprehensive, and can be based on collecting data for each product and service (‘bottom-up’ approach) or by assessing the impact from the organisation’s input and output (‘top-down’ approach). Hybrid solutions may also be feasible.

An O-LCA should address all of the multiple impacts from activities involving all impact categories in the LCA. The Norwegian defence sector may impact the environment in multiple ways. Emission of greenhouse gases occurs directly from fossil fuel consumption and indirectly from use of resources and energy. Military training in shooting ranges and training fields directly impact the environment through emissions into the air, water, or soil and through noise generation. In addition, biodiversity and nature conservation may be affected in training areas and facilities. However, practical conditions make it challenging to address multiple impacts in our case. First of all, most impacts are site-specific, and to adjust for local conditions (for example, in the hundreds of existing Norwegian shooting ranges) within the impact model would be beyond the scope of this aggregated study. Secondly, emission inventories and impact models for assessing indirect impacts only exist for a limited number of impact categories (Mattila, 2018). Finally, most non-climatic impacts are regulated through detailed discharge permits from environmental authorities, limiting the use of the comprehensive results for management purposes. Restricting the assessment in this study to greenhouse gas emissions seems reasonable, but also deviates from the original O-LCA definition (Martínez-Blanco et al., 2015a).

2.2. Goal and scope

2.2.1. Reporting organisation

The Norwegian defence sector is governed through the Ministry of Defence (MoD), enacting governance of four underlying agencies whereof the Armed Forces (AF) is the largest. In addition, the sector contains the Defence Estates Agency (NDEA), the Norwegian Defence Research Establishment (FFI), and the Defence Material Agency (NDMA). Even though environmental data is available at the agency or even sub-agency or unit level, the sector as a whole has been selected as the reporting organisation. The reason is twofold: i) environmental performance is in practice highly interlinked between agencies even though they are administratively divided, and ii) some of the data in disaggregated form is not publicly available due to security restrictions.

2.2.2. Reporting flow

The study assesses greenhouse gas emissions from all operational activities in the Norwegian defence sector in 2017 based on the methodology in the IPCC guidelines for national greenhouse gas inventories (IPPC, 2014). Gasses included are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs). The greenhouse gas emissions are estimated separately, but presented as CO_2 equivalents (CO_2 eq.) in the Results section. Table 1 shows the global warming potential (GWP) values for the greenhouse gasses used in the study.

The reporting flow is the financial budget spent on all activities and assets connected with operating the armed forces during the reporting year. In 2017, this sum was 50.9 billion Norwegian crowns (NOK). The corresponding values for the years 2016 and 2018 were 49.1 and 55.0 billion NOK, respectively. Only economic flows causing greenhouse gas emissions, are considered in the study.

2.2.3. System boundaries

The included activities cover emissions from the complete life cycle, from production via operation to end of life (EoL). As indicated in Fig. 1, the system boundaries and allocation of activities into the value chain follow the requirement in the O-LCA guidelines and also, implicitly, the scope definition of ISO 14064 (with some exceptions). Emissions from ammunition and chemical use are added to fossil fuel consumption (scope 1) as a direct emission from the reporting organisation. Similarly, heating of buildings using fossil fuel or biofuels and fugitive emissions from refrigerants are included as direct emissions. Purchased goods and services and related military transportation and business travels are a part of

Table 1
Global warming potential (GWP) values for the greenhouse gasses used in the study. Based on 5th assessment report (IPPC, 2014).

Component	Chemical formula	GWP-value (100 y)
Carbon dioxide	CO_2	1
Methane	CH_4	34[a]
Nitrous oxide	N_2O	298 [a]
Hydrofluorocarbons (HFC):		
HFC-32	CH_2F_2	677
HFC-125	CHF_2CF_3	3170
HFC-134a	CH_2FCF_3	1300
HFC-143a	CH_3CF_3	4800

[a] Values include climate-carbon feedbacks.

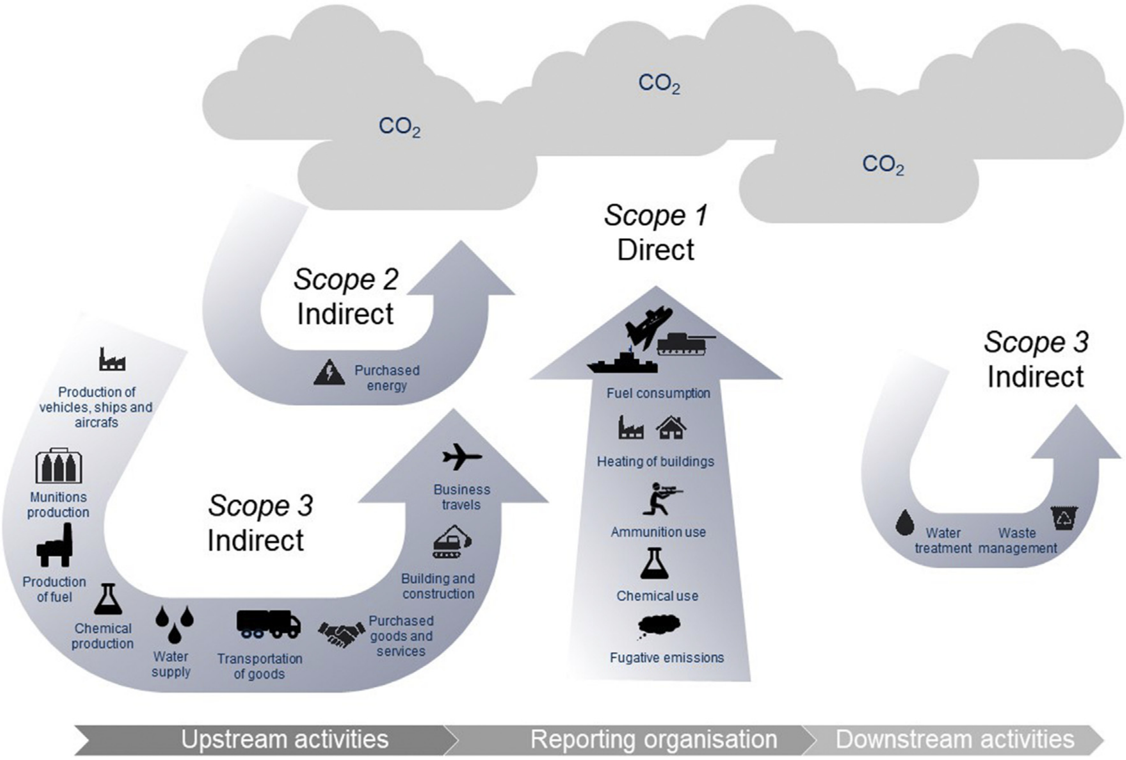

Fig. 1. System boundaries for the study divided in direct and indirect activities and distributed according to the value chain of the organisation.

indirect upstream emissions (scope 3). In addition, all production of fuel, chemicals, munition, and military vehicles fall into this category. Similarly, purchased energy (scope 2) and water supply are considered here. Generated waste and treated sewage water (scope 3) are considered as downstream by-products since waste is recycled to energy or recovered in new materials and therefore is delivered into subsequent material value chains. Following the reporting flow definition, acquisition of future or ongoing military assets and systems is not included. The reason is twofold. First, these acquisitions occur irregularly. This means commission intervals and the expected lifetime are highly uncertain, making allocation of emissions to a single year difficult. Second, the development of this equipment is classified, so access to environmental production data is restricted. GHG emissions of the military assets and systems already in use are included in the study, but are based on production emission data from comparable civilian equipment.

2.3. *Life cycle inventory analysis*

The Norwegian MoD requires all subordinate agencies to comply with the latest version of the ISO 14001 environmental management system (EMS). Significant environmental aspects are identified and reported by the defence sector and associated partners to the Norwegian Defence Environmental Database (NDED). All scope 1 and 2 inventories shown in Fig. 1 and scope 3 data concerning waste and business travel are monitored. This is a typical bottom-up system where data are reported through use of instrumental monitoring together with reporting from operating personnel and subcontractors. We use these data as the primary data source, taking the aggregated sectoral values for the year 2017 (Utstøl et al., 2018). Data is presented in the supplementary information (SI) in the form of tables where inventories are combined with emission factors to calculate the annual emission of greenhouse gases.

According to the O-LCA guidelines, the analysis should include all upstream (and downstream) impacts (in this case GHG emissions), in addition to the direct ones. The sector makes large purchases of equipment and services, builds and refurbishes a number of properties every year, and produces indirect emissions from its operations. We have used the available NDED data in the calculations, but to quantify the totality using bottom-up reporting would be unfeasible given available time and resources. However, since all items are publicly procured, indirect emissions associated with purchased goods and services as declared in the national accounts and may be estimated by combining expenses for the different procurement categories with emission factors (CO_2 eq./NOK). The emission factors are derived from environmentally extended input-output analysis (EEIOA) using data from the year 2017 as a baseline. Values are taken from Larsen et al. (2017) and are replicated in the SI. The EEIOA links country-based economic consumption activities with GHG emissions, including imports of goods and services covering both upstream and downstream activities (Hendrickson et al., 1998; Kitzes, 2013). This top-down method does not allow impacts to be traced directly back to specific operations or environmental aspects, but it does make it possible to estimate the indirect GHG emissions of purchased goods and services from a wide variety of direct sectors without collecting physical data and modelling all working operations involved.

To summarise, the hybrid method proposed for this case uses a feasible combination of physical data for processes more closely related to operational activity and economic data for procured goods and services. A description of the life cycle inventory is given in Table 2, specifying the activities and type of inventory. For the complete inventory tables, see SI.

Table 2
Life cycle inventory of operational activities in the Norwegian defence sector for the year 2017.

Value chain	Activity	Description	Inventory type
Upstream activities	Vehicles, ships, aircraft	Production of land operated vehicles, ships and aircrafts	Process
	Munition	Production of munition	Process
	Fuel	Production of fuel used in vehicles and for heating	Process
	Chemical production	Production emissions from de-icing agents	Process
	Transportation	Contractor services for transportation of military goods, including maintenance	Economic
	Purchased energy	Purchased and own produced electricity and production emissions from heating	Process
	Water consumption	Drinking water used and waste water treated	Process
	Building and construction	Construction of buildings and facilities, including maintenance	Economic
	Purchased goods and services	ICT equipment, education, administrative and economic services. Operational cost of own machines and equipment. Purchase of uniforms, food and various materials	Economic
	Business travels	Emissions from personal transport using civilian vehicles (air transport and cars)	Process
Reporting organisation	Fuel consumption	Use of fossil fuel in military vehicles, ships and aircrafts	Process
	Heating of buildings	Operational emissions from heating (and cooling) of buildings	Process
	Ammunition use	Combustion of gunpowder	Process
	Chemical use	Decomposition of de-icing substances in air, water and soil	Process
	Fugitive emissions	Emissions from ozone depleting substances in heat pumps and air conditions	Process
Downstream activities	Waste management	Produced waste in organisation divided in material recovery, energy generation and disposal	Process

2.4. Life cycle GHG emissions and result interpretation

Unit processes based on the Ecoinvent database in Simapro 8.4 have been used to identify emission factors for production, operation, and EoL as indicated in the SI tables. Emission factors for electricity have been estimated using the method described in Utstøl et al. (2018), where the emissions are calculated based on the physical energy mix in Norway using a rolling 5-year average. The values are in the same range as life cycle emissions presented for hydropower-based energy systems (Turconi et al., 2013). Price mechanisms such as guarantees of origin (GO) are not included (Dahlstrøm et al., 2012).

To estimate the emission factors for production of military equipment, a proxy from the closest civilian type of equipment has been used since corresponding values for military equipment are unavailable. Fugitive emissions have been delegated to operation emissions, based on the study of Zhao et al. (2015) confirming that the service stage is responsible for 99% of life cycle emissions of refrigerants. Municipal and construction waste have been classified according to the respective recycling fractions with corresponding EoL emission factors. For fractions with material recovery, the substituted virgin material has been included as a positive impact (system expansion). Underlying the EEIOA, the emission factors presented in the SI are based on the domestic input-output table for 2014 published by Statistics-Norway (2018) and on the Eurostat statistics (2013) for import contributions (Eurostat, 2019). See also (Larsen et al., 2017). For a more detailed explanation of the methodology, see earlier published work by Larsen and Hertwich (2009, 2010a, 2010b).

The results of the study are interpreted in two ways. First, it is valuable to identify the GHG emissions of the whole organisation in order to correctly assess the impacts from a life cycle perspective. Second, the distinction between direct and indirect emissions gives a valuable overview of where emissions occur in the value chain, which is important for the mitigation management strategy.

2.5. Uncertainty analysis

Performing uncertainty analysis in an organisational study such as this one is challenging due to the aggregation of data from various product streams using different data sources and methods (Martínez-Blanco and Finkbeiner, 2018). In this case, lack of disaggregated data due to data confidentiality adds to the challenge. In addition, EEIOA databases are complex and may produce different results depending on the underlying models, thus making disaggregation of uncertainties difficult (Dawkins et al., 2019). We therefore argue that instead of focusing on quantifying the statistical aleatoric uncertainty as in traditional LCA (Lesage et al., 2018), the epistemic uncertainties important to the organisational perspective may be better illustrated by qualitative discussion. In this paper we have illustrated and discussed uncertainties both by comparing process and EEIOA results and by evaluating the variation in estimates of overall GHG emissions based on different electricity mixes.

3. Results

3.1. Carbon footprint in the value chain

The estimated emissions suggest that the Norwegian defence sector is responsible for 807 764 tonnes of CO_2 eq. or 1.1% of the annual GHGs emitted in the Norwegian economy in 2017, taking into account procurement and imports (Fig. 2). In total, the public sector is responsible for 16% of Norwegian GHG emissions, which are dominated by household consumption (62%) (Larsen, 2019). Globally, Hertwich and Peters (2009) found similar values with 10% of GHG emissions related to government consumption, 72% related to households, and the remaining 18% related to investments.

Table 3 presents results distributed across the value chain, separated into three categories connected to activity. *Military assets and systems* include activities directly connected to the function of the armed forces, whereas *operational assets* include all the direct and indirect impacts from employees. *Building assets* represent all GHG emissions from constructing and operating facilities. The results show that upstream activities are the main contributors to emissions with 545 423 tonnes of CO_2 eq. (68%), with only 262 519 tonnes of CO_2 eq. (32%) allocated to the reporting organisation. Downstream activities give a small reduction of emissions due to substantial material recycling and subsequent replacement of virgin resources (−178 tonnes of CO_2 eq.). Emissions from the reporting organisation correspond well to scope 1 and 2 values in the official greenhouse gas account for 2017, amounting to 268 939

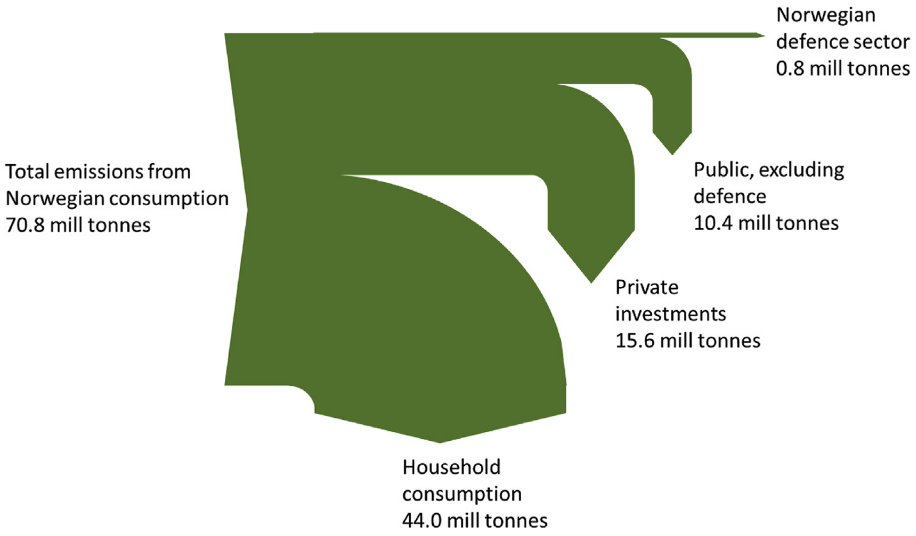

Fig. 2. The contribution from the Norwegian defence sector to total life cycle greenhouse gas emissions from consumption in the Norwegian economy in 2017. Values for the defence sector are taken from this study, whereas the other values are taken from Larsen (2019).

Table 3
Life cycle greenhouse gas emissions in the Norwegian defence sector for the year 2017. Tonnes CO_2-eq. pr year.

Activity	Source	Annual emissions (tonnes CO_2 eq. pr year)				
		Upstream	Reporting	Downstream	Total	Activity total
Military assets and systems	Vehicles, ships, aircraft	10 832	–	106	10 938	370 313
	Fuel	41 611	248 088	–	289 699	
	Munition	5343	0.06	−377	4966	
	Transportation	64 710	–	–	64 710	
Operation assets	De-icing activity	2293	426	–	2719	269 218
	Operation	96 048	–	–	96 048	
	Services	40 912	–	–	40 912	
	Other	36 850	–	–	36 850	
	ICT	23 647	–	–	23 647	
	Competence	6737	–	–	6737	
	Personnel	4930	–	–	4930	
	Communication	2816	–	–	2816	
	Business travels	55 721	–	–	55 721	
	Waste management	–	–	−1162	−1162	
Building assets	Purchased energy	7298	–	–	7298	168 233
	District heating	577	1453	–	2030	
	Local heating	2867	11 774	–	14 641	
	Water consumption	849	–	1255	2104	
	Fugitive emissions	–	778	–	778	
	Building and construction	141 382	–	–	141 382	
		545 423	262 519	−178	807 764	

tonnes of CO_2 eq. (Utstøl et al., 2018). However, scope 3 emissions are significantly lower in the official account (53 822 tonnes of CO2 eq.), suggesting that the included data does not currently reflect the full upstream impact. Our finding that the dominant contribution to emissions arises from upstream activities is not unusual for large procuring organisations and is well in accordance with the literature (Larsen et al., 2013; Lo-Iacono-Ferreira et al., 2017; Thurston, 2011).

3.2. Main contributors to emissions

Regardless of other sources, combustion of fossil fuels in military vehicles, ships, and aircraft remains, as expected, the largest single contributor to GHGs from the sector. As indicated in the treemap presented in Fig. 3, military assets and systems, with fossil fuel use as the dominant contributor, represent approximately 50% of the impact. The remaining emissions are equally distributed between operational and building assets. The operational category consists of a conglomerate of sources, with air-related business travel alone responsible for 7% of the total emissions. Constructing buildings, including production of building materials, is the most important source of emissions in the building category (18% of the total) and dominates over, for example, purchased energy and heating of buildings.

3.3. Uncertainties and limitations of the study

This study uses a hybrid approach with a combination of physical and economic data for the life cycle assessment. Perkins and Suh (2019) discuss uncertainty in hybrid LCA and concludes that this combination is more accurate (closeness of the estimate to the true value) than process LCA, while losing in precision

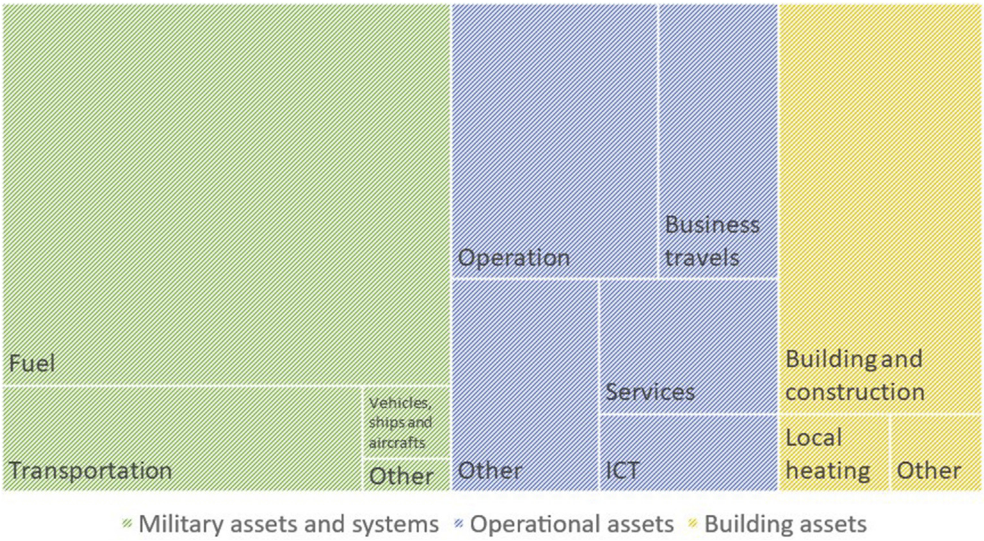

Fig. 3. Treemap showing contribution of the main emissions sources to the life cycle greenhouse gas emissions in the Norwegian defence sector for 2017.

(closeness of agreement among estimates). Uncertainty may be reduced by replacing the most uncertain data with high-precision supplier data. We see this discrepancy in practice for the cases with complementary process and EEIOA data. Business travel shows higher economic emission data compared to process-based LCA (100 971 versus 55 721 tonnes CO_2 eq.). Fuel consumption exhibits the opposite behaviour (68 750 and 289 699 tonnes CO_2 eq., respectively). This is indeed a large variation and may be rooted in how accurately the data represent the aggregated emissions and whether military price mechanisms are equivalent to civilian conditions. In this study we have used physical data when possible to reduce uncertainty, according to the recommendation by Perkins and Suh (2019). However, to encompass the broad scope of the O-LCA, we need to use all available data while acknowledging the imprecision of the economic data which are obtained from publicly available procurement information. As discussed earlier, we view this approximation of military conditions by available civilian data as the largest contributor to uncertainty in the LCA. The emission factors for military equipment in use are taken from the most closely related civilian equipment even though development, production, and cost differ. Using defence-specific emission factors for development and production would most certainly add significantly to the calculated indirect emission values in this study. At the present stage we have not been able to quantitatively assess these uncertainties due to lack of information.

Furthermore, the main uncertainty in the calculation of GHG emissions relates to the characterisation factor used. Here we consider the handling of emissions from purchased energy to be the most important aspect. Following the NDED recommendation for physical allocation of the sources of produced electricity, the emissions from energy consumption are 7315 tonnes CO_2 eq. (13.3 g CO_2 eq. per kWh) or 1% of the total GHGs in 2017. Applying the emission factor corresponding to the average energy mix in Europe for 2017 (296 g CO_2 eq. per kWh) produces the very different result of 162 800 tonnes, equivalent to an 18% contribution to the total emissions; see also the sensitivity analysis in the SI. In addition, including different energy scenarios in the EEIOA emission factors produces a ±10% difference from the values used (Nordic values for production, EU values for import) (Larsen, 2019). The impacts of these variations for management strategies are further discussed.

4. Discussion

The O-LCA guidance document (Martínez-Blanco et al., 2015a) addresses goals in terms of analytical, managerial, and societal aspects. For an enterprise, this typically involves a better understanding of the environmental performance in the life cycle, involving both impacts that are directly controlled by the reporting organisation and emissions occurring upstream in the supplier stage or downstream on the consumer side. These findings may then affect environmental management and strategic decisions. The ultimate societal goals would be to reduce environmental pressure where it may be done most effectively, independent of the organisational borders. Reduction of direct emissions is often highly prioritised in environmental management, since it often relates to the emissions under the direct control of the organisation.

In comparison with the national greenhouse gas account for Norway, the contribution from military sectoral activities is relatively small (1.1%), so a reduction will not have large national impact. Acting with other public procurers in a joint effort to reduce the impact from public investments would, however, be effective from a national perspective.

Nevertheless, these values add to previous studies and are interesting since emission values from the sector are often embedded in the national accounts and have not previously been quantified. Based on worldwide military expenditure, the global emissions from the military sector are substantial (Belcher et al., 2019) and more detailed knowledge of emission sources is important to select proper management strategies on a global level. Notably, while other reported figures mostly focus on combustion of fossil fuel in military assets and systems, we find that this is only responsible for a third of the life cycle emissions of the organisation. Including the indirect emissions from procurement of goods and services would certainly boost the global impact from the sector.

Fossil fuel use in tactical operations and training is the single largest GHG contributor, in line with previous studies, and confirms combustion of fossil fuels as an important emission source to mitigate (Bailey, 2009; Liska and Perrin, 2010; Wood and Dey, 2009). Renewables are already heavily used in Norway and the contribution from fossil fuel in purchased energy is low. However, with increased connectivity in the energy systems within the EU, the composition of the physical energy mix will change. The sensitivity analysis then suggests that the enhanced environmental impact of continued energy savings and increased on-site renewable production will became more beneficial also in Norway.

Bailey (2009) describes carbon reduction strategies for the military sector in terms of short-, medium-, and long-term horizons. *Short-term* initiatives operate with present technology and involve emission control by, for example, use of land power supply for ships, operational optimisation of training activities, or energy savings. *Medium-term* involves use of new renewable energy technology and a transition to renewable fuels in fleet operation. The *long-term* involves a complete transition to renewable fuels, including electricity and hydrogen, in land, marine, and air transportation.

The short-term transition is currently in progress in the military sector. Already substantial effort has been devoted to the net-zero energy concept, reducing the direct impact from military installations and activities (Goodsite and Juhola, 2017; Moschetti et al., 2019). The European Defence Agency (EDA) foresees this development and acknowledges that a transition to renewables is necessary (EDA, 2019). Medium- and long-term initiatives largely depend on the interest of involved parties and the evolution of technology in the civilian sector. However, reducing dependence on fossil fuel in military operations is also highly prioritised for tactical reasons (Nussbaum, 2017). A substitution of biofuel or electricity worldwide would also reduce the likelihood of the need for military inventions and might consequentially be beneficial for reducing GHGs from military activities (Liska and Perrin, 2010).

Even though this strategy may be effective, there are challenges in reducing the operational emissions from the use of fossil fuel in military ships, aircrafts, and vehicles. Their technology and design are different from civilian requirements and their operation is based on tactical and operational requirements rather than environmental optimisation. The life cycle of military assets and systems is long and replacements happen slowly. It is therefore interesting to see that upstream emissions supersede the direct ones in the study. This has previously been confirmed for households (Ala-Mantila et al., 2014), and the present study uncovers a similar pattern in the defence sector. The strategy for mitigating indirect emissions is different than operational reductions and will require implementation of environmental requirements for goods and services through implementation of green public procurement (GPP). This may involve effective resource use in production, energy savings, and waste minimisation for the producers of goods and services. Interestingly, this strategy of GPP has recently been found to be a more effective mitigation strategy than reduction of direct emissions within the organisation (Hertwich and Wood, 2018; PWC, 2010; Sparrevik et al., 2018). Requirements to reduce the embodied GHG emissions from building materials can be an effective emission strategy since building and construction activities are especially resource intensive (Wiik et al., 2018). Business travel by air is another significant aspect with potential for decarbonisation and reduced impact (Murphy et al., 2018).

5. Conclusions

This study demonstrates that organisational life cycle assessment provides an effective instrument to map GHG emissions from a large and complex organisation such as the Norwegian defence sector. Applying a hybrid approach using both process and economic LCA allows the calculations to capture both user and procurement interphases without extensive collection of inventory data. The strength of this approach is its ability to address the totality, acknowledging that substantial uncertainties exist. The EEIOA emission factors are based on national or supranational data and are less suitable for monitoring the effect of mitigation efforts on a local scale. It is therefore recommended that process data be used to monitor progress of mitigation actions for selected focus areas. More research on uncertainty assessment will be important to properly address GHG mitigation strategies.

The results of the study suggest further refinements of the GHG mitigation strategy for the defence sector. Efforts to reduce fossil fuel use and increased use of renewables both in transportation and for housing are warranted, but should be carefully balanced with efforts to reduce the indirect emissions from suppliers of goods and services.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.119196.

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