



Climate change mitigation in the Armed Forces - greenhouse gas emission reduction - challenges and opportunities for Green Defense

By Marju Kõrts

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Executive summary and key recommendations

In the face of growing geopolitical tensions and the potential expansion of alliances such as NATO, climate change may not be the highest operational priority for the world's militaries at the moment. For most, the impacts of climate change – drought, sea-level rise and extreme weather – are likely seen as operational obstacles that can be overcome by building the overall resiliency and adaptability of their armies.

Military infrastructure may become increasingly vulnerable to climate events – particularly if located in the coastal area – and degradation of civilian infrastructure (e.g. energy grids, water systems) may indirectly disrupt military activities. Access to critical supply chain inputs, such as raw materials, may also be impeded by extreme weather events, which could, in turn, increase violent conflict. By understanding the threats, the armed forces will be able to protect their personnel and critical national infrastructure. This makes climate change an issue of national and international security – and thus the military concern.

Therefore, it is also an important issue for NATO although as the core institution itself, it is not the main source of the greenhouse gas emissions, the vast majority come from the forces of its member states. In this context, NATO has announced plans to reduce its greenhouse gas emissions and work towards Net Zero by 2050. It means cutting its civilian and military greenhouse gas emissions by at least 45% by 2030 and become carbon neutral by 2050 as announced by Secretary-General Jens Stoltenberg at the Madrid Summit in 2022.

The armed forces around the globe are heavy emitters of greenhouse gases, although no one knows exactly how much; estimates range between 1 percent and 5 percent of global emissions. During the second half of the 20th century, fossil fuel consumption by the world's militaries substantially increased. As warfare has become increasingly carbon intensive, military aircraft and other large war machines continued to consume massive amounts of gasoline, diesel, and jet fuel. Today's modern armies, air forces, and naval fleets are consuming fossil fuels at unprecedented rates. Military leaders have recognized the need to reduce carbon emissions and use alternative sources of energy.

Simultaneously, defence forces are largely spared from emissions reporting. With no international agreement on accountability, reporting requirements, leadership or will to act, monitoring and cutting military emissions are low priorities. For example, among the 27 member states of the European Union, only 10 militaries had noted the need for greenhouse gas mitigation, out of which only 7 countries had set targets (Rajaeifar et al, 2022)¹. In this sense, the defence sector must adopt green approach, understand the effects of climate change and the technology that

is being developed to adapt and mitigate its effects. Some military bases are already becoming more energy efficient by bringing energy storage and distributed generation inside the installations, using energy derived from landfill gas and solar power. That is important, as military bases with independent renewable power supplies are more resilient.

At the same time, defence forces operate a range of capabilities that are very difficult to decarbonize because they do not have viable replacements for systems like powerful jet and marine engines, and nor do they yet have access to alternative fuels for such systems. The other most significant keywords for defence decarbonization are reducing operational energy demand, increasing fuel efficiency and promoting electrification of the fleet where possible. The focus is on reducing operational energy demand as the systems like airplanes and ships, not facilities or installations contribute about two thirds of the total energy consumption. There are several ways to do so, for example, deploying hybrid-electric tactical vehicles, making engine improvements on ships so less fuel is consumed and reducing airplane drag to improve efficiency.

Solving the more difficult technical problems required to shift away from legacy fuels at scale requires long-term thinking in partnership with industries. Such partnerships could include collaboration among researchers, key industry players, and defence organizations to realize promising technologies like power-to-liquid at a meaningful scale. Targeted but significant investment in research on hydrogen and battery technologies should also be in the policy mix.

The drive to reduce dependence on fossil fuels and the introduction of renewables in the defence sector have opened up new opportunities to promote hydrogen technology. Hydrogen can be generated and used at the tactical edge of the battlefield, whereas petroleum fuels have to be extracted, refined, stored and transported over long distances. Hydrogen fuel cells already power electric vehicles that are nearly silent. Some armed forces are looking at the viability of electrification, however, for the army it will not be easy. Among the challenges will be overcoming heavy reliance on the commercial sector to develop suitable technology, and the complexity of retrofitting an existing fleet.

For many countries, decarbonizing armed forces may be essential step toward achieving government targets without relying on expensive offsets. Given new impetus, sustainability has become important agenda item for defence forces. Making defence sustainable will involve a long journey. It can start with a few steps that in-

¹ Rajaeifar, Belcher, Parkinson, Neimark, Weir, Ashworth, Larbi & Heidrich (2022). “Decarbonize the military – mandate emissions reporting”. In *Nature*, volume 611, 3 November 2022.

volve planning strategically and taking actions that directly reduce environmental impact. Making defence forces more sustainable will inevitably bring change to complex organizations with established operating models. Behavioral change is essential to operating more sustainably.

Key findings and recommendations

- In order to become carbon neutral it is necessary to accurately measure carbon footprint and create a baseline against which future changes can be measured. The assessment needs to establish a baseline from which to measure the reductions that is planned to make. The first step involves establishing the starting point and the destination so that governments can set and track sustainability targets. Setting intermediate short-term steps – for instance those for 2025 or 2035 – also helps to build clarity on the pathway to net-zero emissions.
- Most defence departments follow regular planning cycles, such as those outlined in the U.S. Department of Defence’s National Defence Strategy (2022)² or the UK Ministry of Defence’s Integrated Review (2021)³. The planning cycles could help countries identify the need for capability upgrades that will assist their operations in tougher future environments. These cycles could also be used as an opportunity to identify decarbonization opportunities.
- Militaries across the globe must be held accountable. Although national net-zero pledges have helped to focus attention in some countries, international standards and obligations must be agreed. The United Nations Framework Convention on Climate Change (UNFCCC) is the most appropriate forum and must strengthen and reform its reporting protocols to include militaries. Reporting and reducing military emissions must be transparent, time-bound and measurable.
- Militaries must improve their capacity to calculate, manage and reduce emissions, and train personnel to do so. Researchers should work with the armed forces to exchange knowledge and best practices from the civilian sector; help to develop protocols for military-specific emissions, and use and procure low-carbon equipment.

²U.S. Department of Defence (2022). “National Defence Strategy” sets the Department’s strategic direction and priorities for the Joint Force. The new strategy also include two detailed annexes in the form of a *2020 Nuclear Posture Review* and a *2022 Missile Defence Review*.

³The Integrated Review set out the government’s current assessment of the major trends that will shape the national security and international environment to 2030. See also UK Ministry of Defence “Defence in a competitive age”. Corporate Report, 30 July 2021.

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC), the international body for providing policymakers with regular climate change related scientific assessments, released the second report of its sixth assessment (AR 6) in February 2022. It concluded that the dangers of climate change are mounting so rapidly that they could soon overwhelm the ability of both nature and humanity to adapt (IPCC, 2022)⁴. The most visible effects of climate change today are more frequent and pronounced heat waves, rising sea levels, sea ice retreat (which appears most dramatically in the Arctic as the region is warming at a rate of almost four times the globe average), and changing precipitation patterns, which cause devastating floods and droughts (Fountain, 2020)⁵. Secondary consequences include the degradation of water supplies, reduced agricultural productivity and impacts on energy infrastructure and generation. Stabilizing global temperatures and limiting the effects of climate change require more than just slowing the growth rate of emissions; they require absolute emissions reduction to net-zero or net-negative levels.

Behind the phenomena of global warming and climate change lies the increase in greenhouse gases in the atmosphere. Greenhouse gas emissions cause heat to be trapped by the earth's atmosphere, and this has been the main driving force behind global warming. The main sources of such emissions are natural systems and human activities. Natural systems include forest fires, earthquakes, oceans, permafrost, wetlands, and mud volcanoes, while human activities are predominantly related to energy production, industrial activities and those related to forestry, and land use (Edenhofer et al., 2014)⁶.

The greenhouse gases widely discussed in literature and defined by the Kyoto Protocol are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), ozone (O₃) and fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆) (UNFCCC, 2008)⁷. A greenhouse gas is any

⁴ The sixth assessment of the IPCC includes three special reports. The first, on the physical science basis, was published in August 2021. The second part, "Impacts, Adaptation, and Vulnerability", which deals with the consequences and necessary adjustments, was published on 28 February 2022. The third contribution, "Mitigation of Climate Change", identifies technical and economic possibilities to mitigate climate change and was released on 4 April 2022.

⁵ Fountain (2022). "Arctic Warming Is Happening Faster Than Described, Analysis Shows", The New York Times, 11 August 2022.

⁶ Edenhofer et al. "Climate change 2014: mitigation of climate change. Contribution of working group III to the fifth assessment report of the Intergovernmental Panel on Climate Change". Accessed 05 July 2022.

⁷ UNFCCC (2008). "Kyoto Protocol reference manual on accounting of emissions and assigned amount".

gaseous compound in the atmosphere that is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere. Anthropogenic CO₂ is emitted primarily from fossil fuels combustion. According to the emissions gap report prepared by the United Nations Environmental Program (UNEP)⁸ in 2019, total greenhouse gas emissions in 2018 amounted to 55.3 GtCO₂e, of which 37.5 GtCO₂ are attributed to fossil CO₂ emissions from energy production and industrial activities. Since 1990, annual anthropogenic emissions increased by 59%.

Around half of the emissions released remain in the atmosphere. Nature absorbs the rest, holding it in carbon sinks, such as soil, oceans and vegetation. Under the United Nations Framework Convention on Climate Change (UNFCCC) any process, activity or mechanism, which removes a greenhouse gas from the atmosphere, is referred to as a “sink”. These natural storage solutions slow climate change far more effectively than any human technology – carbon storage factories store just 40 megatons of CO₂ annually or 0.003% of anthropogenic emissions. These sinks are very important in keeping the levels of carbon dioxide in the atmosphere at manageable levels. They continually take carbon out of the atmosphere through the process of photosynthesis. The ocean is another example of a carbon sink, absorbing a large amount of carbon dioxide from the atmosphere. Still scientists believe that carbon sink might hold the key to removing the excess carbon, hereby alleviating some of the pressure of climate change. Human activities influence terrestrial sinks through land use, land-use change and forestry (LULUCF) related activities. Consequently, the exchange of CO₂ (carbon cycle) between the terrestrial biosphere system and the atmosphere is altered. Mitigation can be achieved through activities in the LULUCF sector that increase the removals of greenhouse gases (GHGs) from the atmosphere or decrease emissions by halting the loss of carbon stocks (UNFCCC, 2022)⁹.

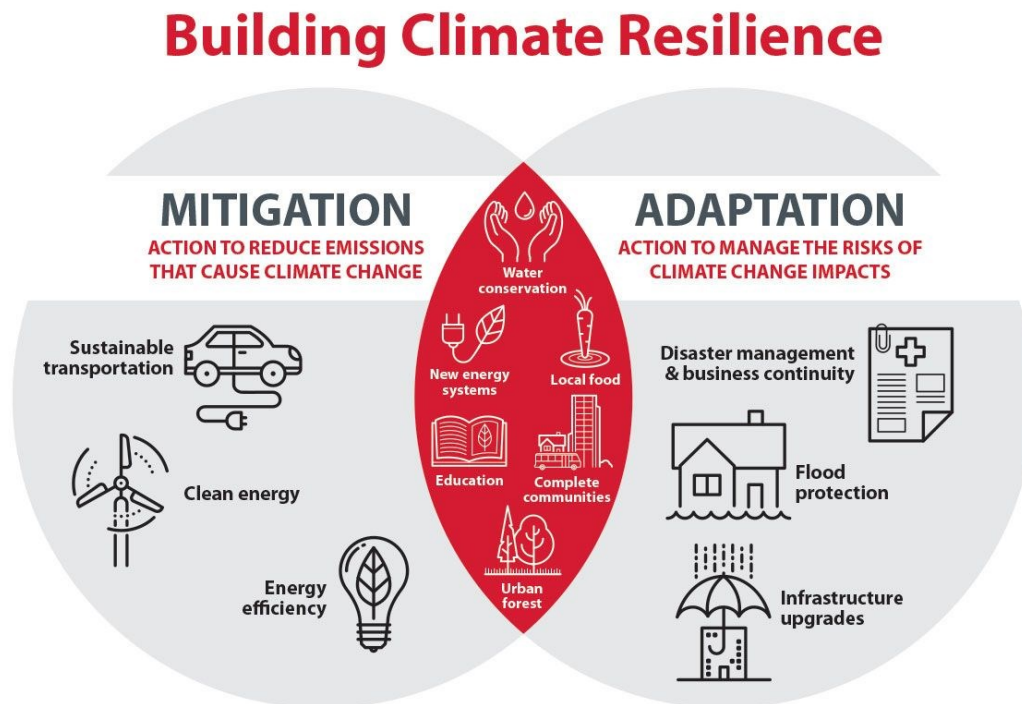
Climate actions to reduce environmental footprint fall into one of the two broad categories: climate change adaptation and mitigation. Climate change adaptation measures involve adjusting policies and actions because of observed or expected changes in climate. Cutting greenhouse gas emissions can slow the pace of global warming – this is known as mitigation. Climate change mitigation and adaptation efforts have traditionally been approached as separate endeavors. However, there are compelling benefits to integrating them, by using solutions that simultaneously reduce GHG emissions and enhance climate resilience. As seen in Figure 1, the difference between climate change mitigation- and adaptation strategies is that mitigation is aimed at tackling the causes and minimizing the possible impacts of

⁸ UNEP (2019) “Emissions gap report”. United Nations Environment Program.

⁹ United Nations Climate Change Secretariat (2022). “Land Use, Land-Use Change and Forestry (LULUCF).

climate change, whereas adaptation looks at how to reduce the negative effects it has and how to take advantage of any opportunities that arise.

Figure 1



Source: City of Calgary, 2013

There are three main climate change mitigation approaches discussed throughout literature. First, conventional mitigation efforts employ decarbonization technologies and techniques that reduce CO₂ emissions, such as renewable energy, fuel switching, efficiency gains, nuclear power, and carbon capture, utilization and storage (CCUS). Most of these technologies are well established and carry a level of managed risk (Ricke et al., 2017)¹⁰. A second route constitutes a new set of technologies and methods that have been recently proposed. These techniques are potentially deployed to capture and sequester CO₂ from the atmosphere and are termed negative emissions technologies, also referred to as carbon dioxide removal methods (ibid, 2017). The main negative emissions techniques widely discussed in literature include bioenergy carbon capture and storage¹¹, direct carbon capture and storage as well as soil carbon sequestration¹² to name some of them (Lawrence et al., 2018)¹³. As both mitigation and adaptation address the same cause of impact, they need to work in an integrated manner to successfully achieve their respective aims.

¹⁰ Ricke, KL et al (2017). “Constraints on global temperature target overshoot”. In *Scientific Reports* 7: 14743.

¹¹ Bioenergy with carbon capture and storage is the process of extracting bioenergy from biomass and capturing and storing the carbon, thereby removing it from the atmosphere.

¹² Soil carbon sequestration includes various ways of managing lands, especially farmlands so that soils absorb and hold more carbon.

¹³ Lawrence, MG et al. (2018). “Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals”. In *Nature Communications* 9:3734.

Climate change is not principally an environmental concern, it is actually a problem that is closely linked to national economic policy, strategic planning, public health, infrastructure, and international security. This topic has been discussed at the UN Security Council, it features in national security strategy documents, and a wide range of think-tanks and academic publications point to the intersection between climate change and security. An understanding of the severe impact on climate change on natural and human systems as well as the risks and associated vulnerabilities is an important starting point in comprehending the current state of climate emergency.

Climate change is one of the most important and immediate challenges that NATO is facing with in the years to come. Climate hazards multiply climate-driven security risks as they threaten critical infrastructure, disrupt energy, financial and agricultural centers, and intensify the scarcity of resources. They also affect military operational readiness, degrade military assets and installations, and introduce new logistics challenges¹⁴. The dominant drive and demand for “climate security” comes from a powerful national security and military apparatus, in particular that of the wealthier nations. This means that security is perceived in terms of the “threats” it poses to their military operations and “national security”, an all-encompassing term that basically refers to a country’s economic and political power. In this framework, climate security examines the perceived *direct threats* to a nation’s security, such as the impact on military operations – for example, the rise in sea level affects military bases or extreme heat impedes army operations. It also looks at the *indirect threats*, or the way climate change may exacerbate existing tensions, conflicts and violence that could spill into or overwhelm other nations. Therefore, climate-related security risks are complex in their pace and geographic scope.

Although the most significant recognitions of the link between security and climate change are recent, NATO has a much longer history in broader terms with the topic. In order to sketch out an evolution, it is appropriate to recall some salient steps in the Alliance history. NATO first addressed environmental challenges with the establishment of the Committee on the Challenges of Modern Society (CCMS) in 1969, which supported studies and fellowships focusing on air and noise pollution, as well as on hazardous waste management. The 2010 *Strategic Concept for the Defence and Security of the Members of NATO* briefly referred to the relationship between climate and security. As the number of scientific studies and the understanding of the far-reaching implications of climate change grew, NATO’s interest in the issue increased (Sikorski and Goodman, 2021)¹⁵. Since 2014, members of NATO

¹⁴ NATO (2021). NATO Climate Change and Security Action Plan”.

¹⁵ Sikorsky; Goodman. “A Climate Security Plan for NATO: Collective Defence for the 21st Century”. In *Environmental Affairs*, spring 2021.

have sought to reduce the emissions of their military forces and infrastructure through the Green Defence Framework, which aims to increase NATO's operational effectiveness by changing its energy use. This document listed numerous proposals to reduce fuel consumption in the armed forces as well as introduce "green" standards in NATO facilities (Rühle & Heise, 2021)¹⁶. However, although the Green Defence Framework aspired to reduce the environmental footprint of military operations and improve NATO's resilience by investing in green technologies to reduce fuel consumption, energy dependencies and mission footprints, no specific targets or commitments were set.

However, there is recognition that military forces need to be better prepared to tackle the impact of climate change. As a result, a growing number of militaries now integrate climate change issues into their planning. NATO Heads of States and Government stated at their 2021 Brussels Summit that climate change is "one of the defining challenging of our times" (NATO, 2021)¹⁷. At the following 2022 Madrid Summit, they decided to include climate change considerations in the Alliance's three core tasks (NATO, 2022a)¹⁸. In addition, the Strategic Concept lays down the Alliance's level of ambition to "become the leading international organization when it comes to understanding and adapting to the impact of climate change on security" (NATO, 2022c)¹⁹.

NATO's *Climate Change and Security Agenda* envisages a comprehensive approach, aimed at increasing the Alliance's awareness of the effects of climate change and, at the same time, developing adaptation measures. To enable the sharing of best practices and lessons learned, NATO has compiled a "*Compendium of Best Practices*"²⁰ which outlines examples of different awareness, adaptation, and mitigation measures that have been put into practice and identified which models can be replicated across the Alliance. This Compendium, published in July 2022, will continue to be updated to reflect ongoing progress. Recently NATO has also decided to establish a NATO-accredited Center of Excellence on Climate and Security (CASCOE) to be hosted by Canada that is expected to be operational in the course of 2023. Given that rapid environmental change in the Arctic is already obvious, and the clear federal commitment to act on climate change, this would be an appropriate contribution by Canada. CASCOE will serve as another platform where Allies can exchange expertise and best practice and work together to build the required capabilities to contribute to

¹⁶ Rühle (2021). „NATO and the Climate Change Challenge“. In *Internationale Politik*, Quarterly, 19 October 2021. Heise (2021). „NATO is responding to new challenges posed by climate change“. NATO Review, 1 April, 2021.

¹⁷ NATO (2021). "Brussels Summit Communiqué", 14 June 2021.

¹⁸ NATO (2022a). "Madrid Summit Declaration", 29 June 2022.

¹⁹ NATO (2022c). "Strategic Concept", 29 June 2022.

²⁰ NATO Climate Change and Security Action Plan. "Compendium of Best Practices". Factsheet, July 2022.

NATO's goal of reducing its environmental footprint (Kertysova, 2022)²¹.

On Allied awareness, NATO released its first Climate Change & Security Impact Assessment at the Madrid Summit in 2022, which forms part of the awareness pillar of NATO's Climate Change and Security Action Plan, agreed at the Brussels Summit in June 2021. The document offers analysis of climate-related impacts on NATO's: (a) strategic environment; (b) assets and installations; (c) missions and multi-domain operations, and (d) resilience and civil preparedness. Assessment calls for a fundamental transformation of NATO's approach to security and defence and the need "to adapt our equipment, training, facilities, operations, technologies and partnerships".

On adaptation, NATO will incorporate climate change considerations into its work on resilience, civil preparedness, defence planning, capability delivery, assets and installations. A number of Allies have brought the notion of climate change as a threat multiplier into their national and defence policies. Public national risk assessments highlight and analyze key risks that hold the potential to cause crises that go far beyond what can be managed locally or with ordinary day-to-day resources. These risk profiles often contain typical climate related incidents, e.g., heatwaves and droughts, storms and hurricanes, coastal flooding, and extreme rainfall and can form the basis for preparedness training. Allies are reviewing their national crisis response plans in order to deal with extreme weather events with regard to energy, water and food supply. National exercises test the resilience of their electricity grids, critical energy infrastructure and energy mix.

Through NATO's Climate Change and Security Impact Assessment²², a number of climate change adaptation measures were identified, from retrofitting and improving the resilience of infrastructure to altering operational planning and training schedules. A general orientation that can serve as a basis for NATO's adaptation efforts is the work of the Intergovernmental Panel on Climate Change (IPCC)²³. The IPCC's scenarios, based on a representative Concentration Pathway²⁴, demonstrate a solid scientific and national consensus and thus should generally guide political action. NATO needs to assess this consensus in a comprehensive manner, including also extreme scenarios and the high dynamics of climatic change processes with all the risks (Heise, 2021)²⁵. It is also important to address

²¹ Kertysova, K. "Perseverance amidst crisis: NATO's ambitious climate change and security agenda after Madrid". European Leadership Network (ELN), commentary, 18 October 2022.

²² "NATO Secretary General's Report: Climate Change & Security impact Assessment". June 2022.

²³ All NATO countries are IPCC members.

²⁴ A Representative Concentration Pathway is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC. Four pathways were used for climate modelling and research for the IPCC fifth Assessment Report (AR5) in 2014.

²⁵ Heise (2021). "NATO is responding to new challenges posed by climate change". NATO Review, 01 April 2021.

the need to adapt its capabilities to the changing climate more prominently in NATO's procurement practices and its partnership with industry.

Regarding climate change mitigation, some initial steps are already underway. To contribute to the Alliance's efforts to roll back carbon dioxide (CO₂) emissions to prevent the worst possible outcomes, NATO announced the development of a new methodology to measure greenhouse gas emissions from military activities and installations (NATO, 2021)²⁶. This methodology will help determine voluntary goals for specific Allied countries. It would enable a comparison of national military emissions, which in turn should help allies formulate targets to reduce emissions voluntarily. Many Allies have created action plans to frame their efforts to mitigate the effects of climate change. Often, these policy measures define greenhouse gas emissions reduction targets for 2030 and include indicative trajectories and objectives for 2040 and 2050. Typically, national efforts to mitigate the effects of climate change include benchmarking emissions and the resources used in defence-related activities (e.g. fuel consumption, waste production, energy expenditure, use of ammunition, water consumption, chemicals, and accidental emissions, etc.). Furthermore, data on energy demand and consumption in the armed forces could inform Allies' investment decisions and help define the role of emerging disruptive technologies, as well as innovative energy-efficient and sustainable technologies.

In developing the methodology, NATO will draw on the best practice of Allies, and can leverage expertise from partner nations and other international organizations, including the EU. Although, it is worth mentioning that military emissions are often exempted from countries' carbon emissions targets. It will be important that the carbon accounting is rigorous, as it will be scrutinized carefully by the NGO community, who would like the alliance to show transparency and accountability in publishing the results annually. Ideally these climate related inputs should be part of NATO's defence planning process and setting of capability targets, which would help ensure that they receive high-level attention in capitals. However, research into the UK and EU militaries shows that it is military equipment procurement and other supply chains that count for the majority of military emissions. NATO should focus on demonstrating leadership with respect to creating more sustainable practices as it carries out its missions and operations, which leave a huge carbon footprint. Yet, for too long, efforts to measure the precise carbon footprint of militaries has been stymied by a lack of data and accountability. Increasing transparency on militaries' GHG emissions could lead to pressure to reduce emissions by limiting military activity. Moreover, decreasing reliance on fossil fuels could confer a unique military advantage, both to NATO countries' militaries and the alliance itself. A Smart Energy project, funded by the NATO Science for Peace and Security Program (SPS), attempted to reduce fuel consumption

²⁶ NATO, (2021). "Brussels Summit Communiqué", 14 June 2021.

in remote bases or field camps by integrating wind and solar energy, thereby reducing greenhouse gas emissions at the same time²⁷. The project focuses on adding wind and solar energy to power some of NATO's remote military bases. "Smart grid" technology uses renewable energy to reload batteries being used in military operations, and is becoming widespread in exercises.

Improving energy efficiency in military operations is also an important pillar of the Alliance's efforts to mitigate climate change. Since 2011, NATO is conducting the Smart Energy initiative, which seeks to reduce the logistical burden of fossil fuels during operations. This initiative was notably tested during the *Exercise Capable Logistician 2019*, which consisted of various scenarios such as power cuts, diesel contamination and pollution of primary water sources. It required the Allied military to conduct smart energy responses using technologies, such as the water production unit that could save up fuel as well as purify water, and a "smart microgrid", which is an interoperable software that powers up diesel generators only when needed (NATO, 2019)²⁸. Overall, these exercises not only make Allied militaries more energy efficient, but they also reduce their reliance on fossil fuels in the field and enhance interoperability between national armed forces.

Climate change-related disasters may also degrade military and civil assets, the capabilities and reduce the state's capacity to confront conventional threats. Defence forces, moreover, have long realized the vulnerability of their energy supplies. As it was referenced in NATO's 2018 report on critical energy infrastructure²⁹, "the armed forces are a large consumer of energy that is a significant vulnerability in military capabilities", making it necessary for measures to increase energy security and for increased energy resilience". Currently that vulnerability manifests itself in the susceptibility of fossil fuel supplies and supply lines to attack. In Afghanistan, American and British troops suffered heavy casualties due to attacks on their slow-moving fuel transports (Birnbaum, 2021)³⁰. Increasing aridity makes fires on ranges and training areas more likely, which disrupts access and limits military mobility. Increased desertification affects the critical water infrastructure of military bases and supplies for deployed forces (NATO, 2022)³¹. Thus, NATO

²⁷ "Smart Energy Team comprehensive report: On Nations Need for Energy in Military Activities, Focusing on a Comparison of the Effectiveness of National Approaches to Reduce Energy Consumption", 06 May 2015.

²⁸ "NATO tests smart energy technologies at exercise in Poland". Press release, 13 June 2019.

²⁹ NATO (2018). Recommendation on the importance of critical energy infrastructure (CEI) stakeholder engagement, coordination and understanding of responsibilities in order to improve security, https://www.enseccoe.org/data/public/uploads/2018/04/d1_2018.04.23-recommendation-on-the-importance-of-critical-energy.pdf

³⁰ Birnbaum. "Militaries are among the world's biggest emitters. This general wants them to go green". The Washington Post, December 30, 2021, https://www.washingtonpost.com/climate_solutions/interactive/2021/climate-change-military-emissions-security/

³¹ NATO (2022). "The Secretary General's Report: Climate Change & Security Impact Assessment". June 2022.

must include climate change in its agenda to tackle national civil and military resilience, reinforce situational awareness, and work on adapting military capabilities to new climate hazards (McDonald, 2013)³².

NATO due to its multinational character, and the constant adaptation of its structure and capabilities, allow it to respond rapidly to a changing security landscape, including environmental change. Russia's invasion of Ukraine and the subsequent global energy crisis, together with the consequences of accelerating climate change, have created new and more complex security environment. NATO's armed forces must adapt to climate changed future operating environment, increase their energy efficiency and introduce cleaner technologies. All these measures will help to preserve collective defence, operational effectiveness and a credible deterrence posture (NATO, 2023)³³.

Military is one of the largest institutional users of fossil fuels in contemporary societies. Thus, defence sector is a major contributor to greenhouse gas emissions. Contemporary combat operations and the training that prepares the world's militaries to engage in them, consume huge amount of fuels. Nevertheless, NATO forces can reduce their environmental footprint in many areas, such as transporting supplies by rail and waterways rather than on road. The US Air Force has long been using solar panels on its hangars, and there is no good reason why vehicle fleets cannot be electrified, as new vehicles are purchased in the years to come. While reaching net-zero emissions by 2050 will be difficult, such programs are essential if the worst impact of climate change are to be avoided in this century (Dalby, 2021)³⁴. Battery-operated vehicles and electric-powered robots will certainly play a larger role in logistics and rear operations. Drones will reduce the numbers of aircraft and ships that the alliance needs to maintain and deploy. 3D printing (known as well as additive manufacturing)³⁵ will also allow for cheaper and more energy-efficient production of many of the weapon systems and components that NATO armies use (Shea, 2022)³⁵.

The aim of this study is to get further insight into climate change impacts on the military activities (infrastructure, installations and equipment) and its coping techniques. A special attention is paid on the decarbonizing potential of the defence forces, which is an important task after setting up the military emissions ac-

³² McDonald. "Discourses of Climate Security". In *Political Geography* 33 (March 2013): 42-51.

³³ NATO press release "NATO co-hosts side event at Munich Security Conference focused on military energy transition". 17 February 2023.

³⁴ Additive manufacturing is a method of creating a three dimensional object layer-by-layer using a computer created design. It is the opposite of subtractive manufacturing processes, where a final design is cut from a larger block of material.

³⁵ Shea. "NATO and Climate Change: Better Late Than Never". Policy Brief, GMF, March 2022.

counting and reporting system. The research objectives are to answer the following questions: (1) How significant are the climate change concerns for different branches of the military? (2) How viable are the proposed solutions to decarbonize the defence sector and what are the main challenges? (3) What is required to map the carbon emissions and what data is to be collected to get a better view of the carbon emissions trajectory?

The research methodology of this study uses a synthesis of literature analysis and interviews. In the study, there is a separate chapter where the defence energy and climate policies are viewed in depth. The interviews with selected representatives from the governmental agencies (e.g. Ministry of Defence) were conducted via online devices. In order to give an overview of broader carbon emissions reduction methodologies, 2 country studies are included (Denmark and the United Kingdom). Case studies will give an overview of the selected countries climate policies, targets set for reducing carbon dioxide reduction as well as the main takeaways from the strategic documents and the initiatives in these countries. The online interviews were semi-structured with a transcript of the interview being scribed throughout, and responses were later reviewed with the person interviewed. Only non-classified information was sought, and included subsequent detailed questioning.

The first chapter of the study will focus on the defence energy and climate strategies in some of the European Union member states and beyond. **The second chapter** will provide an overview of the greenhouse gas accounting framework in the defence sector. **The third chapter** will touch upon the country studies', highlighting Denmark and the United Kingdom as frontrunners in military emissions measuring and accounting. **The fourth chapter** highlights the decarbonizing potential and opportunities for green technologies in the defence sector.

CHAPTER 1

DECARBONIZATION IN THE DEFENCE SECTOR

Staying within two degrees Celsius requires global net GHG emissions to fall to zero by around 2070. Increasing the level of ambition to 1.5 degrees Celsius as agreed within the Paris Agreement in 2015³⁶, brings this date forward to 2050 or earlier. In the absence of credible technologies that would allow large economies to achieve sustained net-negative emissions, this applies that every country must decarbonize fully over the coming 35 to 55 years. Specifically, the Paris Agreement requires countries to declare their own decarbonization plans in the form of Nationally Determined Contributions (NDCs). Under the Paris Agreement, the NDCs are to be revised and resubmitted every five years, with improvements in each five-year cycle. In addition to NDCs, which are now generally designed up to the year 2030, the Paris Agreement also calls on countries to produce “long-term low greenhouse gas emission development strategies” to the year 2050 (CIRSD, 2021)³⁷. The key strategy to limit global warming is to decarbonize the world energy system. The rise of fossil fuels to predominance was not a single, targeted process, rather it occurred over several centuries. Nevertheless, the shift from fossil fuels to low carbon and zero-carbon energy sources must now occur in a coordinated way in a matter of half-century.

In this context, most countries have goals to reach net-zero by 2050 which means that all greenhouse gas emissions produced are counterbalanced by an equal amount of emissions that are eliminated. Along with the net-zero ambition of the energy system, the 4Ds (*Decarbonization, Decentralization, Digitalization and Democratization*) represent another current paradigm shift that directly affects the future energy system. However, the idea of decarbonization and decentralization gives rise to significant transformation in the development of power grids. It can be seen that the installed capacity of renewable plants has increased and that of fossil fuel plants declined. Similarly, decentralization has completely toppled the idea that power would always flow from the large centralized power plants to the demand centers. Together, this has resulted in seismic changes in the way power networks

³⁶ Paris Agreement (2015) is a legally binding international treaty on climate change that was adopted by 196 Parties at COP21. Its goal is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels.

³⁷ Center for International Relations and Sustainable Development (2021). “Implementing the Paris Climate Agreement – Achieving Deep Decarbonization in the Next Half-century”. CIRSD.

are designed, developed, and operated today and will continue presenting further challenges as the net zero energy transition further develops and evolves.

Historically, energy efficiency has delivered the largest share of greenhouse gas mitigation. A significant part of this has relied on replacing fossil fuel technologies with more efficient technologies based on or using fossil fuel directly. The recognition of the scale of the climate crisis means that full decarbonization of the economy rather than partial reduction of emissions is now the target. Major changes are underway moving from sources of heat to sources of work, most importantly via electrification of end-users previously not served by electricity. At the same time, the costs of renewable energy sources and storage have plummeted and are expected to continue to fall further.

Energy efficiency has been promoted in many jurisdiction as part of efforts to achieve least cost planning, an approach that involves examining all demand-side (e.g. energy efficiency, demand response, storage) and supply-side resources (e.g. generation) to meet given level of energy service provision. Next-generation solutions, like digitalization of energy systems and behaviorally informed policy making are opening the door to even further potential for efficiency improvements. New digital solutions can limit production and distribution losses and accommodate growing shares of variable and distributed renewable energy while increasing grid flexibility. Recent major gains in efficiency have been achieved in lighting, buildings' heating and cooling, and in manufacturing industry. With the penetration of smart grid in manufacturing industry, energy efficient production scheduling is a promising roadmap toward not only demand-side management, but also energy efficiency (Rosenow & Eyre, 2022)³⁸.

Electrification is widely seen as a key pillar of full or near full decarbonization of different sectors, with the electricity used is based on renewable energy and other zero or close to zero carbon sources. This is because the main low-cost zero-carbon supply technologies, notably wind and solar photovoltaics, produce electricity, and therefore electrification increases the share of total energy use for which they can compete. All projections show further reduction in the cost of renewable electricity generation and substantial increase in renewable electricity generation capacity in coming years globally. Assuming that it is possible to decarbonize the electricity grid fast enough, electrification of end-users of energy offers a major solution for GHG reduction. The electrification of the building and transport sector as a pathway to get net-zero in these two sectors is easier to achieve from technologi-

³⁸ Rosenow & Eyre. "Reinventing energy efficiency for net zero". In *Energy Research & Social Science*, Volume 90, August 2022, 102602.

cal point of view. However, it is much harder to electrify the industry sector. Significantly more technological R&D is needed to electrify substantial portion of manufacturing sector. Around 75% of total final energy use in industry is fossil fuels. Industry accounts for over 25% of world's total GHG emissions. It should be noted that other solutions such as energy efficiency, material and product demand reduction, CCUS (carbon capture, utilization and storage), and game-changing/emerging technologies need to be all considered along with electrification in order to achieve net-zero industry sector (Global Efficiency Intelligence, 2022)³⁹.

Another important part of this puzzle is fuel switching, which means replacing inefficient fuels with cleaner and economical alternatives, such as substituting coal or kerosene for natural gas. Complimented by modern equipment upgrades, fuel switching is a simple approach to reducing energy consumption and costs for end-users, while also curbing carbon emissions. With significant potential to mitigate emissions and decarbonize energy supply chains, electrification is an important strategy to reach net zero goals.

The European Green Deal sets out an action plan to reach net zero GHG emissions by 2050⁴⁰ that is accompanied by the EU's European Climate Law requiring action across all sectors in economy (setting a legally binding target of net-zero GHG emissions by 2050)⁴¹. It includes the target of reducing net-GHG emissions by at least 55% by 2030, compared with levels in 1990. This requires member states to have plans to reduce national net-carbon emissions, including those made by defence ministries, defence industries and armed forces. It is logical that defence sector, which is itself responsible for high proportions of the GHG emissions from Member States should play an important role in achieving the European Green Deal target of net zero by 2050. In 2021, the EU published a huge package of new proposals to reduce emissions to a level of 55 percent compared to 1990 levels. In this so-called "Fit for 55" package, specific attention is paid to reducing emissions in sectors, but without mentioning the military as a sector where emissions need to be reduced. Military emissions are assumed inclusions in the national emission reduction targets of EU member states (under the so-called effort sharing regulations)⁴² and sectors that are covered by emissions trade, including the newly proposed Emissions Trading System for fuels used in transport and the built environment.

³⁹ Global Efficiency Intelligence (2022). "Electrification & Net-Zero Industry".

⁴⁰ A European Green Deal, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

⁴¹ See Council Regulation (EU) 2021/119 establishing the framework for achieving climate neutrality ("European Climate Law") [2021] OJ L243. Summary available at https://ec.europa.eu/climate/eu-action/european-green-deal/european-climate-law_en

⁴² It sets binding national greenhouse gas targets for each of the 27 Member States of the European Union, collectively amounting to a 30 percent cut in emissions by 2030.

Although in comparison with other sectors, defence sector remains at an early stage of its journey to reduce greenhouse gas emissions. This sector covers a wide range of elements across most sectors. It is both an operator of aircrafts, ships, and vehicles, as well as a transportation and logistics organization and an educational facility. At the same time, defence forces need to function under the most difficult and dangerous conditions. Since it needs to work both in times of peace and crises, the dilemma is how to reduce emissions and at the same time increase operational efficiency, security of supply and enhance the safety of soldiers. Therefore, it is not entirely surprising: safety, reliability and performance have been and will continue to be the paramount requirements in the armed forces. Many defence systems and supporting infrastructure are also inherently more difficult to decarbonize than in most other sectors.

On the other hand, greening defence forces is a small but an important piece of the broader effort needed globally to reduce greenhouse gas emissions at the scale that is meaningful for security. It is obvious that maintaining NATO's military competence must always have priority. Therefore, reducing emissions, for example by gradually moving away from fossil fuels is possible if it does not impair the operational effectiveness of the armed forces. Experiments conducted within the forces of many NATO countries indicate that reducing emissions and increasing military performance are not inevitably contradictory. The vehicles used today are cleaner and yet more powerful than previous models, military equipment can be made "greener" without sacrificing its combat power. For example, the navies of Italy and the USA have jointly tested biofuels, which no longer compete with food production (e.g. rapeseed). Some NATO nations' defence forces are also experimenting with biofuel additives, hydrogen fuel cells, electric vehicles, and improvements in aerodynamics (Rühle, 2021)⁴³.

⁴³ Rühle (2021). „NATO and the Climate Change Challenge“. In *Internationale Politik*, Quaterly, 19 October 2021.

1.1 European and NATO nations' climate mitigation strategies

Resilience to climate change is likely to become a key focus area for many defence ministries, as climate change will continue to affect a range of defence activities to 2035 and beyond. Personnel may have to operate in climate-degraded conditions more often – affecting physical and mental wellbeing – and climate events could reduce access to training sites, increase the vulnerability of military infrastructure, impede the performance of equipment, and compromise the delivery of logistics support. For example, climate change affects NATO's air and maritime operations as aircrafts require specified temperatures, pressures, and wind to perform properly during take-off and landing. Rising temperatures, as in Iraq and Afghanistan, have impeded the functioning of transport planes and helicopters. NATO's critical infrastructure is also threatened, given its allies and partners reliance on pipelines and cables that are potentially vulnerable to environmental disasters for energy supplies. It illustrates that the alliance should also not neglect the link between climate change and energy security. Today, military operations are still largely powered by fossil fuels, but with the objectives of the EU, the USA and other countries to become carbon neutral by 2050, this is set to change. In the face of these challenges, there is an ever-growing need for coherent policy and planning on climate change, with a key role for Ministries of Defence.

Most European and North American countries recognize and are prioritizing the defence energy transition, and are committing to addressing a problem that they acknowledge they contribute to. National plans are at varying stages of development and implementation. Most strategies set achievable interim targets for emissions reductions, while highlighting that reliable fuels and technologies cannot be implemented yet for defence at a scale that would allow deep cuts enough to achieve net zero in the near or medium term perspective. The most prioritized measure across these strategies include increasing energy efficiency on the estate and in the built environment, electrifying the non-tactical vehicle fleet, installing renewable energy systems, and training in simulated environments. A number of countries are also running pilot projects testing the integration of new technologies, such as hydrogen or synthetic fuels. Promoting a culture of conservation and behavioral change was another common feature across defence climate initiatives.

Table 2. Areas of opportunity for climate change adaptation and mitigation

Category	Example
Sustainable mobility	<ul style="list-style-type: none"> • Alternative fuels – synthetic fuels • Alternative propulsion systems –electric, hybrid, hydrogen • Improving fuel efficiency and reducing emissions
Energy storage	<ul style="list-style-type: none"> • Portable batteries
Platforms	<ul style="list-style-type: none"> • Uncrewed systems
Training	<ul style="list-style-type: none"> • Simulation systems • Training on lower emissions vehicles
Energy systems at installations	<ul style="list-style-type: none"> • Installing renewables – photovoltaic (PV), solar thermal, wind power systems • Microgrids, distributed energy generation
Building offsets on the defence estate	<ul style="list-style-type: none"> • Siting renewables on the estate • Carbon sinks – reforestation, carbon sequestration in soils • Rewilding, ecosystem restoration
Improve emissions data collection	<ul style="list-style-type: none"> • Standardizing measures • Addressing emissions involved in defence supply chains
Other sustainable initiatives	<ul style="list-style-type: none"> • Circular economy • Promoting awareness and behavioral change

Source: Adapted from the study “Green Defence: the defence and military implications of climate change for Europe” (The International Institute for Strategic Studies, 2022).

1.2 Defence energy and climate strategies

Militaries are beginning to pay more attention to climate mitigation, for strategic reasons as well as to contribute to national net-zero emission targets as there are many ways in which reducing emissions and making the energy transition can enhance operational effectiveness and confer strategic advantages. Many countries are now acknowledging climate change in their defence strategies. There has been a range of responses to the issue, from comprehensive climate strategies like the UK's⁴⁴, to not mentioning climate by name but nevertheless discussing climate-sensitive issues like water or energy security. Whether countries acknowledge climate change per se, or merely note its impacts, it is now commonly addressed in defence strategic planning. There are several categories under which defence agencies are taking action on emissions reduction, energy transition and environmental sustainability, across both installation energy – including installations and non-tactical vehicles – and operational energy⁴⁵. A major reason why the military has not always seen net zero as a priority is that militaries risk their capabilities by adopting new equipment that may prove ineffective. The operational requirements of the military mean that in order to introduce a new fuel or technology, there should be certainty that it works. However, while challenges around decarbonizing more complicated military hardware, like fighter aircraft and battleships remain, the technology to decarbonize other equipment or facilities is already widespread.

A number of countries have well-developed defence mitigation and adaptation strategies. Below there are some examples of these strategies in the defence sector in Europe and beyond.

The **UK Ministry of Defence** (MoD) has made the most comprehensive examination to date how defence can make the energy transition and contribute to national net-zero goals that manifests itself in its “*Defence Climate Change and Sustainability Strategy*”. The strategy amplifies existing declarations that UK forces must become far less dependent on fossil fuels. According to the policy paper, the services’ military aviation is responsible for around two-thirds of the MoD’s fuel consumption; therefore, tackling this element of the armed forces’ emissions is important. The report identifies the potential of increased use of sustainable fuel source to re-

⁴⁴ In March 2021, UK’s Ministry of Defence launched its “Climate Change and Sustainability Strategic Approach” highlighting three interlocking ambitions: adaptation and resilience, sustainability and net zero, as well as global leadership.

⁴⁵ Operational energy is the energy required during the entire service life of a structure such as lighting, heating, cooling, and ventilating systems; as well as operating building appliances.

duce environmental impact. Furthermore, the Royal Air Force's Astra campaign⁴⁶ to develop the service sets out medium- and long-term goals for infrastructure and training that, if implemented, will markedly reduce carbon emissions⁴⁷. By 2040, ahead of the wider national 2050 target, the aim of the air force is to have carbon-neutral estate, which includes bases, infrastructure and accommodation. Additionally, the intent is to shift far greater use of synthetic environments to supplement and reduce actual training flights. This again, will markedly reduce the consumption of aviation fuel and the related emissions, and will apply to both the land and maritime environments. The army, which is the largest owner of defence estate, has begun pilot schemes addressing sustainability, and trials are also under way using hybrid electric drives on its Jackal 2 light scout vehicle.

The MoD intends to adopt a "fast follower" approach, leveraging carbon-reduction technology being developed by the civil sector, along with measures specific to the military. Defence Ministry has an active program for R&D including an experimental electric aircraft, synthetic aviation fuels and fitting electric drives to several in-service army vehicles. The MoD has also decided that rather than simply purchasing carbon offsets⁴⁸ on the commercial market, it would instead be better served to generate its own (IISS, 2021)⁴⁹.

Other European countries are also developing more comprehensive strategies and implementing defence energy, sustainability and GHG mitigation measures. **The Netherlands'** "*Defence Energy and Environment Strategy 2019-2022*" and "Defence Energy Transition Plan of Action" set fossil fuel-reduction targets. The abovementioned strategy foresees that by 2030, dependence on fossil fuels has been reduced by at least 20% relative to 2010, inter alia by 2030, 50 percent of the energy required at camps is sustainably generated and that they are entirely self-sufficient by 2030 in terms of energy. The plan also details the incorporation of biofuels, exploring the use of hydrogen for long-range drones in maritime surveillance, researching energy-independent camps and increasing energy efficiency in

⁴⁶ Astra is the name given to the Royal Air Force's (RAF) journey in building the Next Generation RAF. The RAF of the future must be ready to face the threats and challenges of the future in rapidly changing world, particularly with technological advancement.

⁴⁷ Sustainable fuels include biofuels such as hydrotreated vegetable oil (HVO), or bioethanol, and synthetic fuels (synfuels) such as ammonia or methanol. They can be used as drop-in fuels in conventional internal combustion engines.

⁴⁸ A carbon offset is a reduction or removal of emissions of carbon dioxide or other greenhouse gases made in order to compensate for emissions made elsewhere. Some common examples of projects include reforestation, building renewable energy, carbon storing agricultural practices, and waste and landfill management.

⁴⁹ International Institute for Strategic Studies (2021). "Dealing with hot air: UK defence and climate change". In *Military Balance Blog*, 16 April 2021.

the defence estate (Dutch Ministry of Defence, 2021)⁵⁰. To gain insight into the energy consumption and associated CO₂ emissions, the Netherlands is developing a methodology for the structured collection and analysis of data on energy consumption from different sources. The methodology consists of the following steps: observing and recording, explaining the use and controlling the energy needs. For this purpose, a dashboard is created that is integrated into the MoD's regular work processes. Full implementation of the methodology will take approximately three years (with set deadline in 2023).

In addition, MoD has started taking stock of the historical energy data, recording and monitoring current energy consumption. For this purpose, the Defence organizations purchasing data related to fuels and electricity is used. The first annual energy report was also included in the MoD's 2019 annual report.

France's Ministry of the Armed Forces was one of the first militaries globally to publicly state the need to consider climate change and national security as a linked issue. National Low Carbon Strategy 2020 sets out guidelines for a transition to a low-carbon economy for all sectors but does not specifically refer to or exclude the military sector⁵¹. In April 2022, France released an updated *Climate and Defence Strategy*. Heavily emphasizing the need for co-operation and partnerships, the Strategy revolves around four axes: (1) developing knowledge and capacities to anticipate climate risks; (2) adapting to effects of climate change; (3) driving emissions mitigation and energy transition; and (4) creating and strengthening inter-ministerial and global partnerships. The MoD is committed to reducing final energy consumption by 30% overall and to specifically reducing real estate related energy emissions by 50% by 2030, as compared to 2010 levels.

Like in the UK, France also plans to adapt civil climate innovations for military use; the Directorate General for Armaments (DGA) and Defence Innovation Agency (DIA) are leading efforts to support new innovations in energy and across land (e.g. hybridization of armored vehicles), sea (e.g. introducing fuel cells in surface vessels), and air (e.g. hydrogen fuel cells for small drones) domains.

France has sought to weave climate change and national security considerations into all decisions and will likely show preferences for industry players that offer the greenest solutions across all procurement decisions, although there are limited green criteria in defence request for tenders (RFPs) at present.

⁵⁰ Dutch Ministry of Defence. "Defence Energy Transition Plan of Action", 21 July 2021, <https://english.defensie.nl/downloads/publications/2021/07/21/defence-energy-transition-plan-of-action>

⁵¹ Ministry for Ecological and Solidarity Transition (2020). "National Low Carbon Strategy", https://www.ecologie.gouv.fr/sites/default/files/2020-03-25_MTES_SNBC2.pdf

Spanish Ministry of Defence's Program to Combat Climate Change has since 2012, developed and implemented a methodology for the estimation of GHG emissions derived from military activities. It aims to set institutional standards and focuses on providing tools and training for participation in GHG measurement and reduction, verification and independent certification of its findings. Although, no timeline is set, the program aims to reduce defence emissions to as close as possible to “zero carbon” in line with the government's commitments' through efficiency, transitioning to renewable, alternative and complementary energy sources, adaptation of fuels, improving carbon sinks and incentivizing lower emissions in the supply chain (Spanish Ministry of Defence, 2018)⁵².

Ministry of Defence has developed SINFRADEF, an energy and asset management system that contains information on the energy consumption and efficiency of all its buildings⁵³. Although the earlier national action plan for 2017-2020 stated that the information is not included in the national inventory for security reasons, data is collected and may be used for improvement action.

Slovenia focuses on sustainable mobility projects and is looking for alternative fuels to be used in the defence and security sector. The relevant projects are aimed at improving and sustaining mobility and that is why investments in national and international research and development projects are made. The MoD identified hydrogen as a potential alternative solution at an early stage. Slovenian Armed Forces are one of the few defence forces to have introduced hydrogen technology into operational use as early as 2010; their activities and experience in this field led to the idea of building a defence and security infrastructure in the EU. This led to the conceptual design of the RESHUB project, where Slovenia is the lead. It is a project, supported by the European Defence Agency (EDA), which goal is to create a network of self-sufficient energy hubs aimed at distributing energy generation and storage for defence (bases and barracks) and civil (disaster relief and other crises') use. Longer objective is to expand these hubs beyond the barracks of the Slovenian Armed Forces and establish a “hydrogen motorway” across the EU⁵⁴.

Germany - Emissions reduction has historically been a focus of the German military, and the MoD has successfully reduced emissions over the past 30 years. Leaders have specifically been focused on reducing transport emissions, with a 47%

⁵² Spanish Ministry of Defence. “Strategic Dossiers 193 B – Climate Change and Its Impact on Defence”, Spanish Institute for Strategic Studies, October 2018. Available at http://www.ieee.es/en/Galerias/fichero/cuadernos/CE_193-B_CLIMATE_CHANGE_AND_ITS_IMPACT_ON_DEFENCE.pdf

⁵³ Spain (2017). “National Action Plan of Energy Efficiency 2017-2022”, https://ec.europa.eu/energy/sites/ener/files/documents/es_neeap_2017_es.pdf

⁵⁴ Si ENE. “RESHUB Project”. March 2021

decrease in emissions in mobility from 2005-2019 (Euromil, 2022)⁵⁵. Defence forces achieved a 33 percent reduction in heating and electricity CO₂ emissions between 2008 and 2018⁵⁵. The German armed forces issued a concept to optimize energy supply in static field accommodation “Increasing the Security of Supply by Optimizing the Energy and Utility Supply in Static Field Accommodations” (Federal Office of Bundeswehr Infrastructure, Environmental Protection and Services)⁵⁷ in 2017, which lists measures to limit primary energy and water demands in operational infrastructure and camps.

In Germany, the main objective of the *Climate Protection Act, the Climate Protection Program 2030* and other national strategies (such as the *National Hydrogen Strategy*) is to contribute to the carbon reduction goals. The *Climate Protection Act* sets greenhouse gas reduction targets of at least 35% by 2020 and 55% by 2030 compared with 1990 levels. The 2020 Sustainability Report indicates that the Federal Ministry of Defence will need to achieve around 40% overall reductions over the next 10 years but also gives an ambitious objective to achieve carbon neutrality by 2023 through its roadmap to avoid, reduce and compensate for GHG emissions. The MoD and Federal Ministry of the Interior have also come out in favor of synthetic fuel use for military vehicles and argue for intensifying R&D efforts into green vehicle solutions. No specific defence climate strategy has been passed, but industry should be prepared for sustainability-related defence procurements guidelines, especially given the role the Ministry of Economic Affairs (controlled by the Green party) plays in procurement regulation. Reductions in transport emissions are likely to be continued focus of the MoD climate change and national security strategy going forward, so industry should be ready to meet a growing demand for electric vehicles, synthetic fuels, and more green vehicle technology (e.g. energy storage, mobile generators, etc.).

Italy’s Integrated National Energy and Climate Plan (dated from December 2019) makes no specific reference to the military. The Ministry of Defence has produced guidelines for energy saving and energy reduction of its buildings and systems⁵⁸, and the policy directive on energy efficiency of military infrastructure

⁵⁵ Euromil (2022). “Climate Change and the Defence Sector – Survey Report”.

⁵⁶ “Sustainability report 2020 of the Federal Ministry of Defence and the Bundeswehr”. German Federal Ministry of Defence, 2018-2019, <https://www.bmvg.de>

⁵⁷ Federal Office of Bundeswehr Infrastructure, Environmental Protection and Services. “Konzept – Massnahmen zur Steigerung der Versorgungssicherheit durch Optimierung der Energie- und Medienversorgung in stationärer Unterbringung im Einsatz”.

⁵⁸ Ministry of Defence, Italy (2012). “Guidelines for energy savings, energy reduction and optimization of the Technical-Administrative Area of the Ministry of Defence.

includes short-, medium- and long-term objectives⁵⁷. The Defence Energy Strategy Plan, and the Joint Force Directive, were both issued in 2019, and include commitments to improve the energy efficiency of buildings, replace fossil fuels with renewable energy sources and gradually reduce GHG emissions (Italian Defence Staff, 2019)⁵⁸. Italian defence forces co-operate with the utility company ENEA to implement an energy diagnosis plan and renew the defence infrastructure according to the model of the “smart military district”. The public-private sector projects in this domain are aimed at energy saving, the rationalization of consumption and the development of renewable energy sources. They also include the study and development of technologies in the field of hydrogen production for transport, robotics and surveillance drones, monitoring of critical energy infrastructure through sensor networks, use of block chain technology for safe management of energy flows. There are also many collaborative activities already successfully conducted by the defence forces - “Task Force for the enhancement of buildings, energy and the environment” including the realization of the energy redevelopment project of the Celio Military Polyclinic in Rome and two editions of the joint high-level training course in energy management (Calabrese, 2021)⁵⁹. In addition to developing green basing and smart military districts, the defence energy strategy establishes a basis for planning to identify the most appropriate weapon systems and force structure of the future. The Italian Navy previously had a Flotta Verde (“Green Fleet”) project to develop and trial green diesel biofuels, in partnership with the U.S. Navy⁶⁰. As with many other defence energy or environmental strategies, the Italian program sets out ways it will contribute to and comply with national, EU and NATO regulations or objectives on decarbonization, without setting a fixed target or timeline for defence emissions reductions.

Numerous other defence energy and environment strategies work towards similar aims, including those from Denmark, Finland and Greece, which focus on: emissions reductions across buildings; the estate and procurement; more efficient fossil fuel use; and installing renewables, with the aim of reducing other defence emissions when possible. For example, the **Finnish Ministry of Defence** has set a target for the Defence Forces to significantly reduce GHG emissions, and in particular, halve GHG emissions from civil and maritime transport from their 2020 levels by 2030. The precondition for the reduction is that the national defence capability is not compromised. The most important means to achieve the desired emission

⁵⁷ Defence Staff (2014). “Logistics and Infrastructure. Policy Directive for Energy Efficiency of the Military Infrastructure”, <https://www.difesa.it>

⁶⁰ Italian Defence Staff. “Piano per la Strategia Energetica della Difesa [Plan for Defence Energy Strategy], 2019.

⁶¹ Calabrese (2021). “Agreement between the Ministry of Defence and ENEA for energy efficiency and sustainability”. Press release, 16 February 2021.

⁶² Italian Navy, Flotta Verde, <https://www.marina.difesa.it>

reductions is renewable liquid fuel, as it will not be possible to solve the capability requirements of the Defence Forces by other energy solutions in the 2030s. Electric power is also a possible power source in garrisons and official vehicles (Finnish Ministry of Defence, 2022)⁶³. Sweden for instance, has a “*Fossil-free Armed Forces 2045*” project, aiming to reduce its dependency on fossil fuels and meet national net-zero targets (Swedish Armed Forces, 2017)⁶⁴. Among other efforts, it has conducted tests with a 50/50 mix of biofuels in JAS 39 *Gripen*⁶⁵ aircrafts engines, showing unchanged function and performance⁶⁶.

In North America, **Canada** is taking significant steps towards reducing its emissions by 40-45% below 2005 levels by 2030, and towards reaching net-zero by 2050. As the largest user of energy and the single largest emitter of GHGs in the federal government, Defence has a key role to play in helping the Government of Canada reach its net-zero targets. Its “*Defence Energy and Environment Strategy 2020-2023*” set out sectoral GHG reduction targets (40% cut from defence department infrastructure and commercial light-duty vehicle fleets by 2030, net-zero in these sectors by 2050). This will be accomplished in part by sourcing energy for defence building from green power sources, such as wind, solar, or hydro (water) power. Increasing building efficiency is another key to decreasing emissions and some Canada’s Department of National Defence Department (DND) buildings have won awards for their effectiveness in this regard (Government of Canada, 2022)⁶⁷. *Defence Energy and Environment Strategy* also focuses on improving the energy efficiency of bases and command wings, clean energy procurement, modernizing the vehicle fleet and increasing the energy independence of remote installations such as Canadian Forces Station Alert on Ellesmere Island in the Arctic. It aims to use cleaner fuels for military activities and operations when they are available, affordable and meet both military technical requirements and the NATO standards that enable interoperability. The affordability and market availability of technological solutions remain a challenge for reducing emissions from real property and military equipment. DND has an older real property portfolio that requires significant investments in order to improve its environmental performance. The strategy also focus-

⁶³ Finnish Ministry of Defence. “Defence Forces strive for significant emission reductions and prepare for energy transition”. Press release, 30 June, 2022.

⁶⁴ Swedish Armed Forces. “Environmental Report 2017”. See more information at <https://www.forsvarsmakten.se>

⁶⁵ The SAAB JAS 39 Gripen is a light single-engine multirole fighter aircraft manufactured by the Swedish aerospace and defence company SAAB AB. The Gripen has a delta wing and canard configuration with relaxed stability design and fly-by-wire flight controls.

⁶⁶ Swedish Armed Forces. “Successful tests with fossil-free fuel”. December 2020, <https://www.forsvarsmakten.se/en/news/2020/12/successful-tests-with-fossil-free-fuel/>

⁶⁷ Government of Canada (2022). “Defence Energy and Environment Strategy (DEES) 2020-2021 Results Report”.

es on designing more efficient troop equipment and kits, and providing more efficient power solutions for operations, including for camp infrastructure and utilities (Canadian Armed Forces, 2020)⁶⁸.

There is significant momentum in the **U.S. Department of Defence** (DOD) (as well as in the intelligence community and across the national security apparatus) to address climate change and the energy transition. The Department of Defence has released a number of documents outlining how it plans to adapt to and address climate change including the 2021 “DOD Climate Risk Analysis⁶⁹ and the DOD Climate Adaptation Plan”. Department of Defence Directive 4715.21 “Climate Change Adaptation and resilience” took effect in 2016⁷⁰. It defines climate change as variations in average weather conditions that persist over multiple decades or longer that encompass increases and decreases in temperature, shifts in precipitation, and changing risk of certain types of severe events. According to the DOD’s *Climate Risk Analysis* report⁷¹, these variations could produce climate hazards such as sea or glacial ice retreat, rising sea levels, flooding, drought, extreme heat, wildfires and tropical cyclones. The DOD has sought to increase military readiness and may propose changes in military equipment or force structure in anticipation of increased operations due to climate change. For example, glacial ice retreat could lead to increased regional competition in the Arctic, with an increase in demand for specialized, cold-weather military equipment for U.S. forces.

In February 2022, the Department of the Army released its Climate Strategy, detailing the service’s plans for adapting to climate change and enhancing resilience across the force. The strategy outlines a number of metrics by which its implementation can be assessed and highlights ambitious renewable energy and decarbonization goals, including installing a micro-grid at every Army base by 2035, fielding electric combat vehicles by 2050 and reaching net-zero emissions in all of the Army’s procurements by 2050 (U.S. Army, 2022)⁷². The microgrid goal outlines the two-pronged approach taken by the report: cut emissions as much as possible to mitigate climate change while also pushing the service to build resilience to climate change’s future like grid unreliability due to increased extreme weather. The Army will also look to switch all of its procurement to net-zero greenhouse gas emissions

⁶⁸ Canadian Armed Forces. “Defence Energy and Environment Strategy 2020-2023”. October 2020.

⁶⁹ U.S. Department of Defence (2021). “Department of Defence Climate Risk Analysis”. DOD, October 2021.

⁷⁰ Department of Defence Directive 4715.21. “Climate Change Adaptation and Resilience”. Office of the Under Secretary of Defence for Acquisition, Technology, and Logistics, January 14, 2016.

⁷¹ “Department of Defence Climate Risk Analysis”. U.S. Department of Defence, October 2021.

⁷² United States Army. “Climate Strategy”, 02 August, 2022. The strategy is broken down into 3 lines of effort – installations, acquisitions and logistics, and training.

by 2050, based on Department of Defence estimations, 95% of emissions can come from an organization's supply chain activities.

Likewise, in May 2022, the Department of the Navy released Climate Action 2030, which identifies two performance goals – building climate resilience and reducing climate threat – for the Navy and Marine Corps. The U.S. Navy's climate action plan focused on installing cyber secure microgrids, boosting its supply of lithium-ion batteries and slashing greenhouse gas emissions. The Navy's strategy directs the service to achieve a 65% reduction in greenhouse gases by 2030 and net-zero emissions by 2050.

In October 2022, the Department of the Air Force released its first plan to reduce its carbon footprint and adapt to climate change. According to the plan it is foreseen that operating bases will become net-zero emissions by 2046, while moving toward “sustainable aviation fuel blends”, an ambitious effort to rein the sizable carbon footprint of the U.S. military's air wing. The action plan also takes into account how the Air Force will need to adapt its operations to changing climate conditions, most notably within the infrastructure of its bases and where the energy comes from. Extreme weather and environmental conditions are already imposing high costs on Department of the Air Force installations and operational missions, while simultaneously posing new risks to their ability to train and operate effectively. As the climate action also includes space force, it is planned to modernize its bases around the world. Such strategies described above are not, however, statutorily required. As it conducts oversight of climate adaptation and resilience efforts, Congress may consider whether to require the services to release climate strategies that detail how the respective service plans to implement overall DOD and executive branch requirements (Congressional Research Service, 2022)⁷³.

Many initiatives are underway to increase efficiency at installations; diversify energy generation; electrify the non-tactical vehicle fleet; explore tactical and combat vehicle electrification; investigate the requirements for supporting electric-vehicle fleets and capabilities; and improve supply chain security for energy storage, among other mitigation-delivering activities. These are driven in part by federal regulations on energy efficiency that apply to installation energy, but not operational energy (Gogoreliani et al., 2021)⁷⁴. While not creating mandatory GHG mitigation

⁷³ Congressional Research Service. “Climate Change and Adaptation: Department of Defence”, July 12, 2022.

⁷⁴ Gogoreliani, Indeo & Puluzashvili (2021). “Energy Efficiency and Renewable Energy Solutions in NATO and PfP Countries' Military Operations”. NATO Energy Security Center of Excellence. In “Energy Highlights”, July 2021. See also <https://www.enseccoe.org/data/public/uploads/2021/09/nato--ensec-coe-energy-efficiency-and-renewable-energy-solutions-in-nato-and-pfp-countries-military-operations-study-report-2021.pdf>

targets, the United States’ “Operational Energy Strategy” addresses issues around efficiency and improving capabilities (U.S. Department of Defence, 2016)⁷⁵.

At the multilateral level, a number of EU policies and structures will drive action on defence energy transition, including the European External Action Service’s “Climate Change and Defence Roadmap”, and EU Concept for Environmental Protection and Energy Optimization for EU-led Military Operations and Missions (EEAS, 2021)⁷⁶. The European Defence Agency (EDA) is an organization, which assesses current demands and helps create courses of actions. Its efforts also include the *Energy and Environment Program*⁷⁷ and the *Go Green* project⁷⁸. The EDA recently took the initiative to create the “*Incubation Forum for Circular Economy in European Defence*” to help achieve the European Green Deal and the new Circular Economy Action Plan within the defence sector.

The institutional infrastructure to deliver on these objectives includes the European Defence Agency’s (EDA) Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS)⁷⁹, which supports individual nations in strengthening their defence energy transition processes as well as fostering multinational collaborative projects, including around research and innovation. Its main areas of focus are energy efficiency, particularly in the built environment; using renewable energy in the defence sector; and the protection and resilience of defence-related critical energy infrastructure. The Consultation Forum is a platform for sharing best practice and knowledge within the European Defence Energy Network, which engages 30 European countries and over 150 members (EDA, 2020)⁸⁰.

The Consultation Forum for Sustainable Energy in Defence and Security Sector’s work is linked with the EDA’s Energy and Environment Working Group (ENE WG), which looks at resilience and sustainability issues related to climate change as well as resource security issues. It also looks at alternative energies, efficiency and sustainability, with a focus on alternative fuels and drive/propulsion sys-

⁷⁵ US Department of Defence (2016). “Operational Energy Strategy”.

⁷⁶ European External Action Service. “EU Concept for Environmental Protection and Energy Optimization for EU-led Military Operations and Missions”. May 2021, <https://data.consilium.europa.eu/doc/document/ST-9263-2021-INIT/en/pdf>

⁷⁷ The initiative states that the principles of circular economy can be used to decarbonize the military sector and achieve energy efficiency: the extraction of critical resources is highly polluting and their reuse rates are not high.

⁷⁸ It seeks to produce energy from the renewable sources.

⁷⁹ A European Commission initiative managed by the EDA to assist the EU Ministries of Defence to move towards green, resilient, and efficient energy models.

⁸⁰ European Defence Agency. “CF SEDSS III Handbook Version 6.0”. August 2020, <https://eda.europa.eu/docs/default-source/consultation-forum/handbook.pdf>

tems; engine and power-distribution system efficiency technologies. The other important topics include energy storage (electrical, electrochemical, mechanical, structural and thermal); innovative and efficient energy management systems; renewables including wind and solar (thermal and electric), and sustainable procurement⁸¹.

1.3 Circular economy in the defence sector

In November 2016, the EU Commission adopted the European Defence Action Plan (EDAP), which includes a directive to transpose circular economy principles into the defence sector. Circular economy is a resource-oriented economic model that focuses on efficiency through restorative and regenerative design and structure. The objective of the circular economy is to keep products, components and materials circulating in active production and consumption chains for as long as possible, thus preserving and extracting additional value by extending the life cycle of all material units, parts and particles. The principles of a circular economy can play an important role in decarbonizing the defence sector. At the same time the circular economy provides a vision that is attractive to the defence sector as it allows it to remain competitive within the industry but in more sustainable way, reducing both the environmental impact and the logistical footprint. The implementation of the circular economy in the defence sector implies not only a change in production and consumption patterns but also an improvement in military performance, greater material security, efficiency and industrial-technological integration.

In this context, it is the best time to start considering how the principles of the circular economy can apply to a military context, where all equipment and resources are mission critical. For aerospace production, inputs are raw materials and outputs are typically either landfill waste or materials recycled into other industries, but with historically very little being brought back into the aerospace production chain. The initial raw materials extraction being one of the biggest sources of carbon emissions during production (Soufani et al., 2018)⁸². By some estimates, a well-implemented circular economy in general could reduce Europe's consumption of new materials by more than 30% within 15 years and by a 53% by 2050.

The argument for the need to be agile and responsive in the defence sector is a valid one, and to integrate circular economy models into the defence sector suc-

⁸¹ European Defence Agency. "Energy and Environment (ENE) Programme", <https://eda.europa.eu/what-we-do/all-activities/activities-search/energy-and-environment-programme>

⁸² Soufani, Tse, Esposito, Dimitriou & Kikiras (2018). "A Roadmap to Circular Economy in EU Defence inspired by the Case of the Dutch Ministry of Defence". In European Financial Review, February – March 2018".

cessfully means that these models must not only address resource consumption but also the priorities of the armed forces; namely capability performance, security of material supply, efficiency and research and technology. Examples of circular economy in the defence sector is already exhibited in some EU Ministries of Defence. In Monte Real, Portugal, for example, the nation's Air Force Base No 5 implemented circular resource-saving measures in the F-16 alienation program to Romania. This program involved modernizing the aircraft to integrate recovery and reuse of materials into the future maintenance of the jets without affecting military efficiency and operational capacities. In the UK, the Ministry of Defence utilizes a process known as through-life management, which shares principles of circular economy in its unified approach in acquisitions and equipment support, beginning with the identification of military capability needs and ending with recycling and disposal. In addition, technological forces like renewable energy, additive manufacturing, and sophisticated computer-aided production design have also made it possible to advance circular economic principles in the defence sector on an industrial level.

Shifting this process will be no small challenge, but there are some new and emerging technologies to help us. First, 3D printing – also known as additive manufacturing – where components are built up through an addition of material to create the end product. Additive manufacturing also opens up the increased possibility of using recycled, end-of-life components as the input material, which by their nature are powder or wire. These are much better suited for creating critical structural components than those used in a typical subtractive process, because they have greater purity. In this way, this development too supports the case for a circular economy; it requires fewer raw materials and less energy. Remanufacturing is another key activity; using a component as the basis for a completely new component, such as wind turbine blades being trialed for use to reinforce concrete on parts of the Britain's high speed rail line projects (HS2) being built from London to the North-West, with HS2 trains linking the biggest cities in Scotland, Manchester, Birmingham and London. Rolls-Royce has announced its closed-loop recycling program. Airbus also dismantles the aircraft “in a manner that maximizes reuse and recycling and focuses on the safe disposal of non-recyclable parts”, but, crucially, these parts tend to leave the aerospace value-chain. Aviation – both civil and defence – is of course a safety-critical endeavor, but as the civil sector takes these early steps the defence sector must, too, start its exploration of decarbonizing component production (SNC-Lavalin, 2022)⁸³. The potential that additive technologies have on defence capabilities is manifested in mobility, environmental sustainability and security. In turn, they make efficient use of resources, optimize design and pro-

⁸³ Domone (2022). “Why the circular economy is taking off –and what this means for the UK Defence sector”. SNC-Lavalin.

duction with increased reusability, repairability and manufacturability of products and thus significantly reduce the “military logistics footprint” in terms of cost, infrastructure, personnel and availability.

The use of circular materials in defence is key to eliminating at least 90% of the hazardous substances that cause biodiversity and environmental degradation. The *Cradle to Cradle Products Innovation Institute* identifies materials that follow the circular cycle, since once a good has fulfilled its function, the waste can be converted into nutrients in another system. In defence, it is necessary, as a roadmap, to define lines of development from the current scenario towards textronic-based textiles. The materials CapTech of the EDA is working on multifunctional smart textiles, which, together with the standardization of recycling processes, will improve circularity processes⁸⁴. New technologies are not only critical to supporting traditional industrial and military success, they also play a key role in advancing a sustainable development. Saulters et al (2007)⁸⁵ emphasize that the “proactive and holistic approach can facilitate efficient research, design, testing, evaluation, and fielding for novel and off-the-shelf products⁸⁶, thereby assisting developers, end users, and other diverse stakeholders in better understanding tradeoffs in the defence industry and beyond”. Some authors go a little further, mentioning that for military organizations the process of organizational greening is a quantum leap, not only technologically, but also mentally (Sandström, 2004)⁸⁷.

Ministries of Defence’s procurement rules are also an incredibly challenging part of the whole circularity equation. The scope for improvements is simply vast from mandating the eco-design of commercial-off-the-shelf technologies to the recycling of batteries to more use of electronic communications for reducing paper consumption. Indeed, digitalization becomes a key principle for the circular economy. The reduction or re-use of operational waste is a key circular economy goal, as would be requirements that commercially produced goods and supplies which militaries purchase have longer life-cycles built into them. Europe’s armies obviously seek that for their weapons and platforms, but there are many other areas of military activities that could be reoriented toward circular efficiency and recycling, such

⁸⁴ EDA has established a number of specific Capability Technology groups (“CapTechs”) to undertake research & technology activities in response to agreed defence capability needs.

⁸⁵ Saulters et al (2007). “Enhancing Technology Development Through Integrated Environmental Analysis: Toward Sustainable Non-Lethal Military Systems”. In *Integrated Environmental Assessment Management*, 2007, 6, pp. 281-286.

⁸⁶ Off-the-shelf is the opposite of bespoke, tailor-made, or customized. An off-the-shelf item is ready for anybody to use without modification.

⁸⁷ Sandström (2004) „Greening the Swedish Defence Material Administration - A Case Study on the Force of Industry in Environmental Policy-Making“. In *European Environment* 2004, 14, pp. 356-367.

as clothing or other personnel gear. For example, the Dutch army has moved determinedly in this direction in recent years (EDA, 2021)⁸⁸.

In the Netherlands, the Dutch Ministry of Defence, through its branch *Kleding en Persoongebonden Uitrustingsbedrijf* (KPU – clothing and personal equipment company) uses circular principles to reduce waste and to extend the service life of uniforms, helmets, and other personal equipment for the navy, army, air force and military police. Prior to utilizing a circular method, used work-wear and personal equipment would be turned in and new items dispensed. The practice of burning clothing materials ceased after the realization that incineration was an unnecessary expense for the MoD and that, by the process of burning, replacement uniforms had to be purchased. It cost the Netherlands approximately €500,000 per year (Defensie Materieel Organisatie, 2016)⁸⁹ to destroy materials that still had use-value in them. Eliminating waste is a key in solving many sustainability and environmental issues and problems.

The defence sector increasingly recognizes that climate change can potentially accelerate insecurity and armed conflict (NATO, 2021)⁹⁰. Defence organizations in the USA, UK and beyond are now addressing sustainability in recent reports, statements, innovations and strategies (e.g. Honeywell, 2021; MoD, 2021; Rolls Royce, 2021; U.S. Army, 2022)⁹¹. Typically, in the past, the defence sector has not been subjected to standard obligations under EU resource-efficiency directives under the conviction that armed forces of member-states need to be free of environmental rules and regulations in case they needed to expand resources as needed in order to maintain capabilities and operational effectiveness. The transition of the defence industry towards more sustainable production models is unavoidable and could benefit the entire industrial and economic ecosystem, as well as the activities of capability acquisition, life-cycle management and employment of military assets. Both the institutions and countries within the European Union and NATO should refine their energy agenda in line with the new requirements of production management and service delivery to fight against climate change and achieve a green transition.

⁸⁸ “Circular Economy in Defence”. Official Magazine of EDA, European Defence Matters, 20th Issue.

⁸⁹ Defensie Materieel Organisatie (2016, May 3). English version (MVO in defence) [Video file]. Retrieved from <https://www.youtube.com/watch?v=1nhVKqTGBPo>

⁹⁰ “NATO Climate Change and Security Action Plan”, 14 June 2021.

⁹¹ Honeywell (2021). “How We Will Reach Carbon Neutrality by 2035”; Rolls Royce (2021). “Our Decarbonization Strategy: Plotting Course for net zero”.

CHAPTER 2

FRAMEWORK FOR MILITARY GREENHOUSE GAS REPORTING

Tackling the climate crisis requires action from all industrial and economic sectors to markedly reduce their impact on the planet. The global military sector – including its supply chain – is a major element of government expenditure and a huge consumer of fossil fuels. Hence it is essential that military greenhouse gas emissions are both reported robustly and subject to emission reduction targets. Some scientists estimate that together militaries and their supporting industries might account for up to 5.5 % of global emissions: more than civilian aviation and shipping combined. Based on different reports, the data indicates that the U.S. military is the largest single institutional consumer of hydrocarbons globally (Belcher et al., 2019; Crawford, 2019)⁹². This ranks its annual greenhouse gas emissions (GHG) higher than 140 countries. As global military spending increases, military GHG emissions are also set to increase. An increasing number of countries are including military greenhouse gas (GHG) emissions in their domestic net zero targets, and NATO and other international organizations have acknowledged that these targets will not be met without military emissions reductions. It is not only a question of obliging countries to report on their military emissions, it is about what they report, and how they do it.

The trace of the greenhouse gases produced by human activities are known as the carbon footprint. This environmental indicator measures both direct and indirect emissions of compounds like methane (CH₄), nitrogen oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) sulphur hexafluoride (SF₆), and above all, the most abundant and most important contributor to global warming since 1990: carbon dioxide (CO₂). Each gas has different physical properties, meaning that each traps different amounts of heat in the atmosphere, molecule for molecule. Reaching net zero GHG emissions is more difficult than reaching net zero CO₂ emissions, as reducing some sources of non-CO₂ emissions towards zero remains very difficult, especially for methane and nitrous oxide from agriculture. Methane, currently the second-largest contributor to global warming, has much shorter lifetime than CO₂. Therefore, if methane emissions reduce to zero, concentrations fall faster, and their contributions to global temperature will decline. Typi-

⁹² Crawford (2019). “Costs of war, Pentagon Fuel Use, Climate Change, and the Costs of War”. Brown University, Rhode Island. See also Belcher, Bigger, Neimark & Kennelly (2019). “Hidden Carbon Costs of the “Everywhere War”: Logistics, Geopolitical Ecology, and the Carbon Boot-Print of the US Military “. In *Transactions of the Institute of British Geographers*.

cally, net zero GHG emissions are achieved with significant negative CO₂ emissions balancing the remaining GHG emissions (IPCC, 2018)⁹³.

To calculate the carbon footprint, the CO₂e (carbon dioxide equivalent) is estimated, but GHG emissions are reported in “tons of carbon dioxide equivalent” or tCO₂. This is a standardized measure, which takes into account of the fact that there is a number of different GHGs – carbon dioxide being the most prevalent. As the effects of climate change become even more apparent, the accurate measurement of GHG emissions is becoming increasingly important to better understand their sources and how to best reduce them.

Greenhouse gases can be measured by recording emissions at source, by continuous emissions monitoring or by estimating the amount emitted using activity data (e.g. the amount of fuel used) and applying relevant conversion factors (e.g. calorific values, emission factors, etc.). Conversions of fuel quantities –from physical units to energy units – require conversion factors expressing the heat obtainable from one fuel unit. Conversion factors are termed the “calorific value” or “heating value” of fuels as seen in Figure 3. These conversion factors allow organizations and individuals to calculate GHG emissions from a range of activities, including energy use, water consumption, and waste disposal and recycling, as well as transport activities. The direct measurement of GHG from a physical source is rare, which is why emission factors are needed to measure the CO₂ emissions of an activity. Generally, emission factors are averages of current and available data and need to be updated regularly, as long-term values can change in different localizations, leading to uncertainty in the data.

Figure 3. Conversion factors for energy units

From	To kWh
Therms	29.307
Btu	2.931x10 ⁻⁴
MJ	0.2778
Toe	1.163x10 ⁴

Btu = British thermal unit;

MJ= Mega-joule;

Toe = tons of equivalent oil.

Source: Adapted from “Conversion factors – energy and carbon conversion guide”. Carbon Trust (2022).

⁹³ IPCC (2018). “Special Report: Global Warming of 1.5 degrees Celsius”.

The use of fuels leads to emissions of carbon dioxide and small quantities of other greenhouse gases – including methane (CH₄) and nitrous oxide (N₂O). Scientists and policymakers have established “global warming potentials” (GWPs) to express the heat trapping effects of GHGs in terms of CO₂ - equivalents (annotated as “CO_{2e}”). GWPs are defined for different time horizons, to account for differences in the residence time of different gases in the atmosphere. Greenhouse gases warm the earth by absorbing energy and decreasing the rate at which the energy escapes the atmosphere. These gases differ in their ability to absorb energy, that is, they have various radiative efficiencies. Each gas has a specific global warming potential (GWP), which allows comparisons of the amount of energy the emissions of 1 ton of a gas will absorb over a given time period, usually a 100-year averaging time, compared with the emissions of 1 ton CO₂. As CO₂ has a very long residence time in the atmosphere, its emissions cause increases in atmospheric concentrations of CO₂ that will last thousands of years. Methane’s average atmospheric residence time is about a decade. However, its capacity to absorb substantially more energy than CO₂ gives it a GWP ranging from 28 to 36. The GWP also accounts for some indifferent effects; for example, CH₄ is a precursor to another greenhouse gas, ozone (Vallero, 2019)⁹⁴.

The carbon footprint from EU military spending in 2019 was estimated to total some 24.8 million cars (Parkinson & Cottrell, 2021)⁹⁵. However, current trends in military GHG emissions levels in the EU are difficult to determine due to a lack of data, and as such, the report’s conclusions provide only highly conservative estimates of CO₂ emission levels. The data for military GHG emissions across the world are frequently of low quality – often incomplete, hidden within civilian categories, or not collected at all. The root cause of this problem was government concern about potential restrictions of military activities – which led to exemptions first under the 1997 Kyoto Protocol. Currently, under the United Nations Framework Convention on Climate Change (UNFCCC), countries are obliged to provide an inventory of their GHG emissions. Reporting obligations for countries vary, depending on their historic contribution to the climate crisis. Guidelines from the Intergovernmental Panel on Climate Change (IPCC) state that inventories submitted to the UNFCCC should include emissions from some military activities. In 2015, however the Paris Agreement made military emissions reporting mandatory, meaning that there are significant gaps in the datasets submitted to the UNFCCC and no accurate data on the true scale of the problem. Without even a minimum reporting obligation to the UNFCCC, most countries – including those with large military

⁹⁴ Vallero (2019). “Air pollution biogeochemistry”. In *“Air Pollution Calculations: Quantifying Pollutant Formation, Transport, Transformation, Fate and Risks”*, Chapter 8.

⁹⁵ Parkinson (2020). “The Environmental Impacts of the UK Military Sector”. Scientists for Global Responsibility (SGR).

expenditures and military personnel – do not require their militaries to provide any meaningful GHG emissions reporting. These problems have been largely overlooked by the climate science community (Parkinson & Cottrell, 2022)⁹⁶. For example, the latest (sixth) assessment report of the IPCC⁹⁷ barely discusses this sector at all.

Nevertheless, military sector has begun to recognize their big role in contributing to climate change. The U.S., UK and some EU member states (such as France, Italy, and the Netherlands) are making progress, with military energy policies and initiatives to support the move to lower carbon energy use and reduce military reliance on fossil fuels. GHG reporting is required to monitor progress and the effectiveness of these GHG reduction strategies. As militaries have historically been largely excluded from GHG reduction goals, their ability to track their emissions lags behind other sectors. For the 20 top military spending countries in 2021, only Germany was reporting its GHG emissions from military fuel use in line with the basic UNFCCC requirements⁹⁸.

To achieve carbon emissions reductions, and to comply with the international rules, the EU and its member-states have committed to reporting their final greenhouse gases emissions to the UNFCCC each year. They do so in the form of “greenhouse gas inventories” defined as a quantified estimation of annual emissions produced by human activities on a country’s territory. In order to report the greenhouse gas emissions associated with an organization’s activities, the carbon emission need to be converted into “activity data” such as distance travelled, liters of fuel used or tons of waste disposed. This requires a sound framework for monitoring and reporting on greenhouse gas emissions, as well as reliable information on projected changes in emissions resulting from existing and planned policies and measures.

⁹⁶ Parkinson & Cottrell (2022). “Estimating the Military’s Global Greenhouse Gas Emissions”. Conflict and Environment Observatory, 10 November 2022.

⁹⁷ The Working Group I contribution to the Sixth Assessment Report, “Climate Change 2021: the Physical Science Basis” was released on 09 August 2021. The Working Group II contribution, “Climate Change 2022: Impacts, Adaptation and Vulnerability” was released on 28 February 2022.

⁹⁸ Although IPCC guidelines request that emissions from military fuel are reported under IPCC category 1A.5 (Other, not elsewhere specified), it is often absent, or aggregated and reported elsewhere. This category includes all mobile fuel consumption, such as ships, aircraft and road vehicles. It also includes all stationary fuel consumption, such as heating buildings and military bases.

2.1 Military emissions reporting gap

Some countries bundle their military emissions together with civilian emissions. 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 (Lawrence et al., 2015; Zentelis et al., 2017)⁹⁹. Indirect correlations between, military energy use, especially fossil fuels, and greenhouse gas (GHG) emissions have been discussed previously (Bildirici, 2017, Nuttall et al., 2017)¹⁰⁰, but quantitative estimations are scarce. 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. Figures from the U.S. are within the same range, varying from 25.4 million tons annually from direct fuel consumption (Belcher et al., 2019)¹⁰¹ to 172 million tons including electricity use and upstream emissions. This is equivalent to 0.5-3.3% of the total U.S. emissions in 2017 (EIA, 2019)¹⁰². A lack of transparency makes it hard to calculate the true scale of military emissions, although it is clear that they are significant.

Internationally, military sectors typically disclose less information than civilian sectors. As pressures upon all sectors continue to rise, it is anticipated that military emissions reporting pressures will also increase. In November 2021, the United Kingdom-based Conflict and Environmental Observatory (CEOBS) launched a public-facing resource, which analyzes and aggregates UNFCCC military emissions reporting. The purpose of this campaign is to highlight leaders and laggards in military emissions reporting.

In this study¹⁰³ CEOBS analyzed military emissions reporting from 72 states. Of these, emissions data accessibility was categorized “fair” for only four nations – Germany, Norway, Luxembourg and Cyprus Island. Of these countries, Germany has the largest military and, as such may be understood as the leader in emissions

⁹⁹ Lawrence, Stemberger, Solderado, Struthers & Cooke (2015). “The effects of modern war and military activities on biodiversity and the environment”. In *Environmental Review* 23 (4), pp. 443-460.

¹⁰⁰ Bildirici (2017). “The effects of militarization on biofuel consumption and CO₂ emission”. In *Journal of Clean Production* 152, pp. 420-428.

¹⁰¹ Belcher, Bigger, Neimark & Kennelly (2019). “Hidden Carbon Costs of the “Everywhere War”: Logistics, Geopolitical Ecology, and the Carbon Boot-Print of the US Military “. In *Transactions of the Institute of British Geographers*.

¹⁰² EIA, 2019. In Administration, U.S.E.I (Ed.), June 2019 – Monthly Energy Review. Eurostat, 2019. ESA Supply, Use and Input-Output Tables.

¹⁰³ Conflict and Environment Observatory (2022). “A framework for military greenhouse gas emissions reporting”. CEOBS, June 2022. See also CEOBS (2022). “Estimating the military’s global greenhouse gas emissions”. November 2022.

transparency. Thirty-six states, including the U.S., Russian Federation, China, UK, Japan, France, and Canada were categorized by the CEOBS as having “poor” quality emissions data accessibility. The remaining 32 states categorized as having “very poor” data accessibility including India, Egypt, Türkiye, and Saudi Arabia.

As governments elevate climate priorities and emphasize the need for net-zero emissions, they have begun to recognize the challenge posed by defence-related decarbonization. For many countries, decarbonizing their defence forces may be an essential step toward achieving government targets without relying on expensive offsets (Barry et al., 2022)¹⁰⁴. Carbon offsets are a credit that an individual or organization can claim when it takes one action that cancels out the carbon emissions created by a different action. For example, forests can trap or sequester large amounts of carbon dioxide through photosynthesis. There are two types of forest management projects that may be useful to create carbon offsets around military installations: avoided conversion and improved forest management. An avoided conversion project, sometimes referred to as forest conservation, involves preventing the loss of forest (to a non-forest use) by permanently dedicating land to continuous forest cover and maintaining or increasing stocking levels. Improved forest management includes better harvesting in areas where logging occurs, protection or set-aside, of some areas from logging, and silvicultural practices to improve growth. Reforestation is another common type of carbon offset project and involves planting forests from seeds and saplings, but it may not be the most efficient for the defence forces because large, mature forests already exist in the areas surrounding military installations.

2.2 Military emissions categories and GHG reporting

The classification of military related GHG is based on the criteria established by the IPCC. The standard methodology for measuring GHG emissions from the carbon footprint is categorized using three different areas or scopes – as set out by the GHG Protocol. Using this classification, studies and reports have been published on the extent of Norwegian, British and European military carbon footprints (Scientists for Global Responsibility, 2020¹⁰⁵; Parkinson & Cottrell, 2021¹⁰⁶; Sparrevik & Utstøl, 2020)¹⁰⁷.

¹⁰⁴ Barry, Fetzek, Emmett (2022). “Green Defence: the defence and military implications of climate change for Europe”. The International Institute for Strategic Studies.

¹⁰⁵ Scientists for Global Responsibility, Declassified UK (2020). “The Environmental Impacts of the UK Military Sector”.

¹⁰⁶ Parkinson & Cottrell (2021). “Under the Radar: the carbon footprint of Europe’s military sectors. A Scoping Study”. Scientists for Global Responsibility, Conflict and Environment Observatory, 16 February 2021.

¹⁰⁷ Sparrevik & Utstøl. “Assessing life cycle greenhouse gas emissions in the Norwegian defence sector for climate change mitigation”. In *Journal of Cleaner Production* 248 (2020).

Emissions from fossil fuel and from energy production (often referred as scope 1 and 2) are compulsory to report according to the ISO 14064 greenhouse gas reporting standard (Weng & Boehmer, 2006)¹⁰⁸, since they can be directly connected to the reporting organization. However, it is likely that multiple impacts may also rise from indirect emissions originating from both upstream and downstream in the value chain (scope 3), which are only partly influenced by the reporting organization. Indirect emissions may occur in all life cycle stages and their contribution to the overall life cycle emissions may be substantial, especially for large procuring organizations such as the military sector (Huang et al., 2009)¹⁰⁹. A life-cycle greenhouse gas accounting evaluates and reports the full life-cycle GHG emissions related with the raw materials extraction, manufacturing or processing, transportation, use, and end-of-life management of a good or service. Therefore, a life-cycle perspective accounts for all emissions connected to the good or service, regardless of which industrial or economic activities or sectors produce these emissions (e.g. energy, mining, manufacturing, or waste sectors) and when these benefits occur over time. This is fundamentally different from GHG inventories that quantify emissions from different industrial or economic sectors on an annual basis.

The reports of the Intergovernmental Panel on Climate Change (IPCC), the United Nations' scientific advisory body on the issue, have barely mentioned the defence sector. National security restrictions have considerably limited access to data, with very few nations reporting separate figures for military GHG emissions, and many not compiling them at all. The situation became embedded in international reporting standards following a demand from the U.S. that the targets agreed as part of the 1997 Kyoto Protocol excluded emissions related to military activities (Lorincz, 2015)¹¹⁰. Under the Kyoto Protocol agreed in 1997 industrialized countries annually have to provide a national inventory report (NIR). Decision 18/CP.8 in 2002 (UNFCCC, 2003)¹¹¹ specified the details of the NIR, and stipulates that domestic military emissions are to be included in national inventories. However, bunker fuels for international transport were exempted. While the official reason was not to burden world trade, implicitly large countries with a “maritime empire” (U.S., FR, UK) as well as those operating military globally benefitted from this provision. The advent of the 2015 Paris Agreement, which has led to a more flexi-

¹⁰⁸ Weng & Boehmer (2006). “Launching of ISO 14064 for greenhouse gas accounting and verification”. In *ISO Management System*, 15 (2006), pp. 14-16.

¹⁰⁹ Huang, Weber, Matthews (2009). “Categorization of scope 3 emissions for streamlined enterprise carbon foot-printing”. In *Environmental Science Technology* 43 (22), pp. 8509-8515.

¹¹⁰ Lorincz (2015). “Demilitarization for Deep Decarbonization”. Presentation at SGR conference, 4 November. See more information at the website: <https://www.sgr.org.uk/resources/demilitarization-deep-decarbonization>.

¹¹¹ UNFCCC (2003). “Report of the conference of the parties on its eighth session, held at New Delhi from October 23 to 1 November 2002”.

ble approach to military-related emissions, has opened the door to greater recognition of the issue¹¹².

In a nutshell, emissions related to military action can be divided into the following types:

1. Direct emissions from operations of military forces (emissions from the use of weapons and ammunition in training and conflict, as well as fuel consumption for transport).
2. Indirect emissions that are associated with the generation of electricity acquired and consumed at the organization's facilities, heating and cooling of buildings, and emissions of non-fossil fuel related GHGs.
3. Other indirect GHG emissions from sources that are not owned or controlled by the entity, such as extractions and production of acquired materials, business trips through external means, products and logistics activities carried out by the third parties.

2.2.1 Direct emissions of the military and its reduction potential

Defence departments will encounter challenges when attempting to reduce the emissions for which they are directly responsible because of the primacy of having mission-critical capability (that is, the ability to achieve a desired effect in a specific operational environment). Roughly 30 percent of the military emissions comes from “installations’ emissions”, meaning the energy used in military bases and other installations. The other 70% comes from “operational emissions” (e.g. energy use of trainings, missions, transport, and other activities).

By defining the division between the energy used in military operations and the amount used in facilities, and proven that the former one is the major source of consumption and spending, it is necessary to properly define the meaning of “energy used in operations” or “operational energy” (OE) in the military area. In the civil sector, many definitions of OE can be found. Among them, OE is defined as the “energy consumed for lighting, heating, cooling and ventilation excluding energy used for hot water generation and life-style appliances such as computers,

¹¹² 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 are often embedded into other activities, such as energy production, transportation, and industrial activities, or taken out of the reporting.

washing machines (Praseda et al, 2017)¹¹³. Unfortunately, there is no agreed definition of OE in NATO yet. One of the NATO Allies, Canada, does not have a proper definition of OE, but it clearly distinguishes two types of energy consumed by the Canadian Armed Forces: the energy consumed in installations and the one used for mobility purposes by the fleets. Hence, while the energy used in installations (buildings) includes energy from electricity, natural gas, fuel oils, kerosene and solar photovoltaic, the energy used for military and expeditionary operations refers to the aviation and ship's fuel, combat equipment and the energy used in domestic operations, such as training (Labbe et al, 2015)¹¹⁴.

The real challenge lies in reducing Scope 1 emissions from ships, aircraft, and combat vehicles, which are significantly greater than infrastructure emissions. Military infrastructure is made more energy dependent, but experiments with sustainable propulsion fuel, one of the largest sources of military emissions, are met with technical, financial and environmental constraints. It is much harder to update military transport and mobility fuel sources, which is where most climate pollution takes place. A shift to sustainable fuel is not expected soon, and the military will therefore continue to be huge fossil fuel consumer. For example, transport and mobility of modern Western armies account for about 70 percent of their energy consumption, the majority of which is consumed in the form of jet and diesel fuel. This in turn is a major source of greenhouse gas emissions. Each air mission produces hundreds of tons of CO₂ pollution.

While it may be possible to power military bases or even drones with solar energy, there is no viable prospect for electrifying a majority of the military arsenal. Decarbonizing aviation is particularly challenging, as there is no comparable alternative to energy-dense jet-fuel, and at current trends, climate change urgency far outpaces technological innovation in the electrification of air travel. Among the most ambitious attempts to transition military machinery from fossil fuels, the so-called “*Great Green Fleet*” is made up of planes, submarines, and ships powered by biofuels and nuclear power – which may be alternatives to fossil fuels but not without their own ecological footprint and high price¹¹⁵. Considerable controversy surrounds the extent to which biofuels can even be characterized as carbon neutral undermining the supposed benefits of a biofuel-powered arsenal.

¹¹³ Praseda, Reddy, Mani (2017). “Life-cycle Energy Assessment in buildings: Framework, Approaches, and Case Studies”. In *Encyclopedia of Sustainable Technologies*, pp. 113-136.

¹¹⁴ Labbe, Ghanmi, Amow, Kan, Jayarathna, Voicu, Strat (2015). “Evidence base for the development of an enduring DND/CAF Operational Energy Strategy (DOES)”. Defence Research and Development Canada.

¹¹⁵ The U.S. *Great Green Fleet* is intended to usher in a new era of naval energy innovation that will increase both combat capability and operational flexibility.

Although land and sea forces use considerable amounts, the air force is the larger consumer of petroleum jet fuel of all branches of the armed services. Military jets typically fly at higher altitudes than commercial airlines. As well as emitting greenhouse gases, aircraft flying at high altitude can also cause additional atmospheric heating effects due to contrails left by aircraft, which can persist as large, thin sheets of cirrus clouds. Contrail cirrus, as well as other non-CO₂ effects like NO_x emissions from aviation, are significant contributors to the climate warming impact of aircraft emissions. This means that fuel consumption data alone is not reliable for assessing the full climate impact of military emissions.

The other important source of greenhouse gas emissions is related to military installations, which produces about one third of its GHG emissions. This may seem to be easy part, since buildings and infrastructure are simple to model and modify. New buildings can also be fitted with new sensors to feed more data into future modelling, though smart installations initiatives, which should help defence ministries much better understand how it is using and in some cases wasting power. Changing the power source for facilities such as barracks, airbases, forward operating bases (FOBs) and headquarters is possible with existing technology and offers certain operational advantages. For example, a distributed array of solar panels might be more difficult to disable than a single, centralized generator or a single electricity grid access point.

Military training lands and estates are estimated to cover between 1-6% of the global land surface. Because of this, how they are used and managed could have a significant bearing on global GHG emissions. The military training estate often includes areas of ecological importance, and is typically closed to the public and remains relatively undisturbed, compared with other intense land uses. Improved land management to optimize carbon sequestration and minimize carbon losses from soil is needed. These improvements could also increase biodiversity and help build climate resilience.

Soil temperature, drainage, erosion and deposition can all influence carbon sequestration and losses, meaning that improved land management and reduced soil disturbance can increase soil's carbon content. Military lands have significant but underutilized scope for carbon sequestration –despite a scoping study in 1995 showing the potential, for example, the U.S. Department of Defence has not developed the idea until recently¹¹⁶. Military training exercises themselves of course also

¹¹⁶ Barker, Baumgardner, and McFarlane (1995). "Carbon Sequestration and Forest Management at Department of Defence Installations: An Explanatory Study". USA Environmental Protection Agency, EPA/600/R-95/037.

generate significant GHG emissions, including from land degradation. This is particularly true when undertaken in fragile environments such as semi-arid deserts. Although, it is worth underlining that there is not much information available in the public about the issue that examine the carbon footprint of specific training exercises. However, there have been recent pushbacks against training drills due to climate and environmental concerns. Whilst exercises are now incorporating climate security, there must be a commitment to undertake climate and environmental assessments related to all military assessments for all military exercises in order to mitigate any adverse impacts.

Besides aforementioned possible GHG emissions, military waste and surplus is another major contributor. The armed forces must both significantly reduce the volume of waste it generates and manage any waste it does responsibly. This includes surplus materiel and equipment, like ammunition, which is commonly destroyed by open detonation or burning. This can cause ground contamination, generate noxious air pollutants and release greenhouse gases. Waste disposal practices across the military have been poorly managed in the past according to Conflict and Environment Observatory (CEOBS), with the use of open burn pits, burial and weak compliance with standard waste management protocols¹¹⁷.

Reducing emissions by enhancing energy efficiency and introducing sustainable energy in infrastructure is relatively easy and already in progress. Solar panels and bio-waste installations increasingly contribute to the energy supply of military installations, improving the endurance of military forces during conflict. The strategic value is undisputed: fuel supply lines are very vulnerable, especially during deployment. Easily transportable, easy to handle, and quick to set up power systems are already advertised as “combat proven”, meaning their merit has been demonstrated on the battlefield which is the ultimate recommendation for military products. Renewable energy can also be used for modest purposes such as heating or cooling barracks or powering small electric vehicles. Despite the current impossibility of reducing direct emissions from military vehicles and aircraft, defence forces still have great potential to reduce its carbon footprint.

¹¹⁷ Parkinson & Cottrell (2021). “Under the Radar: the carbon footprint of Europe’s military sectors. A Scoping Study”. Scientists for Global Responsibility, Conflict and Environment Observatory, 16 February 2021.

2.2.2 Indirect emissions of the military

Indirect or scope 2 emissions represent one of the largest sources of GHG emissions globally. These include emissions from the generation of purchased energy, such as heating and cooling buildings as well as emissions resulting from goods and services delivered through an outside provider. According to the GHG Protocol, Scope 2 emissions represent one of the largest sources of global greenhouse gas emissions accounting at least one third of it. That is why accounting and measuring Scope 2 emissions present a significant emissions reduction opportunity.

It is not always easy to make distinctions between scope 1 and scope 2 greenhouse gas related emissions, for example, electricity purchased from the utility company is generated offsite, so they are considered indirect emissions. Although some military installations generate and store renewable energy on-site by integrating battery storage, building integrated photovoltaics (PV), microgrids and electric vehicles (EV) charging stations for this purpose. Therefore, if the reporting organization, generates energy on-site from owned or controlled sources, the greenhouse gases associated with the energy generation are classified as direct scope 1 emissions. The same applies to organizations, such as electricity utilities or suppliers, which control their energy generation installations and sell their power into the local grid. The greenhouse gases from these generation facilities are reported in Scope 1 emissions.

Measuring emissions requires different types of data, for example some of it is primary data, like energy consumption at facilities, which is quantifiable and easily accessible by the organization. However, most of the data used in measuring GHG emissions are secondary data, which is derived from estimations based on a region or organization's emission factor for a certain commodity or raw material. Once an accurate and standardized measurement is taken, an organization is ready to begin creating emissions reduction goals. One of the ways to do this is by using automated tools like building management systems (BMS)¹¹⁸, which can ultimately reduce energy use for an organization's facilities. These systems can use weather data, energy costs, historical data, and operational requirements to detect patterns in energy use of a machine. A BMS is a great tool to help build efficiencies over time and assist with preventive maintenance detection. Although, it should be highlighted that building automation systems have become a soft target for cyberattacks. This is caused by the large numbers of intelligent devices connected

¹¹⁸ A Building Management System is a computer-based system installed in buildings to manage and monitor equipment such as air-conditioning, heating, ventilation, lighting, power systems, security devices, and IoT, energy and gas meters.

over open networks, sophisticated threats designed to attack control systems, as well as dependency on third-party service providers connecting to the systems remotely over the internet. Therefore, for its use in the defence sector certain mitigation measures should be also implemented to ensure security.

Renewable energies will play a more important role, and the generation of electric power by the military will further cut emissions. While reducing energy consumption is a great starting point, producing renewable energy onsite is another pillar that can help organizations and third party energy suppliers reach their Scope 2 GHG emissions reduction goals (Farrenkopf, 2022)¹¹⁹. Solar panels are a common way organizations choose to produce renewable energy on-site. However, since manufacturing requires substantial energy, this will only address a fraction of the energy needed for operations. Since an organization's ability to produce renewable energy for its own use can be limited due to factors like installation size, location and ownership, the next pillar is clean energy procurement.

Tools like Power Purchase Agreements (PPAs) where renewable energy is delivered to the site from a renewable source, are an effective mode for procuring clean energy. A corporate Power Purchase Agreement is a contract between the corporate buyer (off-taker) and the power producer (developer or independent power producer) to purchase electricity at pre-agreed prices for pre-agreed periods. The electricity can be supplied by existing renewable energy assets or new build projects. Some utility companies also offer solar, hydro and wind power to customers. It has become common for organizations to rely on procurement strategies like renewable energy certificates (RECs)¹²⁰ or guarantees of origin (GOs).

Although, PPA in the defence sector is not yet widely used there are already some promising examples that it can also be used to reduce military's carbon footprint. In 2017, Australia's Ministry of Defence launched a tender with the aim of sourcing up to 40 percent of its Robertson Barracks and Royal Australian Air Force (RAAF) Darwin's base electricity requirements from the two solar farms (with nameplate 14 MW of solar PV and battery storage capacity). The use of solar and battery storage help ensure energy security (Vorrath, 2019)¹²¹.

¹¹⁹ Farrenkopf (2022). "4 Strategies for Reducing Scope 1 and 2 Emissions". Contribution by Project Manager, Global Energy at the Jabil blog.

¹²⁰ Known as Guarantees of Origin (GO) in Europe, provide proof that energy has been generated from renewable sources (as defined in the Renewable Energy Directive), specifying the source of the energy. The main provisions of the RES Directive are contained in article 19, which requires the member-states to ensure that GO is issued on request by producers of electricity, gas, hydrogen, heating or cooling from eligible renewable energy sources.

¹²¹ Vorrath (2019). "Defence signs contract to power Darwin bases with solar and battery storage". In *Renew Economy newsletter*, 18 July 2019.

2.2.3 Indirect greenhouse gas emissions including military supply chain

Organizations can normally easily measure their Scope 1 and 2 emissions, and can control them by taking steps like switching to renewable energy or electric vehicles. In this respect, Scope 3 emissions are under the control of suppliers, so they are affected by decisions made outside the organization. That means measuring Scope 3 emissions involves tracking activities across the entire value chain – from suppliers to end-users.

Militaries have extensive and complex supply chain, comprising a large proportion of their carbon footprint. Emissions from supply chain typically far exceed an organization's own operational (scope 1 and 2) emissions, with estimates varying depending on sector. Data on the military sector is again sparse, although notably, some carbon footprint data has been published by the military technology corporations Thales¹²² and Fincanteri¹²³. As the above mentioned examples indicate, for defence supply chains, the complexity of the full supply landscape presents a challenge to quantifying and directly managing emissions. Defence forces have unique suppliers and unique products. This prevents the creation of an ecosystem to generate mutual benefits between defence forces and their suppliers, akin to ones developing in the automotive sector that could help electric vehicles (EVs) to displace vehicles with internal combustion engines. It may therefore be most effective to address supply chain emissions by setting decarbonization requirements aligned to national targets for all suppliers, as opposed to quantifying emissions directly and actively trying to reduce them.

Defence organizations in the U.S., UK and beyond are now addressing sustainability in their recent reports, statements, innovations and strategies. Decarbonization to net-zero is a complex organizational challenge. That means that the countries will not be able to reach its net-zero targets without the defence industry and MoD activities moving toward more sustainable solutions. For example, defence accounts for 50% (UK) and 80% (U.S.) government greenhouse gas emissions, so decarbonization of this sector is vital to achieve the UK and U.S. governments' net-zero ambitions (Frazer-Nash, 2020)¹²⁴. For Armed Forces, which are reliant on fossil fuels, a considerable test lies ahead. To reach zero emissions pathway, the mil-

¹²² Thales (2019). "Committing to Environmental Protection: Strategy for a Low-Carbon future". This strategy also includes 50% reduction in operational CO₂ emissions (resulting from internal operations and employees mobility, with an interim target of 35% in 2023, aiming Net Zero by 2040.

¹²³ Fincanteri (2022). "Greenhouse gas emissions". In 2022, to align with its objective to play a leading role in the decarbonization of shipping industry the company expanded the scope 3 emissions reporting to include CO₂ emissions from 'Employee Commuting' and "Use of Sold Products" as required by the Greenhouse Gas Protocol reporting standard.

¹²⁴ Frazer-Nash (2020). "Where next for UK Defence in an era of climate crisis?"

itary must take transformative action at the moment that changes the way the military “fight, live and train”. The Armed Forces, moreover, bring volume and mass to civil and commercial sectors and therefore have the ability to influence through their spending power and example, creating catalyst for innovation and experimentation. However, the MoD, or any other government body, cannot do it alone. It is vital that defence companies play a role not only in developing and delivering solutions that are more sustainable, but also in reducing internal emissions and ensuring that the supply chain follows the same trend.

Governments can accelerate their path to net-zero operations by adopting the green procurement framework – an approach designed by the World Economic Forum and Boston Consultation Group (BCG) for the Mission Possible Partnership. It contributes to closed material and energy loops, by minimizing and in certain cases avoiding the environmental pressure and the waste creation across the whole life-cycle. The EU Circular Economy Action Plan (CEAP)¹²⁵ recognizes public procurement as a key driver in the transition towards the circular economy. Environmental criteria can be placed both on the supplier’s systematic environmental work and on the procured product/service. A life-cycle perspective, including life-cycle cost (LCC), allows procurer to choose the option with the best value over its entire life-cycle.

The defence industry’s customers are increasingly embracing mitigation of climate change as a strategic priority. Safety, reliability, and performance will remain crucial for securing contracts, but “green procurement” principles that already are widely applied in other areas of government will permeate the defence sector in the coming years and translate into new requirements for suppliers. Some governments are already signaling that they will exert their strong influence over contractors to enable them to meet their climate goals. Although 2050 may seem a long way down the road, departments of defence are moving fast. The UK Ministry of Defence has announced that it may start including environmental criteria in its tenders as early as this year. In the U.S., the Biden Administration has committed to a 50% national reduction of carbon emissions by 2030, leaving just over 8 years for public and private organizations alike to achieve a new step in their climate efforts. These announcements indicate that the carbon efficiency of defence products will soon draw greater customer scrutiny and increasingly become a differentiator. It can be assumed that contractors will be required to publicly disclose emissions and other climate-related risks when bidding for government contracts. Ministries of

¹²⁵ European Commission. “Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the committee of the Regions: A new Circular Economy Action Plan For a cleaner and more competitive Europe”. 11 March 2020, COM (2020) 98 final.

Defence worldwide will increasingly ask their contractors to set emission-reduction targets and plans. Over the medium-term, these targets and plans – and progress toward their realization – are expected to be incorporated into procurement criteria (Dimitrova et al., 2021)¹²⁶.

The UK Ministry of Defence takes further efforts to ensure that it is playing its role in the delivery of the UK’s climate ambitions, notably through its “*Climate Change and Sustainability Strategic Approach*” and recent changes in defence procurement. A Code of Practice (CoP), co-developed by the Ministry of Defence and the Defence Industry through the Defence Suppliers Forum that seeks to answer these questions, recognizing the critical role that the MoD’s suppliers have in the race to Net Zero. The CoP sets out defence-specific guidance for Greenhouse Gas (GHG) measurement, covering the main aspects of Defence. It also includes Scope 3 emissions and encompassing all areas of Defence acquisition and support (products, systems and services as well as infrastructure and estates). The CoP’s aim is not to replicate existing guidance and requirements, but to signpost the best practice that is applicable – including the Greenhouse Gas Protocol (GHG Protocol)¹²⁷.

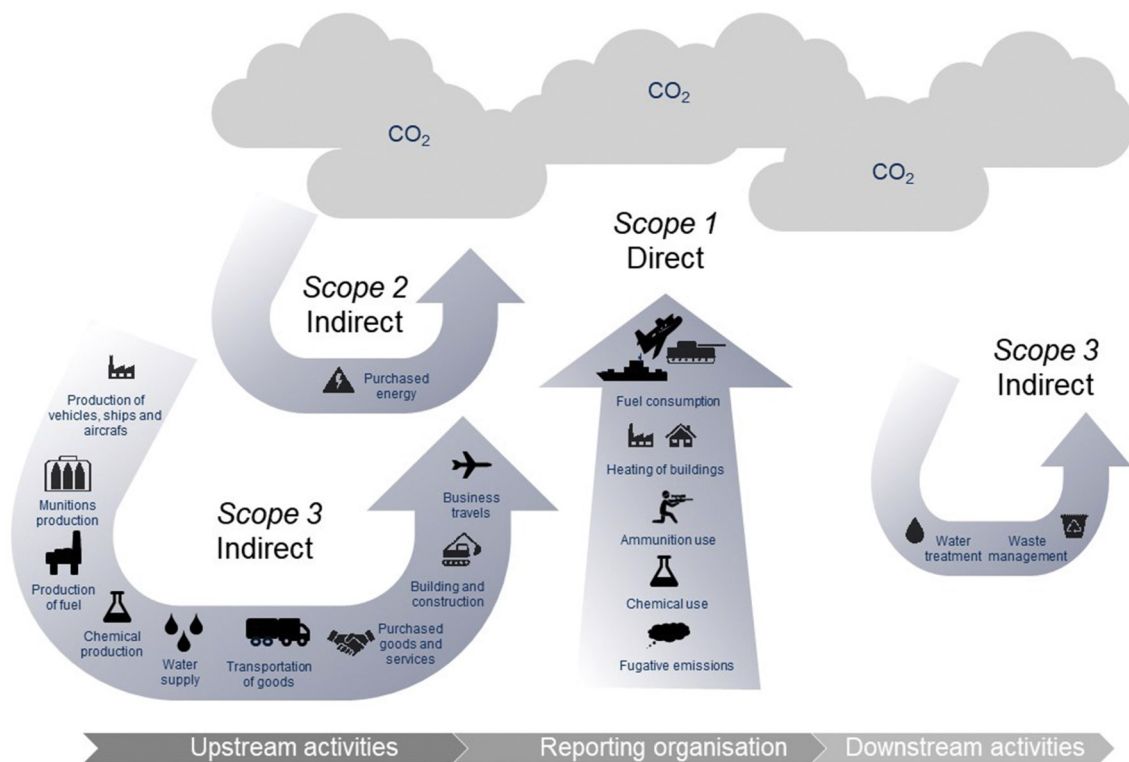


Figure 4. System boundaries are divided into direct and indirect activities and distributed according to the value chain of the organization.

Source: Sparrevik & Utstøl, Journal of Cleaner Production 248 (2020) 119196.

¹²⁶ Dimitrova, Lyons, Losada, Mester, Zusek-Arden, Baudin-Sarlet, and Schmitt. “The Growing Climate Stakes for the Defence Industry”. Boston Consulting Group, 10 September, 2021.

¹²⁷ Turner. “Measuring Greenhouse Gas Emissions in the Defence Sector – a Code of Practice”. 30 November 2021.

Environmental sustainability has been a low priority for most defence contractors. At present, the industry is facing mounting pressures to decarbonize. Compared with other sectors, the global defence industry remains at an early stage of its journey to reduce greenhouse gas emissions. As a result, it is conceivable that the global industry's contribution to worldwide CO₂ emissions could increase from 2% today to 25% by 2050 – unless contractors work more aggressively to reduce their carbon footprints. Contractors that fail to act will face increased pressure from investors and customers, who are placing a higher priority on environmental sustainability in their portfolios. Such companies could incur higher capital costs; they could lose market share or opportunities supply new products and services that will help defence ministries achieve their nations' climate goals.

The defence and security industry is aware of this new challenge. Most leading defence companies have begun efforts to cut what are known as Scope 1 and Scope 2 emissions – those related to their operations and energy usage, respectively. Although these emissions currently account for only a small fraction of defence contractors' total emissions. Contractors have barely begun to curtail the 90% to 95% of emissions that occur outside their direct control: those from the parts and materials they procure, which are referred to as Scope 3 upstream emissions, and from the usage of products they sell (known as Scope 3 downstream emissions). The defence industry is also taking action. Many defence companies are improving their own energy efficiency and reducing GHG emissions, and helping customers to do the same. The notion of greener or socially responsible arms production will seem ironic to many. Several military technology companies do however produce Corporate Social Responsibility (CSR) reports and provide GHG emissions and environmental data¹²⁸. The quality and scope of these CSR reports varies considerably. For example, Lockheed Martin includes the “use of sold products” within its emission data, whilst the data from many other military technology companies is far less complete.

Some technologies offer carbon reductions and military advantages at the same time. Fitting vehicles with hybrid or electric engines reduces the signature from noise, emissions and heat, which means, the vehicles can be far less easy for the enemy to find on the battlefield. Becoming more self-sufficient in deployable bases through renewable energy, recycling water and potentially growing food in vertical farms¹²⁹, all reduces the need for resupply patrols, or logistic supply lines,

¹²⁸ CSR policies aim to guarantee that companies work ethically, considering human rights as well as the social, economic and environmental impacts of what they do as a business.

¹²⁹ Vertical farming is the practice of growing crops in vertically stacked layers. It often incorporates controlled-environment agriculture, which aims to optimize plant growth, and soilless farming techniques such as hydroponics, aquaponics, and aeroponics.

thereby freeing up those troops for other duties, reducing emissions and increasing resilience.

It is essential that militaries measure and report on the emissions from their large and complex supply chains¹³⁰, which are significantly greater than the emissions from military fuel and energy use. Decarbonization includes measuring current emissions, reductions over time and how much can be mitigated by sequestration and other methods. The more any organization decarbonizes, the more reliant on data it becomes. Collecting the data will rely on technological solutions such as sensors. These allow organization to gather and analyze the emissions of everything from brake pads to buildings. Data analytics can at present achieve a level of insight that extends beyond a description of past behavior and instead use data strategically to look ahead at future possibilities. Known as predictive analytics, this new application can help decarbonization by offering updates on key metrics in real time.

2.3 GHG emissions accounting and reporting

Efforts to reduce greenhouse gas emissions, and thus to limit global warming are helped by having accurate information about emission levels, trends, and the policies and measures aimed at improving them. However, reducing emissions necessitates a precise understanding of their sources. This is where greenhouse gas accounting comes into picture. Carbon accounting is the process of calculating GHG emissions. Although there are a number of different GHGs to consider, the term carbon accounting comes from the harmonization of emissions into what is referred to as carbon dioxide equivalents, or CO₂e. To estimate total CO₂e, organizations need to compile operational information like fuel combustion for process or comfort heat, as well as greenhouse gas emissions in the supply chain.

Carbon accounting, also known as a greenhouse gas (GHG) inventory, is the process by which organizations quantify their GHG emissions¹³¹. Quantifying emissions provides insights to organizations so that they may understand their climate impact and set goals to limit their emissions. Policymakers use inventories to establish a baseline for tracking emission trends, developing mitigation strategies

¹³⁰ A supply chain is a collection of corporations that encompasses both forward and backwards flows of information, services, finance, and products from primary suppliers through channel affiliates to customers or end users.

¹³¹ A greenhouse gas inventory is an accounting of greenhouse gases (GHG) emitted to or removed from the atmosphere. An inventory will list, by source, the amount of pollutants emitted to the atmosphere during a given time period (annual emission estimates from a base year to the latest year).

and policies, and assessing progress (Wartmann et al., 2017)¹³². Current carbon accounting and reporting practices remain unsystematic and not comparable, particularly for emissions along the value chain (so-called scope 3 emissions).

National assessments of GHG emissions are compiled by government bodies using the Guidelines for National GHG Inventories published by the IPCC¹³³. All nations that are signatories of the UN Framework Convention on Climate Change (UNFCCC) and the range of protocols and agreements that operationalize it, including the 1997 Kyoto Protocol, and the Paris Agreement, are required to compile such assessments. These are used as a basis for emissions reduction targets. Some governments, including the UK, have started to publish figures for their national carbon footprint.

Reporting emissions requires that a robust system of carbon accounting is in place enabling quantification, monitoring and disclosing of GHG emissions in a transparent method that follows a universally accepted standard. The GHG Protocol arose out of the need to help countries account for, report, and mitigate emissions, based on a report that identified an action agenda to address climate change that included the need for standardized measurement of GHG emissions¹³⁴. It provides accounting and reporting standards, sector guidance, calculation tools, and training for businesses and government. The GHG Protocol establishes a comprehensive, global, standardized framework for measuring and managing emissions from private and public sector operations, value chains, products, and policies. A new universal method for logistics emissions accounting was launched in 2016 in collaboration with the World Resource Institute (WRI) and the Greenhouse Gas Protocol. It is called the GLEC framework (Global Logistics Emissions Council). Voluntary corporate carbon reporting standards and frameworks complement the GHG Protocol with the aim to ensure consistency, reliability, and completeness. Prominent examples are the Global Reporting Initiative (GRI) standards, the Sustainability Accounting Standards Board (SASB) standards and the International Integrated Reporting (IR) framework provided by the International Integrated Reporting Council (IIRC) (Klassen & Stoll, 2021)¹³⁵.

¹³² Wartmann, MRV/GHG Team. “Introducing national greenhouse gas inventories”. In *ClimaEast-Support to Climate Change Mitigation and Adaptation in Russia and ENP East countries*, 28 March 2017.

¹³³ IPCC (2020). Task Force on National Greenhouse Gas Inventories Program, <https://www.ipcc-nggip.iges.or.jp/index.html>.

¹³⁴ Greenhouse Gas Protocol is a common approach to emissions reporting set out by independent bodies, the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).

¹³⁵ Klassen, Stoll. “Harmonizing corporate carbon footprints”. In *Nature Communications*, 12, Article number: 6149 (2021).

Defence departments will encounter challenges when attempting to reduce the emissions for which they are directly responsible because of the primacy of having mission-critical capability. The other reasons also include long equipment life cycles, which means fossil-fueled-powered equipment in use now, or coming into service shortly, will be fielded in 2050. In consequence, a complete elimination of all defence emissions is unlikely by 2050. A net-zero defence force will therefore need to find ways to compensate for these remaining emissions, such as by pursuing offsets in countries with high climate change risk or by pushing for decarbonization beyond their own missions. Without a common approach to reporting, it is not possible to compare between militaries, and it is difficult to judge the performance of countries. While NATO is showing leadership on military emissions reporting, it is vital to find a way working towards a global standard and level playing field for military emissions, as part of a global GHG accounting.

Organizational GHG emissions assessment measures the organization's carbon footprint by quantifying the total amount of greenhouse gases the organization produces, whether directly or indirectly from organization's activities within a set of boundaries¹³⁶. To understand an organization's carbon footprint, the first step is to calculate the emissions linked with the entities activities, also within the supply chain. For this, organizations may choose between four different carbon accounting methods: supplier-specific-; physical unit method, spent-based and hybrid methods.

2.3.1 Key methods of greenhouse gas accounting

Much of the existing research analysis on emissions and climate policy are dominantly based on emissions data provided by production-based accounting (PBA) system. There are mainly two different approaches in measuring human induced GHG emissions: production-based accounting (PBA) and consumption-based accounting (CBA). Territorial or production-based accounting calculates emissions that are generated from the domestic production of goods and services irrespective of whether they are consumed domestically or are exported. The production-based emissions of a nation or organization are those from sources within the national (or organizational territorial boundaries). Such emissions may also include those from sources that are deployed internationally, but are owned by the national government (or organization), for example, military ships and aircraft. National GHG inventories – as discussed below – are the most common form of production-based emissions. However, PBA provides an incomplete picture of driving forces behind these emission changes and impact of global trade on emissions, simply by neglecting the environmental impacts of consumption. To remedy

¹³⁶ Boundary is the limit defining which emissions to include in a greenhouse gas inventory.

this problem, several studies propose to consider national emissions calculated by consumption-based accounting (CBA) systems in greenhouse gas assessments for progress and comparisons among the countries.

The consumption-based emissions of a nation or organization are those that occur as part of the lifecycle of activities necessary to support that consumption. Hence, these activities include extraction of raw materials through manufacture and use to disposal of waste products, regardless of where in the world they happen or who owns them. This approach is argued to be more appropriate in that emissions are assigned to those nations whose consumption is responsible for driving them. This methodology permits the evaluation of those environmental impacts associated with all stages of a product or process. Another is the input-output model, which analyses the interdependence of those industries within an economy. The input-output analysis is a top down model able to take into account transactions between activities measured in monetary units and extend them at the environmental level in terms of GHG emissions. Environmental impact analysis studies' using inter-industry analysis have ranged from analyzing the impact of changes in final demand on energy and the environment, to the study focusing on energy consumption and the environmental impact of international trade. This method has been found to be an effective and widely used method to analyze the indirect CO₂ emissions in the construction industry. Using these methodologies, Berners-Lee (2010) calculated that during the Iraq war (2003-2009) a carbon footprint equivalent to that of the entire UK economy was accumulated in an estimated period between 3 and 8 months.

A recent study was based on the same methodology in order to assess the life cycle of GHG emissions in the Norwegian defence sector (Sparrevik & Utstøl, 2020)¹³⁷. The authors estimated GHG emissions from all Norwegian defence sector activities in 2017, referencing the methodology used by the IPCC to formulate national GHG emission inventories. The classification of these activities is found in table 5. The results attained by Sparrevik & Utstøl (2020) show that the main source of military GHG emissions stem from fossil fuel combustion in military vehicles, ships and aircraft, and represents approximately 50% of all emissions from the Norwegian defence sector. According to data from the U.S. (Belcher, Bigger, Neimark, & Kennelly, 2019)¹³⁸, the main GHG emitter within the branches of the armed forces is the Air Force (over 50% of all emissions), followed by the Navy, the Army and the Marines.

¹³⁷ Sparrevik & Utstøl. "Assessing life cycle greenhouse gas emissions in the Norwegian defence sector for climate change mitigation". In *Journal of Cleaner Production* 248 (2020).

¹³⁸ Belcher, Bigger, Neimark, & Kennelly (2019). "Hidden carbon costs of everywhere war: Logistics, geopolitical ecology, and the carbon boot print of the US military", *Transactions of the Institute of British Geographers*, pp. 1-16.

Table 5. Inventory of the Lifecycle of Operational Activities in the Defence sector¹³⁹

	Type and methodology	Activity	Description
Scope 1	GHGs generated within territorial or organizational limits (also at an international level, provided that they are “owned” by the national government.	Fuel consumption	Use of fossil fuels from military vehicles, ships and airplanes
		Heating of buildings	Emissions from heating and cooling buildings
		Use of munitions	Gunpowder combustion
	Official public sources and annual reports of the companies	Use of chemical products	Decomposition of refrigerant substances in air, water and soil
		Fugitive emissions	Emissions of ozone-depleting substances from heat pumps air conditioning machines
Scope 2		Purchased energy	Purchased and self-produced electricity, and emissions from heating production
Scope 3	GHGs from military activities, but the sources are not owned or controlled by the state/organization.	Vehicles, ships and aircraft	Production of vehicles, ships and aircraft
		Munitions	Production of munitions
	To estimate the carbon footprint, economic input-output models have been developed using military spending data	Fuel	Production of fuel for vehicles and heating
		Production of chemical products	Emissions from anti-freeze production
		Goods transport	Contractors’ services for transportation of military goods, including maintenance
		Suppliers of water	Drinking water used and treated waste water
		Purchase of goods and services	ICT equipment, educational, administrative and economic services. Operating cost of own machines and equipment. Purchase of uniforms, food and various materials

¹³⁹ Scope 1: GHG emissions are related to the use of fossil fuels. Scope 2: GHG emissions, which may be related to energy production. Scope 3: Indirect GHG emissions, which may occur in the supply chain phases. Their contribution to global life cycle emissions are considerable, especially in the military sector. Scopes 1 and 2 are subject to mandatory publishing requirements.

		Buildings and construction	Construction of buildings and infrastructures, including maintenance
		Business trips	Emissions from personal transport with civilian vehicles (air and car transport)
		Water treatment	Consumption of drinking water and treatment of waste water
		Waste processing	The waste products produced in the organization are divided into the recovery of goods, energy generation and elimination

Source: Adapted from article by Sparrevik & Utstøl, 2020 “Assessing life cycle greenhouse gas emissions in the Norwegian defence sector for climate change mitigation”.

Following the CBA based methodology, the organization *Scientists for Global Responsibility* has published two reports on the military sector’s carbon footprint in both the UK and the European Union (Parkinson, 2020, Parkinson & Cottrell, 2021)¹⁴⁰. However, current trends in military GHG emissions levels in the EU are difficult to determine due to a lack of data, and as such the report’s conclusions provide only highly conservative estimates of CO₂ emission levels. Furthermore, the combined GHG emissions of the military, the military technology industry and their supply chain do not appear to have been included in the UNFCCC reports, which served as the basis for the data collection of the “Under the Radar” report, and which would again lead to a significant underestimation of EU military GHG estimates.

To set priorities for decarbonization, defence forces can benefit from categorizing their emissions as those for which they are directly responsible (categorized as Scopes 1 and 2) and those resulting from the full supply chain, including both direct suppliers and sub-suppliers (Scope 3). Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting organization. Scope 3 includes all other indirect emissions that occur in an organization’s value chain. The GHG Protocol splits Scope 3 emissions into two broad categories: upstream (from the organization’s suppliers) and downstream (from whoever buys the organizations goods or services). Basically, the greenhouse gases from burning

¹⁴⁰ The Conflict and Environment Observatory and Scientists for Global Responsibility carried out a study “Under the Radar: The Carbon Footprint of Europe’s Military Sectors” in 2020 which concluded that overall, the transparency and accuracy of GHG emissions reporting within the military sectors examined in the study was found to be low.

fossil fuels are called “downstream” emissions in terms of the production, processing, and transportation of those fuels. Indeed emissions may occur in all life cycle stages and their contribution to the overall life cycle emissions may be substantial (Hertwich and Wood, 2018)¹⁴¹. For these categories, defence related emissions can be further assessed based on whether they are linked to mission critical capabilities¹⁴².

2.3.2 Basic reporting principles of GHG emissions

There are certain direct benefits to any organization in measuring and reporting of environmental performance as it will benefit from lower energy and resource costs. Through understanding organization’s operations it is important to have a clear understanding of where the main environmental impacts occur. These are likely to fall into one or more of six categories: greenhouse gases, water, waste, materials and resource efficiency, biodiversity and emissions to air, land, and water. The present subsection will deal with military GHG reporting, special focus is paid on the basic reporting principles of greenhouse gas emissions.

Military GHG reporting and carbon management must drive whole life GHG reductions throughout military activities and the military supply chain. There are five essential requirements for a GHG reporting framework, namely: to be *relevant, comprehensive, consistent, accurate* and *transparent* as depicted in Figure 6. These principles are intended to underpin all aspects of greenhouse gas accounting and reporting to ensure that the reported information represents a faithful, true, and fair account of an organization’s GHG emissions¹⁴³. Clearly defined principles are essential elements of GHG accounting and reporting guidelines, protocols, and standards to address the unavoidable expert judgements that must be applied to address ambiguities in these documents. For example, the IPCC guidelines identify transparency, accuracy, completeness (time series) consistency, and comparability as it foundational data quality principles. The standard approach to calculating and reporting GHG emissions can be set nationally, for example, in the United Kingdom it is set out by Defra’s Company Reporting Guidelines¹⁴⁴. These in turn are based on the established international approach created by the Greenhouse Gas Protocol.

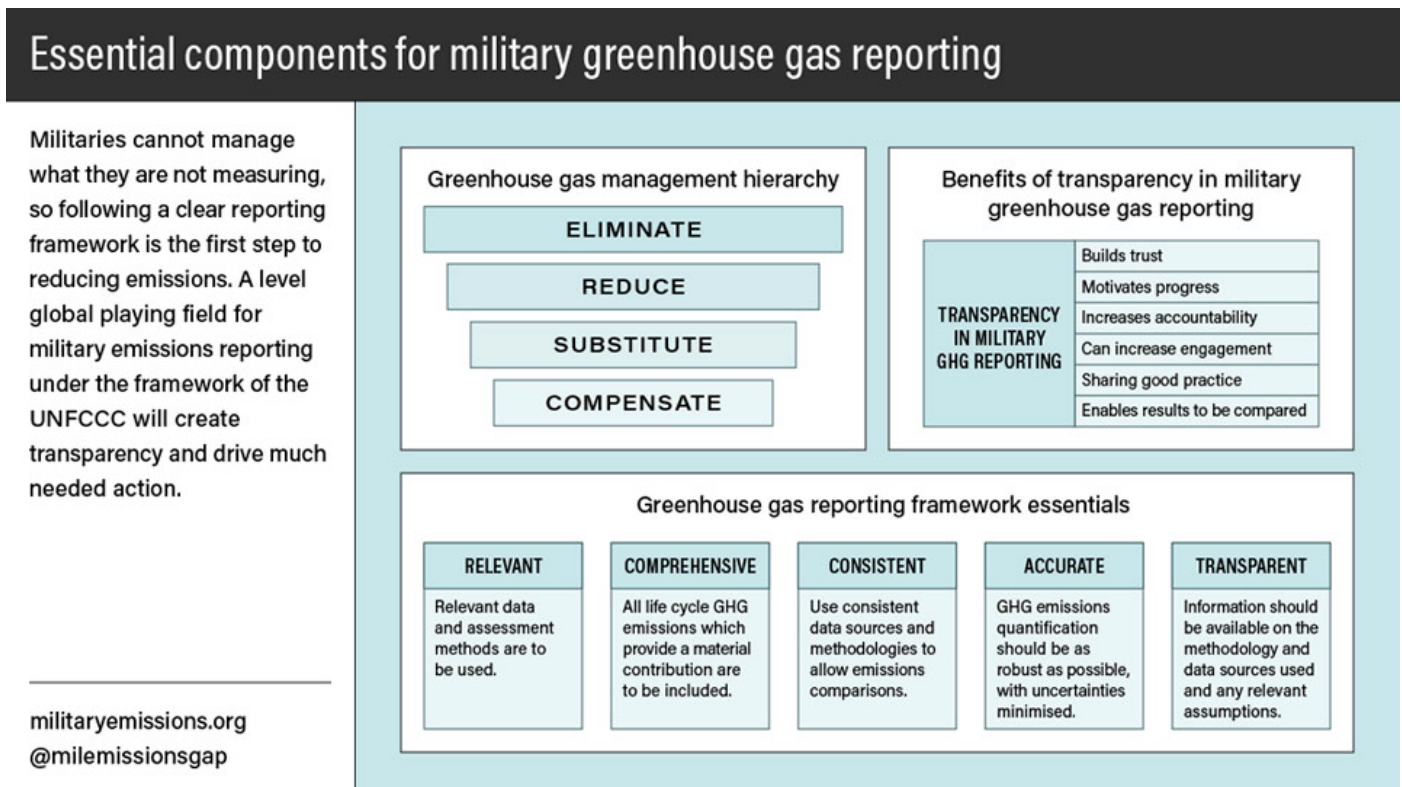
¹⁴¹ Larsen, Hertwich (2009). “The case for consumption-based accounting of greenhouse gas emissions to promote local climate action”. In *Environmental Science policy* 12 (7), pp. 791-798.

¹⁴² Mission-critical capabilities refer to the ability to achieve a desired effect in a specific operating environment.

¹⁴³ World Resource Institute (2021). “GHG Accounting and Reporting Principles”. Standard Guidance, Chapter 1.

¹⁴⁴ Carrot & Sticks (2019). “DEFRA Environmental Reporting Guidelines: Including streamlined energy and carbon reporting guidance”. UK. See also HM Government (2019). “Environmental Reporting Guidelines: Including streamlined energy and carbon reporting guidance”. March 2019 (Updated Introduction and Chapters 1 and 2).

Figure 6. Essential components for military greenhouse gas reporting.



Source: Adapted from “A framework for military greenhouse gas emissions reporting” (Conflict and Environment Observatory, 2022).

The principle of “relevance” is included in most major GHG accounting protocols and standards, but not in the IPCC Guidelines. It helps to ensure that the GHG inventory appropriately reflects the GHG emissions of the organization and serves the decision-making needs of users – both internal and external to the organization. GHG Inventory Boundary is the scope of the assessment in terms of the range of GHG effects (and non-GHG effects, if relevant) sources and sinks, and greenhouse gases that are included in the assessment. An inventory boundary identifies the gases, emissions sources, geographic area and time span¹⁴⁵. It is designed to provide an entity with a comprehensive understanding of where emissions are coming from as well as an indication of where it can take action or influence change.

Similarly, all of these protocols, standards, and guidelines follow the IPCC’s and UNFCCC’s good practice lead for making judgements and include the principles of *accuracy* (i.e. minimization of estimation uncertainties, *completeness* (i.e. avoid-

¹⁴⁵ An entity’s GHG Inventory Boundary may involve: (1) a geographic GHG Boundary; (2) a time period; (3) identifying emissions associated with its operations; (4) categorizing emissions as Direct GHG Emissions and Indirect GHG Emissions; and (5) choosing the scope of accounting and reporting for indirect emissions.

ing omissions and double counting in estimates, and *consistency* in the time series of estimates prepared. All relevant emissions sources within the chosen inventory boundary need to be accounted for so that a comprehensive and meaningful inventory is compiled. In practice, a lack of data or the cost of gathering data may be a limiting factor.

Sometimes it is tempting to define a minimum emissions accounting threshold (often referred to as a materiality threshold) stating that a source not exceeding a certain size can be omitted from the inventory. Technically, such a threshold is simply a predefined and accepted negative bias in estimates (i.e., an underestimate). In order to utilize a materiality specification, the emissions from a particular source or activity would have to be quantified to ensure they were under the threshold. A threshold is often used to determine whether an error or omission is a material discrepancy or not. For cases where emissions have not been estimated, or estimated at an insufficient level of quality, it is important that this is transparently documented and justified. The use of consistent methodologies allow for meaningful comparisons of emissions over time. It is important to transparently document any changes, inventory boundary, methods, or any other relevant factors in the time series. Where methodologies, as more accurate data becomes available, this should be indicated.

Users of GHG information will want to track and compare GHG emissions information over time in order to identify trends and to assess the performance of the reporting organization. The *consistent* application of accounting approaches, inventory boundary, and calculation methodologies is essential to producing comparable GHG emissions data over time. The GHG information for all operations within an organization's inventory boundary needs to be compiled in a manner that ensures that the aggregate information is internally consistent and comparable over time. If there are changes in the inventory boundary, methods, data or any other factors affecting emission estimates, they need to be transparently documented and justified.

Distinct from consistency is the principle of *comparability* between the GHG inventories and estimates for different entities. Comparability is not universally included as a principle across GHG protocols and standards. The IPCC Guidelines for national GHG inventories includes comparability, yet most other major GHG accounting references have neglected this obviously fundamental principle (ISO, 2018, WRI, 2011, 2014)¹⁴⁶.

¹⁴⁶ International Organization for Standardization. "ISO 14064-1", Geneva (2018); World Resources Institute. "Product Life Cycle Accounting and Reporting Standard", Washington D.C (2011); "Policy and Action Standard" (2014).

Data should be sufficiently precise to enable intended users to make decisions with reasonable assurance that the reported information is credible. GHG measurements, estimates, or calculations should be systematically neither over nor under the actual emissions value, as far as can be judged, and that are uncertainties reduced as far as practicable. The quantification process should be conducted in a manner that minimizes uncertainty. Reporting on measures taken to ensure accuracy in the accounting of emissions can help promote credibility while enhancing transparency.

Users of GHG information will want to track and compare GHG emissions information over time in order to identify trends and to assess the performance of the reporting organization. The consistent application of accounting approaches, inventory boundary, and calculation methodologies is essential to producing comparable GHG emissions data over time. The GHG information for all operations within an organization's inventory boundary needs to be compiled in a manner that ensures that the aggregate information is internally consistent and comparable over time. If there are changes in the inventory boundary, methods, data or any other factors affecting emission estimates, they need to be transparently documented and justified.

Transparency should be seen as a meta-principle. Without transparency – through the disclosure of GHG accounting data inputs, methodologies, and assumptions – none of the other data quality principles can express themselves. Unsurprisingly, all major GHG accounting protocols, standards, and guidelines include this principle of principles used in each major GHG reference (IPCC, 2006; ISO, 2018; WRI, 2011)¹⁴⁷. Transparency is especially important for building trust and confidence in the effectiveness of military climate and GHG reductions policies. Regular reporting helps to assess progress towards GHG commitments, and identify where further support is necessary. Transparency efforts are particularly important around military emissions in the context of the historic reticence of some countries to publish data on perceived national security grounds.

¹⁴⁷ “IPCC Guidelines for National Greenhouse Gas Inventories”, Volume 1, Japan, (2016); International Organization for Standardization. “ISO 14064-1”, Geneva (2018); World Resources Institute. “Product Life Cycle Accounting and Reporting Standard”, Washington D.C (2011).

CHAPTER 3

CASE STUDIES ON MILITARY CARBON ACCOUNTING METHODOLOGY

International militaries have set ambitious environmental targets, most noticeably based around radical reductions in energy consumption, reliance on fossil fuels and carbon emissions. Although activities aimed at green transition have been going on in the NATO and EU for some years, this topic has not received much attention. NATO only started seriously addressing a green transition at its 2021 summit and at present there is great interest in reducing carbon emissions from military activities and establishments. For example, the U.S. administration has announced that addressing climate change must be a key element of America's national defence and security policy. The U.S. Department of Defence and the services are continuing to mitigate GHG emissions and enhance energy security through increased electrification, adoption and deployment of electric vehicles, as well as installing microgrids on installations. In the European Union, there is a strong movement towards green transition, including through the European Defence Fund (EDF), which inter alia, focuses on green technologies in the European defence industry.

There are certain countries in Europe, which can be considered frontrunners in this field: Denmark and the United Kingdom. Denmark is a pioneer on green transition when it comes to technological advances and willingness to make supportive political decisions about ambitious targets. For example the Danish Armed Forces are already engaged in the green transition and for years have focused on reducing the consumption of energy. The Royal Danish Air Force could become the first air force in the world to use electric aircraft operationally, depending on the outcome of a two-year trial that started in 2021. Two airframes purchased from electric aircraft manufacturer Pipistrel will help the air force investigate whether the technology can be used operationally. The two-year test out phase of the electric aircraft will help to uncover the maturity of the technology and identify if electric planes could be included as part of the air force's tasks in the future (State of Green, 2021)¹⁴⁸. These efforts are being further strengthened in the Ministry of Defence's "*Green Action Plan 2021-2025*" aimed at supporting the Government's ambition to reduce carbon emissions by 70 percent by 2030 (The Danish Government, 2021)¹⁴⁹.

¹⁴⁸ State of Green. "First air force with electric aircraft". 18 October 2021.

¹⁴⁹ Ministry of Industry, Business and Financial Affairs, Ministry of Defence, Ministry of Foreign Affairs, Ministry of Higher Education and Science (2021). "National Defence Industrial Strategy of the Danish Government: Strengthened co-operation for Danish security".

In the United Kingdom, different sectors within the overall framework of public services have declared their decarbonization plans. Defence sector has emissions in almost every sector of the UK's Net Zero Strategy¹⁵⁰ covering transport through agriculture and industry. For example, emissions from the UK's based estate as measured through the Greening Government Commitments (GGC)¹⁵¹, alone account for 51.5% of Central Government emissions. In its 2020 progress report¹⁵², the UK Climate Change Committee (CCC) suggested that the MoD decarbonize buildings and fleets, and assess the potential for alternative fuels for land vehicles, ships, and aircraft. However, the MoD does not just use energy for heating and lighting buildings, fossil fuels are used to generate electricity (both grid and self-generated) for use to power ships alongside, air traffic and defence radars, digital assets, training simulators and a range of industrial processes. Therefore, the pace at which defence can decarbonize is not only linked to the use of fossil fuel to produce heat but also to the utilization of the building stock and its linkage to the generation of military capability.

As aviation emissions account for three-quarters of UK Royal Air Force (RAF) carbon emissions and half of the Ministry of Defence's footprint, an ambitious strategy has been outlined¹⁵³. By 2025, the RAF intends to have created its first net-zero airbase, with the entire estate net zero by 2030. By 2040, the service intends to be carbon net balanced - 10 years ahead of Defence's scheduled timeframe. This ambition might be prudent given the latest UN reporting, but equally runs the risk of befitting on technology too early, before the science has been proven.

This chapter at first gives an overview of the climate policies in Denmark and the United Kingdom, thereafter the main takeaways from the strategic documents and main initiatives in the defence sector are provided. A special attention is paid to the carbon accounting methods and measures focusing more on military infrastructure, equipment and logistics.

¹⁵⁰ The "Net Zero Strategy: Build Back Greener" (2019) sets out policies and proposals for decarbonizing all sectors of the UK economy to meet the net zero target by 2050.

¹⁵¹ Scope set for MoD Greening Government Reporting for 2015-20.

¹⁵² Climate Change Committee (2020). "Reducing UK emissions: 2020 Progress Report to Parliament". London, UK.

¹⁵³ The strategy is divided into three areas: net-zero aviation, estate and Business-as-Usual.

3.1 Denmark

In recent years, Denmark has steadily emerged as a leader and role model in the global green energy transition. Its greenhouse gas (GHG) emissions since 2010 have been reduced at greater pace than those of the European Union (EU) average. In the 2018 Energy Agreement, the Danish Parliament agreed that Denmark will have net-zero emissions by no later than 2050. This means that the country can only have very few emissions, which must be counterbalanced by an equal uptake of greenhouse gases from the atmosphere. From its highly publicized success in offshore wind, to its ambitious goal of cutting GHG emissions by 70% by 2030 - which would put Denmark as a European and global frontrunner, with only Finland being more ambitious. Given the recent announcements and climate goals set by the European Commission led by Ursula von der Leyen, Denmark serves as an interesting case study for other European and world nations like how to embark on their own energy transitions.

The Danish government has a clear ambition: the country should be independent of fossil fuels by 2050. A key element in fulfilling the target is energy efficiency, along with an increased use of renewable energy. Energy efficiency will reduce energy consumption and it is together with renewable energy and electrification an important element in a cost-effective strategy to meet the long-term objectives. The actual government has set an objective that renewable energy in 2030 shall cover at least 55% of gross final energy consumption. In 2021, Denmark pledged to end oil and gas explorations by 2050, reinvesting those funds into re-training workers for jobs in greener technologies. More recently, the country announced the construction of an artificial island in the North Sea that would house an enormous wind farm, supplying energy and storage for Denmark and other neighbouring countries.

The Danish Climate Act which was adopted in 2020 and amended in 2021¹⁵⁴ sets a target to reduce Denmark's emissions by 70 percent in 2030 compared to 1990 and climate neutrality by 2050. The United Nations' accounting rules are used to calculate greenhouse gas emissions and reductions against the target. The Danish Government's new long-term strategy on global climate action sets the direction for Denmark's international climate efforts. In addition to the energy sector, such as agriculture, transport and industrial manufacturing play a key role in the climate fight, as they account for a large and growing share of resource consumption and global greenhouse gas emissions. Green technologies, energy efficiency, effective use and reuse of resources, new methods of cultivation and production in agri-

¹⁵⁴ The Act was amended in December 2021 to include the emission reduction target for 2025 of 50-54%.

culture, reduced deforestation, innovation and new technologies are all necessary to counteract and adapt to climate change. Establishing circular economy is thus also a core element of the green transition¹⁵⁵.

Closing the gap between current climate change mitigation policies and those needed to deliver on the Paris Agreement's temperature targets requires significant scaling up of policy ambition. Policy action that aims to reach a minimum level of effective carbon prices can increase countries' ability to implement ambitious climate change policies, including carbon taxes and emission trading schemes. Carbon pricing is a tool increasingly used to translate greenhouse gas emissions into a financial cost, and can be used by governments to help reduce emissions and meet climate goals. There are different pricing mechanisms in place such as emissions trading schemes, carbon taxes and internal carbon pricing. They are all related, but each has its own logic to determine the carbon price. Emissions trading schemes – or carbon markets – are part of the toolbox of governments to reduce greenhouse gas emissions. Many other initiatives have followed the establishment of the European Union Emission Trading Scheme (EU ETS) in 2005. Denmark also participates in the EU ETS, which covers power generation and manufacturing industries (26% of greenhouse gas emissions). To reduce carbon emissions even further would require removing an estimated 20 million tons of carbon from the Danish economy. The Danish Council on Climate Change has proposed to introduce a uniform carbon tax across all sectors, which would be the same level for all of the sectors. Under carbon tax schemes, governments set the price of pollution while markets determine the amount of pollution – companies can pollute and pay the tax or reduce emissions to avoid it. While there is general agreement that carbon pricing should be the centrepiece of Denmark's climate mitigation strategy, pricing needs to be effective, address equity and leakage concerns¹⁵⁶ and be reinforced by additional measures at the sectoral level (Batini et al., 2020)¹⁵⁷.

3.1.1 Emissions reporting in the Danish Ministry of Defence – strategic documents and the major initiatives

Building on the Danish tradition for public-private partnerships and recognizing the private sector as a central actor, the Danish government has formed 14 climate

¹⁵⁵ Danish Foreign Ministry (2020). "A Green and Sustainable World: the Danish Government's long-term strategy for global climate action".

¹⁵⁶ Carbon leakage refers to the situation that may occur, if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints. This could lead to an increase in their total emissions.

¹⁵⁷ Batini, Barry, & Wingender. "Climate Mitigation Policy in Denmark: A Prototype for Other Countries". IMF Working Paper 20/235.

partnerships, including defence. The climate partnership on defence, launched in the spring of 2021 would underpin a certain security of supply and thereby increase Denmark's resilience. Overall, this will require harmonizing the approach and prioritizing efforts with resources as well as competences. New types of partnerships will also be required between the armed forces, trade, industry and academia, as many new solutions are developed in the civilian sector. With the war in Ukraine, the need to become independent of fossil fuels and more energy-efficient has taken on a new security policy dimension. For example, in the future, the Danish Defence Forces must use Power-to-X based fuels for propulsion and therefore be linked to current private-sector initiatives to build production and supplies¹⁵⁸. Until the Power-to-X technology matures, they have to test the use of alternative fuels such as biofuels via the advances taking place in the civilian aviation industry and the maritime domain.

Military operations nationally and abroad often have a significant impact on the environment. Oil-based fuels are by far the most dominant energy source for aircraft, ships and land vehicles, as well as for providing electricity and heating, not only for the deployed forces, but also for base installations in the Arctic and other remote locations such as the island of Chrtiansø in the Baltic Sea. Large amounts of diesel fuel and other cargo are often transported to remote and/or dangerous areas, with increased risk to personnel and equipment. By consistently including a green element in planning, execution and evaluation of operative deployments, a reduction in logistical needs and energy consumption is enabled. Consequently, this may lead to significant environmental benefits that ultimately could increase efficiency in the mission areas. Additionally, this may also result in lowering the cost of operations (Danish Ministry of Defence, 2015)¹⁵⁹.

Carbon emissions from the Danish Armed Forces amount approximately 0.5% of Denmark's total CO₂ emissions. Approximately 82 percent comes from propellants, particularly those used by the Navy and the Air Force; 15 percent from buildings; and the remaining approximately 2 percent comes from non-operational transport activities and similar tasks. Today, the overall emissions of the Danish defence sector are approximately 254,000 tons CO₂ e¹⁶⁰.

To date, the Danish Ministry of Defence (MoD) has concentrated its green initiatives within its administrative department, the MoD Estate Agency and the

¹⁵⁸ Power-to-X is a number of electricity conversion, energy storage, and reconversion pathways that use surplus electric power, typically during periods where fluctuating renewable energy generation exceeds loads. It is the umbrella term for both hydrogen electrolysis and a series of steps that can be added to yield products such as green hydrogen, e-methanol, and e-ammonia, among others.

¹⁵⁹ The Danish Ministry of Defence. "Environment and Energy Strategy 2016-2020".

¹⁶⁰ The Danish Government's Climate Partnerships. "Climate partnerships for a greener future".

MoD Acquisition and Logistics Organization, and only to a very limited degree in Defence Command Denmark, the Home Guard and the Emergency Management Agency. Ministry of Defence operative tasks are performed by three agencies: the Defence Command, the Emergency Management Agency and the Home Guard Command. The Defence Command¹⁶¹ is the overall military authority under the MoD and is responsible for the development, formation, and deployment of the MoD's operative capabilities to perform national and international tasks. The Home Guard Command and the Emergency Management Agency play an active role in the general emergency response preparedness. The Emergency Management Agency is a civilian authority under the MoD that works to ensure the robustness of society in case of accidents and disasters and to prevent injury to people and damage to property or the environment. The Home Guard Command is a military organization that makes its capacities, primarily volunteers, available for the entire society. The Home Guard Command supports, as part of the armed forces, other agencies and authorities under the MoD in performing their tasks.

Common for the operative work in the three agencies is that they operate in the land, maritime and air domain on a daily basis at home as well as abroad. Forward operating bases (FOBs) are built and operated under very diverse climatic conditions and with demanding requirements for personnel and equipment. There is a common need for logistical solutions to ensure mobility, flexibility and safety.

3.1.2 Environmental Policy, Energy Management, and Climate Accounts

The Danish Ministry of Defence has had a number of environmental and energy strategies in place since 1993 (Danish Ministry of Defence, 2015)¹⁶². The Defence Ministry's aim is to create improved conditions for environment, nature and climate when performing its core tasks by limiting the amount of waste, achieving lower energy consumption, and by reducing impacts on the surrounding ecosystem, the air and the marine environment. At present, the Defence Ministry has a Green Action Plan 2021-2025¹⁶³, covering initiatives within climate, energy, environment and nature. The MoD is one of Denmark's largest governmental workplaces with more than 20,000 employees and establishments all over the country. The wide range of tasks both in Denmark and abroad requires many resources, affects the environment, and causes greenhouse gas emissions.

¹⁶¹ The Defence Command includes the Army, the Royal Danish Army, the Royal Danish Air Force, the Joint Arctic Command and the Special Operations Command.

¹⁶² The Danish Ministry of Defence. "Environment and Energy Strategy 2016-2020".

¹⁶³ The focus will still be on reducing energy consumption, increasing energy efficiency and work on green transition of the entire organization.

There are many ways to economize energy use, with many technologies and systems available to monitor and reduce consumption. An energy management system is a framework for implementing technical and management strategies that will significantly cut energy costs and greenhouse gas emissions over time. System components include the creation of an energy policy, objectives for improving the efficient use of energy, a timeline with target dates for meeting objectives and an action plan that specifies exactly how the organization’s objectives will be met.

The accentuated importance of energy management has resulted in the introduction of ISO50001 standard on energy management system (EnMS). This standard is designed to support organization in all sectors by providing a practical way to improve energy use, through the development of an energy management system. ISO50001 uses the plan-do-check-act framework, which is also supported by the U.S. Department of Energy. As seen in Figure 7, Plan-Do-Check-Act cycle consists of five clauses i.e. Energy Policy, Planning, Implementation, Monitoring, Corrective Action and Management Review (Eccleston et al., 2012)¹⁶⁴.

Figure 7. Plan-Do-Check-Act



Source: Adapted from the “Energy Management- Plan Do Check Act”. Emerson, Automation Experts Blog (30 August 2016).

¹⁶⁴ Eccleston, March, and Cohen “Developing and Managing an ISO50001 Energy Management System”. Congressional Research Service, 2012.

During the *planning phase*, the organization sets objectives and targets, using current energy efficiency measurements to establish a baseline. During the *do phase*, the organization implements actions to improve energy efficiency. During the *check phase*, the organization measures and evaluates its energy performance and compares the results to its baseline. During the *act phase*, the organization decides what changes to make to improve energy performance.

Efficient and effective energy management¹⁶⁵ is also fundamental to defence sector. Energy management in the building is recognized as one of the critical topics for better sustainability since the fixed installations are responsible for one-third of total energy consumption. Different technological applications help to identify trends, problems, and areas of improvement in energy use. This data helps to establish the energy baseline in order to be able to develop suitable energy efficiency measures that can target Significant Energy Use (SEU)¹⁶⁶ areas, and gathering this data also means that energy reductions from proactive improvements can be quantified.

Since 2012, Ministry of Defence (MoD) publishes its annual overview of the energy consumption and climate impact of the entire organization's activities in the "Carbon Account"¹⁶⁷. The main idea behind developing the climate accounts is to be used actively as part of the decision-making process, such as the choice of actions for emission reductions. With the cut-of-date the end of September every year, the MoD will publish climate accounts for the previous year with an accompanying management report. Based on the climate accounts, the MoD will identify focus area for reducing nitrogen compounds (NO_x), sulphur dioxide (SO₂) and particle emissions (PM₁₀). These emissions are used to describe the emissions of the MoD with the greatest impact on the local environment. Since 2017, it is possible to set percentage targets for CO₂ reductions, while still considering the achievement of maximum operative energy.

These accounts are based on available data but not broken down by activity. The most recent and in English available "Carbon Account 2020" includes two appendixes that provides a more detailed deep-dive into the calculation methods and the reasoning underpinning the use of method (Emissions Factors and Accounting Data)¹⁶⁸. The Carbon Account 2020 also documents that the MoD meets the re-

¹⁶⁵ Energy management is the process of tracking and optimizing energy consumption to conserve usage in a building.

¹⁶⁶ Significant energy uses (SEU) are energy uses identified by the organization as having substantial energy consumption and/or considerable potential for improvement.

¹⁶⁷ The Danish Ministry of Defence. "Carbon Account 2020".

¹⁶⁸ The accounting data can be found in Annex 1 of this study.

quirements of the Circular on Energy Efficiency in the Institutions of the State from the 5th of July 2016. The goal of this circular is to implement government's decision to reduce the national's energy consumption by at least 14% in 2020 compared to 2006, and to reduce state water consumption¹⁶⁹. This is achieved by promoting energy efficiency behavior in government institutions and to ensure energy-efficient operation and maintenance of buildings owned and leased by the State. Reduction of energy consumption should be measured in kWh and include: energy consumption for heating, cooling, including process energy. The Danish Energy Agency publish guidance on the methodology to be used for the calculation of energy consumption.

The Danish MoD use the Greenhouse Gas Protocols as a basis for its carbon accounts. Based on this international carbon accounting standard, the emissions can be divided into 3 scopes depending on how direct influence the MoD has on the extent of the emission. Using this method, it becomes easier to identify, where the potential for improvement is the biggest. Scope 1 contains the MoD's indirect climate impacts including fuels, cooling- and extinguishing agents and individual heating of the estates of the MoD. Scope 1 is the primary source of CO₂ emissions, and it is directly related to the operative activities. Scope 2 is the MoD's indirect climate impacts through purchase of e.g. electricity and district heating. Based on the data (from "Carbon Account 2020) in scope 2, the emissions have fallen despite increased energy consumption. This is due to a reduced fossil warming and cleaner electricity production in Denmark. For example, the MoD's own solar cells contributed in 2020 with a production of 4.3 gigawatt hours (GWh), which corresponds to 3.7 percent of the MoD's total energy consumption. Scope 3 covers the Ministry of Defence' travels, where has been a slight decrease as compared to 2019 due to a declining travel activity.

3.1.3 Data quality

The transformation toward a low-carbon economy and net-zero is challenging, especially when there is a lack of reliable emissions data. Data, artificial intelligence and analytics are key levers to secure and execute the organization's sustainability agenda. It is also an essential lever to build resilience and reduce climate risks by addressing three main objectives: (1) measure to steer progress; (2) improve to reduce impact; and (3) anticipate, adjust the climate action plan. The Danish MoD uses the metrics mentioned below in their Carbon Account 2020 to give an accurate overview of the climate impact of the MoD activities.

¹⁶⁹ CIRH1H no 9477.

Fuels – this category covers the consumption of fuels for the operative branches of the MoD including for aircrafts, ships, operative and administrative vehicles. The Danish Ministry of Defence Acquisition and Logistics Organization is responsible for the procurement and administration of fuels. The consumption of fuel in diesel generators for electricity and heating purposes on sites such as Station Nord and Grønnedal in Greenland, as well as the Danish military camps abroad, are included in the category. The same holds for fuel used for transportation of fuels.

Refueling from the MoD's own fuel system allows for direct registration of fuel consumption of each unit such as a vehicle or an aircraft. This process results in an exact registration of the consumption because the fuel system is digitalized in the MoD's database. Refueling amounts from other suppliers are registered when the MoD receives an invoice about refueling. This might result in minor data inaccuracies and delays in the carbon account, which will be evened out between carbon accounts reports. The emissions from fuels with respect to personal transportation in one's own vehicle, in work related travels, is accounted for in the category "travels".

Cooling and Extinguishing Agents - the Emergency Management Agency reports on its own consumption of cooling and extinguishing agents while the Danish Ministry of Defence Acquisition and Logistics Organization reports on the amount of cooling and extinguishing agents used in the rest of the MoD. The emission calculations of cooling and extinguishing agents are based on the Intergovernmental Panel on Climate Change Assessment Report. It is assumed that all purchases are consumed immediately in this category.

Estate – the Danish Ministry of Defence Estate Agency assess the consumption of energy from the establishments. The majority of the MoD's consumption of electricity is calculated by remote reading and settled according to the actual consumption. The remaining part, which primarily are in cases, where the MoD has rented a part of its' building out to some tenants, are calculated according to a fixed share taking into account, how big as part of the building the MoD is using. The consumption of water and heating is extracted by customer login from the different suppliers' home pages. Afterwards the information is validated by a review of the MoD's consumptions bills. Those places, where electricity is used to heating, either through heat pumps or as direct electric heating, the (heating) consumption will count as a part of the electricity consumption, and not the heat consumption. The reason is, that the input is electricity, but also because the MoD does not have meter data from those places, where electricity is used for heating.

The last available *Carbon Account 2020* was provided through a long manual process by collection of data, which poses a risk of human error in the process. It builds on collection of bills. There is a small chance that there can be a meter that no longer belongs to the MoD. Overall, the data in this category are considered slightly more uncertain than the account of fuels.

Travels – Danish Ministry of Defence Accounting Agency generates an account of travels made in the MoD relying on travels completed in the MoD's digital travel management module. The accounts build on travels converted to person kilometers. Under some travel postings, the economy from the transport is gathered with other travel expenses. It can be additional costs, which are not directly related to the promoted numbers of kilometers. It is not possible to exclude these additional costs, and therefore the account will be higher than the actual consumption. It is assumed that pool vehicles, rented vehicles and private cars in average consume fuel similar to cars in energy class b. It is further assumed, that 75% is on highway, 15% on country road and 10% as city driving. The data in this category is considered of middle quality, because the account is based on a series of assumptions and conversions. The statement is prepared according to the same principles as in previous years. As the calculation method is similar to previous years, the trend in travel activity is considered accurate.

3.2 The United Kingdom

Since 1990, the United Kingdom has reduced its greenhouse gas emissions by 44 percent, while growing its economy by over 75 percent during the same period. The UK was the first country in the world to create a legally-binding national commitment to cut greenhouse gas emissions. This was the Climate Change Act, adopted in 2008, which pledges to cut the emissions as a country by 80 percent by 2050, from 1990 levels. This includes reducing emissions from the devolved administrations (Scotland, Wales and Northern Ireland), which currently account for about 20 percent of the UK's emissions. The Climate Act requires the aforementioned governments to set legally binding carbon budgets, each budget providing a five-year cap on total greenhouse gas emissions. The notion of national carbon budgets is related to, but different from the global carbon budgets calculated by scientists, which estimate the total level of emissions that is still permissible under an agreed climate objective, such as the rise of 2 degrees Celsius above pre-industrial levels.

Carbon budgets are set by Parliament on the advice of the independent Committee on Climate Change. They are set 12 years ahead of time to provide sufficient long-term guidance to investors. So far, five carbon budgets have been set in law, covering the period from 2008 to 2032. The first three budgets (for 2008-23) were set in 2008 and the fourth (for 2023-27) in 2011. The fifth carbon budget was

set in 2016 limiting UK greenhouse gas emissions from all sources to 1,725 MtCO₂ between 2028 and 2032. This is equivalent to a 57 percent reduction in annual UK emissions over this period on average, relative to 1990 levels.

Carbon dioxide has always been the dominant greenhouse gas emitted in the UK. Emissions of CO₂ have reduced by 47% (around 284.3 MtCO₂) since 1990 to 321.1 MtCO₂ in 2020, mainly due to decreases in emissions from power stations (BEIS, 2022)¹⁷⁰. Over half of the decrease in greenhouse gas emissions between 2019 and 2020 was from the reduction in emissions from transport, which were down 19.2 percent (23.5 MtCO₂) due to the large reduction in the use of road transport during the nationwide lockdown. Despite this decrease, transport remained the largest emitting sector, responsible for 24% of all greenhouse gas emissions in the UK.

In 2019, the United Kingdom became the major economy to pass into law a domestic requirement for net zero greenhouse gas emissions by 2050. Since then, it has increased the ambition of its Nationally Determined Contribution (NDC) to align with this long-term target, aiming to reduce emissions to 68 percent below 1990 levels by 2030. The UK has already taken bold steps towards net zero, including bringing forward the end of sales of new petrol and diesel cars to 2030. In 2021, the country released its Net Zero Strategy: Build Back Greener¹⁷¹, which brings together these sectoral plans and makes a range of additional commitments. This new “Net Zero Strategy” sets out for the first time, how the UK Government plans to deliver its emissions targets of Net Zero by 2050 and a 78 percent reduction from 1990 to 2035 (-63 percent relative to 2019).

Action on climate change can be divided between measures to cut carbon emissions and promote cleaner alternatives in energy supply: to support energy efficiency; drive corporate reporting of carbon emissions; and support climate action overseas. For companies in energy-intensive sectors such as power generation, steel, chemicals and ceramics, a major policy measure for reducing emissions is the European Union Emissions Trading Scheme (EU ETS). The UK Emissions Trading Scheme (UK ETS) entered into force on 1 January 2021, replacing the UK’s participation in the EU ETS. Under the Ireland/Northern Ireland protocol, electricity generators in Northern Ireland remained within the EU ETS. It also applies to the same industries, where it is mandatory (energy intensive industries, the power generation sector and aviation). They receive permits to emit greenhouse gases and can trade them at the market rate. In addition to the UK ETS, the UK govern-

¹⁷⁰ Department for Business, Energy & Industrial Strategy (2022). “2020 UK Greenhouse Gas Emissions, Final Figures”. National Statistics.

¹⁷¹ Her Majesty’s Government (2021). “Net Zero Strategy: Build Back Greener”, October 2021. This strategy sets out Government’s long term plan to end the UK’s domestic contribution to man-made climate change by 2050.

ment introduced the Carbon Price Support that requires UK power generators to pay a minimum carbon price, known as the Carbon Price Floor (CPF)¹⁷². This measure is designed to provide an incentive to invest in low-carbon power generation by providing greater support and certainty to the carbon price in the UK's electricity generation sector.

Increasing renewable energy production is one fundamental way that will allow the United Kingdom to meet its binding net zero target by 2050. This in turn, will require revamping climate change policies and promoting “clean” technologies. On the other hand, based on the IEA (2019) report¹⁷³ the global potential for offshore wind alone is several times larger than current world electricity demand, and much of that potential is located in the UK waters. Although the UK has been slow to adopt renewable electricity generation, particularly compared with European neighbors such as Denmark and Germany. To drive uptake of renewables, the government has focused most support on the electricity sector, where the most cost-effective technologies are available. Progress has already been achieved – in 2020, 42% electricity was generated from renewables compared to 41% from fossil fuels. However, if the UK is to reach its goal of net zero low carbon sources will need to account for 100% of electricity generation or fossil fuels must be used in conjunction with carbon capture and storage technology.

In large-scale power generation, Britain replaced the market-based Renewable Obligation¹⁷⁴ with a Contracts for Difference (CfD) scheme, which guarantees a fixed price per unit of low-carbon power generation. The Contracts for Difference (CfD) scheme is the government's main mechanism for supporting low-carbon electricity generation. CfD incentivize investment in renewable energy by providing developers of projects with high upfront costs and long lifetimes with direct protection from volatile wholesale prices, and they protect consumers from paying increased support costs when electricity prices are high¹⁷⁵. Under the CfD, projects compete against each other for support in auctions. “Established technologies” defined as onshore wind and solar power, compete in one auction. “Less established technologies”, including onshore, offshore wind and tidal compete in a second (Black, 2021)¹⁷⁶.

¹⁷² The government has capped the Carbon Price Floor at £18 per ton until 2021. See also Black (2021) “How the UK tackling climate change?” In *Energy and Climate Intelligence Unit*, 18 October 2021.

¹⁷³ International Energy Agency (2019). “Offshore Wind Outlook 2019”.

¹⁷⁴ The Renewable Obligation (RO) is one of the main support mechanisms for large-scale renewable electricity projects in the UK. It places an obligation on licensed electricity suppliers in the UK to source a proportion of their supply to customers from eligible renewable sources. The RO closed to all new generating capacity on 31 March 2017.

¹⁷⁵ Department for Business, Energy & Industrial Strategy (2022). “Policy paper: Contracts for Difference”, updated 13 May 2022.

¹⁷⁶ Black (2021) “How the UK tackling climate change?” In *Energy and Climate Intelligence Unit*, 18 October 2021.

3.2.1 Emissions reporting in the United Kingdom’s Ministry of Defence – strategic documents and the major initiatives

In the UK, climate change is a government priority and the MoD like all UK government departments, must play its part in helping the UK government deliver its climate change program. Global environmental, social and economic pressures pose real threats to defence’s ability to meet its strategic objectives. These challenges will also present new demands on people, infrastructure and equipment. Embracing sustainable development will ensure that defence is prepared for these challenges (adaptation) and that MoD play its part in reducing the severity of any environmental, social or economic threats to defence capability in the first place (mitigation).

The Ministry of Defence includes the UK’s armed forces – the British Army, the Royal Navy (including the Royal Marines), and the Royal Air Force – as well as numerous civilian agencies. In reporting its environmental impacts, the MoD tends to classify its activities into two broad areas:

- *Estates* – which includes military bases (both the UK territory and in other countries), civilian buildings; and
- *Capability and Equipment* – which includes marine vessels (warships and submarines), aircraft (planes and helicopters), and land vehicles (tanks and other armored vehicles)¹⁷⁷.

In May 2020, the National Audit Office published an “Environmental Sustainability Overview on the Ministry of Defence. It gives an overview of the approach taken by the Department to environmental sustainability and the extent to which this supports the government’s long-term objective in this area. The Ministry of Defence’s *Climate Change and Sustainability Strategic Approach (CCSSA)* outlines an ambitious vision as to how Defence will achieve national environmental targets. On first appearance, the CCSSA is ambitious and all-encompassing in scope, making a vast range of commitments and promises. The epochs appear sensible and steady: setting the foundations (2021-25), minimizing and fitting for the future (2026-35), and harnessing the future (2036-2050).

The strategy amplifies existing declarations that UK forces must become far less dependent on fossil fuels. According to the policy paper, the services’ military aviation is responsible for around two-thirds of the department’s fuel consumption; therefore, tackling this element of the armed forces’ emissions is important.

¹⁷⁷ Transport for civilian activities is generally grouped with Estates, while transport for military activities is generally categorized with Capability.

In November 2020, the Defence Strategic Fuels Authority, working in partnership with industry, made changes to the MoD's aviation fuel standards to allow for sustainable fuel blends of up to 50%. While Sustainable Aviation Fuel (SAF)¹⁷⁸ has been performance tested at 100% in basic military aircraft, incorporating these blends into higher-specific airframes will require adaptation to ensure safety; consequently limits remain in place to gain further data. The Defence standard is used by UK civil and commercial airlines and by many NATO countries to influence their choice of fuel.

In addition to SAFs, the MoD's Rapid Capabilities Office is investigating the use of synthetic fuels made from CO₂ and hydrogen using renewable energy in the manufacturing process; these fuels could save 80-90% of carbon emissions per flight (Beard & Ashbridge, 2022)¹⁷⁹. Synthetic kerosene is entirely fossil fuel-free, made by mixing raw materials with higher sugar levels, such as food waste, with bacteria to create an oil substance that is then converted into aviation fuel using chemicals and heat. As the process does not require large-scale infrastructure, synthetic kerosene can be made everywhere, making it an attractive option for military deployments around the world.

Furthermore, the Royal Air Force's Astra campaign to develop the service sets out medium- and long-term goals for infrastructure and training that, if implemented, will markedly reduce carbon emissions. By 2040, ahead of the wider national 2050 target, the aim of the Air Force is to have carbon-neutral estate, which includes bases, infrastructure and accommodation. Additionally, the intent is to shift to far greater use of synthetic environments to supplement and reduce actual training flights. This again, will markedly reduce the consumption of aviation fuel and the associated emissions, and will apply to both land and marine environments. Transport for civilian activities is generally grouped with Estates, while transport for military activities is generally categorized with Capability.

3.2.2. Environmental Policy, Energy Management, and Carbon Measurement

The UK Government is tackling environmental issues in public sector activities through what it calls Greening Government Commitments (GGC). These set out the actions government departments and their agencies should take to reduce their impact. Since 2011, Departments of central government within the UK have been required to report their carbon emissions under the Greening Government

¹⁷⁸ Sustainable Aviation Fuels (SAF) are defined as renewable or waste-derived aviation fuels that meet sustainability criteria. As it is produced from sustainable feedstocks, it is very similar in its chemistry to traditional fossil jet fuel.

¹⁷⁹ Major Beard & Dr Ashbridge. "Greening Defence: RAF Ambitions in Search of Jet Zero". Royal United Services Institute (RUSI), Commentary, 28 June 2022.

Commitments (GGC). The Department of Defence achieved its Greening Government Commitments (GGC) target for reducing carbon emissions in 2018-19, reporting 830,000 tons of greenhouse gas emissions – a 42% reduction since 2009-10¹⁸⁰. For example, new commitments have been set out for the period from 2021 to 2025. They include targets to reduce water consumption, reduce greenhouse gas emissions, minimize waste and promote resource efficiency. They also set out commitments for departments: to improve sustainable procurement, develop and deliver Climate Change Adaptation Strategies and reduce environmental impacts from ICT and digital services.

The UK defence sector's environmental impact is significant due to the number of weapons, vehicles, aircraft and ships, as well as natural resources used. An Energy Management System (EMS) is the best way to both protect the environment and maintain operational readiness. The UK's MoD is a large organization whose activities inevitably affect significantly on the environment. An adequate response to those issues requires a robust and methodological approach to identify potentially significant environmental impacts at the earliest possible stage in the acquisition cycle. Such a process helps procurement teams to design out environmentally damaging and unsustainable features (using processes such as a Design for the Environment and Best Practicable Environmental Option) and to procure package switch service (PSS) with fewer impacts through life.

Design for the Environment (DfE) is the process of investigating the possible environmental impacts of a product and refining the product design as necessary to reduce or negate the potential impacts. A product may harm the environment by containing non-renewable resources, or creating hazardous by-products through its consumption. For example, improper disposal of electronics can leak lead, nickel, cadmium, and mercury into water supplies (Lindahl, 2005)¹⁸¹. On the other hand, the Best Practicable Environmental Option (BPEO) is the idea that there is a unique, supremely beneficial – or least environmentally damaging – method of disposing wastes in a cost-effective manner, in both the short- and long-term. Based on the example of the UK defence company Thales, products and services within the defence industry also have a role to play by incorporating eco-design principles into products and seeking environmental applications for existing products (e.g. trialing military-grade surveillance cameras on unmanned surface vessels from an autonomous counter mine program so they can inspect wind turbine blades as they

¹⁸⁰ GGC reported emissions cover government departments' estates and vehicle use. Other defence emissions cover defence activity out of GGC scope, such as fuel use as part of defence operations.

¹⁸¹ Lindahl (2005). "Designers' Utilization of and Requirements on Design for Environment (DfE) Method and Tools". In *Fourth International Symposium on Environmentally Conscious Design and Inverse Manufacturing, 2005*. Eco Design 2005, pp. 224-231.

rotate). The recently released Defence Capability Framework (2022)¹⁸⁰ for the first time, gave the defence industry a very clear indication on future capability acquisition plans from the MoD. There is an opportunity to go further and link up the capabilities required to their “Climate Change & Sustainability Strategy”. Among drivers of electrification in the defence market, modernization and concerns over energy security has been key. These concerns have increased the pressure on defence companies to develop novel solutions with more eco-friendly credentials without sacrificing critical capabilities. By 2025, it is expected that MoD will implement appropriate weighting to low carbon options and sustainability in the acquisition process. This should incentivize industry to offer whole life carbon solution for new equipment while also exploring lower emission modifications existing capabilities.

While each service will seek to reduce carbon emissions in its own sector, the MoD estate offers the greatest short-term potential given that domestic infrastructure is the third largest carbon-emitting sector in the UK. Promisingly, both the MoD estate and its users are broad, and a variety of approaches can be adopted to reduce emissions. The most understood solution lies in renewable energy such as solar and wind, where industry already possesses cost-effective technology. A further opportunity for quick gains exists in the renovation of an aging housing stock and retrofitting it with greener technologies. Examples such as draught-proofing houses or modernizing heating systems improve energy efficiency, reduce the usage of gas and electricity and decrease the need to construct new accommodation. This last point is key in reducing carbon emissions; it is estimated that 51 percent of the life-cycle carbon from a typical residential development is emitted during construction.

Finally, not all projects involve new technology. The rewilding of some parts of the MoD estate – that is, the restoration of land to its natural state – has already proven popular with the general public. Rewilding offers benefits for biodiversity, water quality, and health and carbon sequestration while reducing flood risk. Though the proposed changes to the estate are relatively low-key compared to projects like vehicle electrification, they utilize existing technology, meaning they are relatively cheap to implement and will reduce emissions quickly. If the methods described were rolled out *en masse* across the MoD estate, the environmental impact would be significant, rapidly reducing carbon output and providing financial savings with minimal impact on Defence output. In contrast, it will take time to develop suitable technology for the electrification of operational platforms, and the rollout will be financially expensive. Defence can begin to transform its estate instantly through the utilization of existing methods that do not require military con-

version. This is a cost-effective and efficient approach to achieving climate change and sustainability targets (Asbridge & Beard, 2022)¹⁸³.

Similarly to the public sector, Greenhouse Gas emission measurement in the UK defence sector follow the Greenhouse Gas Protocols. Within the MoD's Annual Report and Accounts, a more comprehensive emissions footprint is given. It is built on previous Greenhouse Gas Protocols reporting and captures new emissions areas (fugitive emissions, employee commuting and emissions from waste) as well as worldwide estate energy use and fuel consumption in operations, domestic and international travelling.

The Department of Defence is, therefore, not starting from scratch, but the emissions reported under GGC are only a subset of the whole life cycle emissions that should be captured. It is recommended that the development of a fit-for-purpose baseline and measurement system to capture and track all the relevant emissions be a priority within the next 12 months (Ministry of Defence, 2021)¹⁸⁴. With the exception of greenhouse gas emissions, the targets are aggregate central government targets and no bespoke minimum performance targets for individual departments. However, the Department' of Defence energy mix had not changed significantly over the past 10 years and it has made little progress in increasing the proportion of its energy drawn from renewable sources. Additionally, 1.8 million tons of emissions from military activity, such as operating defence equipment, fell outside the scope of the GGC targets¹⁸⁵.

3.2.3 Data quality

The United Kingdom has one of the best track records in reporting its military carbon emissions. Since 2012, it has published data for direct emissions in the annexes of Ministry of Defence (MoD) reports. MoD's annual progress and performance against the Government Policy requirements, Greening Government Commitments and MoD's contribution to the United Nations Sustainable Development Goals are integrated into the MoD's "Annual Report and Accounts"¹⁸⁶. The MoD currently reports on its GHG emissions in a section of its annual report

¹⁸³ Dr Ashbridge & Major Beard. "Greening Defence: the UK Armed Forces Strategic Approach to Climate Change". Commentary in RUSI, 04 March 2022.

¹⁸⁴ Ministry of Defence/Team Defence Information (2021). "Roadmap for Sustainable Defence Support".

¹⁸⁵ Department for Environment, Food & Rural Affairs (2021). "Greening Government Commitments 2021 to 2025". Policy Paper, 28 October 2021.

¹⁸⁶ The Annual Report and Accounts consists of a Performance Report, an Accountability Report and the Annual Accounts, providing detail on defence activity. The most recent report available covers the time period 2020-2021.

titled “Sustainable MoD”¹⁸⁷. More recently, in its 2020-2021 annual report, the UK MoD listed its military’s total emissions at 2.144 million tons of carbon dioxide equivalent. The same year, its emissions were higher than its carbon impact in 2017/2018, which was 2.109 million tons. The UK Ministry of Defence collect information about its energy use from the main utility meters (electricity, gas and water) at the end of each day. The continual capture of data allows monitoring, how much energy and water is used each day, week and month.

The size and range of the Department of Defence’ activities make its performance vital to government meeting its’ environmental targets, particularly the Greening Government Commitments. For example, in 2017-18, the MoD was responsible for half of the greenhouse gas emissions reported by the central government. Ministry of Defence has also significant sustainability impacts outside the scope of the GGCs. For example, emissions associated with operating and supporting armed forces’ equipment around twice as high as those reported through the GGCs. In addition, over one third of the MoD’s estate is made up of sites of special scientific interest, covering a larger area than those of any other government body (National Audit Office, 2020)¹⁸⁸. These sites are the UK’s very best wildlife and geological sites, covering a range of important wildlife habitats and species from wetlands and rivers, to remote Moorland and peat bogs, to flower-rich meadows.

Table 8. The Ministry of Defence’s significance in meeting the Greening Government Commitments targets in 2020

Area of GGCs	Proportion of total government GGC impact attributable to the MoD (2017-18 (%))	Proportion of the government’s reduction from 2009-10 to 2017-18 attributable to the MoD (%)
Water use	66	58
Waste	56	56
GHG emissions	50	41
Paper use	27	7
Domestic flights	20	11

Source: UK National Audit Office analysis of Greening Government Commitments Annual Report 2017-18 (2020).

¹⁸⁷ “Ministry of Defence Annual Report and Accounts 2020-21”.

¹⁸⁸ National Audit Office (2020). “Environmental Sustainability Overview – Report – Value for money”. 13 May 2020.

UK Ministry of Defence is highly selective of the data it publishes on its environmental impacts within its annual reports¹⁸⁹. In particular, figures for total direct GHG emissions are no longer reported in the main text of the report. It can be expected that the figures that are included in the main text of the Ministry of Defence Annual and Accounts report cover less than one-third of the MoD’s total direct GHG emissions. With regard to the greenhouse gas emissions, in the main text of the MoD report, the figures discussed only cover Estates (including business travel) and not Capability and Equipment, the latter only being revealed in an annex and only for two years behind the reporting year. The disclosed figures indicate that the GHG emissions of Capability and Equipment are over 60 percent of the total for the whole MoD (Scientists for Global Responsibility & Declassified UK, 2020)¹⁹⁰.

For example, the report by Scientists for Global Responsibility (SGR) and Declassified UK (DUK) “The Environmental Impacts of the UK military sector” (2020) concluded that the carbon footprint of British military spending is 11 million tons of carbon dioxide equivalent that is more than 11 times the figure the Ministry of Defence usually highlights when discussing the British military contribution to global heating – and is similar to the emissions produced by over six million average UK cars in a year. In the assessment of GHG emissions the authors of the abovementioned report have compiled the available data from the Ministry of Defence which obviously includes the British armed forces – as well as from businesses that operate in the UK supplying weapons and other military equipment. The estimation of the military also includes the overseas supply chain. Although the authors of the report managed to collect significant amounts of data, but there were notable gaps, and a number of assumptions had to be made in order to make estimates of total GHG emissions levels.

Table 9. Estimate of total GHG emissions of the Ministry of Defence, 2017-18

Category	GHG emissions (thousand tCO ₂ e)
Estates:	
MoD reported level (80% of estate)	942
MoD unreported level (20% of estate)	236
International business travel	40
Capability and Equipment:	
Aviation fuel	1,165
Diesel	5,44
Gas oil/petrol	98
Total	3,025

Source: Scientists for Global Responsibility, Declassified UK (2020). “The Environmental Impacts of the UK Military Sector”.

¹⁸⁹ An example of an accounting data is found in Annex 2.

¹⁹⁰ Scientists for Global Responsibility, Declassified UK (2020). “The Environmental Impacts of the UK Military Sector”.

The Department of Defence has access to one of the largest estates in the country, accounting for 1.5% of the UK landmass. Its estate is crucial to delivering the country's defence capability and it must also retain flexibility so that it can respond to changes in operational requirements and evolving security threats. In 2019-20, it spend £ 4.6 billion (12% of its budget) on its estate (National Audit Office, 2022)¹⁹¹. It is expected that military sites are often isolated and require their own power generation, meaning a smaller proportion of the MoD's energy generation is supplied by the national grid. The MoD's energy mix is one-third grid electricity and two-thirds gas or oil, and the proportion has not changed significantly since the introduction of the GGCs. Therefore, there could be significant opportunities for the MoD to further reduce its emissions through adjustments to its energy mix, such as through increased use of solar panels. The MoD does not have a target for the proportion of energy to be delivered from renewable sources. Its estates' rationalization program, which aims to reduce the built estate by 30 percent by 2040, will also contribute further to reductions in the defence estate's carbon emissions (National Audit Office, 2020)¹⁹².

Based on the findings of the UK's National Audit Office, Ministry of Defence has made limited progress in improving the energy efficiency of its buildings. Since 2016-17 only 38 percent of the MoD's new-builds and major refurbishment projects had low- or zero-carbon technologies included in the design. The MoD is in the early stages of several infrastructure initiatives, which seek to address the energy efficiency of the estate, although it is too early to judge the effectiveness, scalability and cost savings of these initiatives. Ministry of Defence has an internal target to reduce energy consumption by 10% between 2017-18 and 2025-26. It is undertaking several infrastructure initiatives, which seek to address the estate's energy efficiency. These are at an early stage and it is not yet possible to judge their effectiveness, scalability and cost savings.

The Government's net zero emissions target will present a significant challenge for defence and will be considered as part of the Integrated Review. Government has legislated to set a target for the UK to have net zero greenhouse gas emissions by 2050. It has not yet decided whether Ministry of Defence and the agencies in its administrative area will be required to meet the net zero target, or whether the residual emissions will be offset elsewhere. Switching to renewable energy and prioritizing projects that reduce emissions are pivotal to implementing a

¹⁹¹ National Audit Office (2022). "Department Overview 2020-2021", the Ministry of Defence".

¹⁹² National Audit Office (2020). "Environmental Sustainability Review". Report – Value for money, 13 May, 2020.

climate strategy aligned a 1.5 degrees Celsius pathway. However, some limited emissions may remain unavoidable. Those should be addressed via carbon compensation programs, ranging from purchasing voluntary carbon credits to investing in early-stage carbon offsetting projects.

Either choices will require the sector to make major changes to its equipment and estate. Almost all vehicles and weapons in use, or under procurement, rely on fossil fuels, and some of the largest are expected to still be in operation in 2050. These are considerable opportunities to use MoD land for initiatives such as the installation of renewable technology, notwithstanding its existing plan to reduce its built estate by 30% by 2040.

Capability and Equipment

Military activities, such as the operation of defence equipment (including for land vehicles, aircraft, and navy vessels) by the armed forces, are out of scope for the GGCs, yet have a significant impact on the environment. Greenhouse gas emissions from these activities are double those reported through the GGCs, yet they are reducing at a slower rate and are not subject to formal targets. MoD plans to take the opportunity of its upcoming Integrated Security, Defence and Foreign Policy Review to develop wider targets to support government's legislative commitment to net zero greenhouse gas emissions by 2050. Ministry of Defence plans to examine the issue of how to maintain military capability while delivering net zero emissions in the government's ongoing Integrated Review. Based on the National Audit Office data, front-line Commands used 666 million litres of fuel in 2018-19 equating to 1.8 million tons of carbon equivalent greenhouse gas emissions. Military operations provide support to civil authorities in response to environmental crises.

The government's Road to Zero Strategy sets an ambition for 25 percent of the government car fleet to be ultra-low-emission vehicles (ULEVs)¹⁹³ by 2022 and 100% by 2030. At present, only a small proportion of the military sector's vehicles are low emission, meeting the government's target will require the procurement of 1,700 ULEVs by December 2022, equivalent to 2.7% of all ULEVs registered.

To sum it up, carbon effective measuring can rely on data that has laid the foundation to actively manage sustainability targets. Based on the strategic objec-

¹⁹³ A vehicle is currently classified as low emission vehicle (ULEV) if it has CO₂ equivalent emissions of less than 75g/km. This also includes electric vehicles. The only ULEVs procured were 11 in 2017 and 2 in 2018, of which 12 are still in use (two hybrid vehicles and 10 electric). By 2022, the government expects a ULEV to be defined as a car that emits less than 50g/km.

tives stated in the “*Climate Change and Sustainability Approach*” by 2025, data management at the MoD has been realized through a single source data architecture managed from within head office which is recognized as best-in-class by partners and allies. This also means that the defence sector will adopt best practice in corporate CO₂ data governance, which leads to a standardized methodology adopted across the sector. Another key feature is establishment of a single data-dashboard, which can dynamically track and monitor mandated GGC and Defence sustainability indicators. An Energy data dashboard is an information management tool used to track, analyze and display key performance indicators, metrics and data points. A dashboard transforms the raw data into something human-readable. Instead of sifting through columns or rows in spreadsheet, it is possible to analyze relevant data in a table, line chart, or a bar chart.

CHAPTER 4

POTENTIAL FOR GREEN TECHNOLOGIES IN THE DEFENCE SECTOR

Sustainability has become a key driver for policies, economies and societies at large. At the same time, there is an intrinsic, but often neglected link between sustainability and defence. The environment and its ongoing sustainable management is a critical enabler of defence capability. Currently, most of Europe's military equipment is optimized for operational advantage, with little consideration paid to sustainability issues such as emissions. Whilst many of Europe's planned equipment acquisitions appear to continue in this mode, the defence industry has begun to explore emerging "next generation" greener technologies. These technologies could reduce emissions and provide useful options for balancing military effectiveness with improving climate resilience and establish new, imaginative concepts for future warfare.

Investing in climate innovations such as biofuels and other emerging technologies is in the militaries best interest – directly, as it provides warfighters with solutions that address important facets of the operational environment, and indirectly, by catalyzing and giving the military increased national economic power. For example, extreme weather and rising sea levels are increasing the concrete degradation rate. To keep runways and piers mission-capable, the military is investing in innovative solutions to this problem, such as self-healing concrete. The Defence Advanced Research Projects Agency (DARPA) plans to develop a bio-inspired "self-repairing" technology for deteriorating concrete structures. The capability will reportedly be integrated deep within aging military facilities such as missile silos and airfield pavement to extend their usability (Saballa, 2022)¹⁹⁴.

However, it is worth mentioning that such innovations are not limited to resilience. New missions can also spark transformational innovations. For example, rising sea levels may offer increased opportunities for submarine-based intelligence collection along coastlines. Such missions will prioritize stealth above other considerations, perhaps making air-independent propulsion systems (which rely on energy-efficient fuel cells) even more useful than nuclear propulsion in some cases. With more investment, such technologies could develop into forms that may provide cheap, clean energy in small packages to the wider world.

¹⁹⁴ Saballa (2022). "DARPA to Develop "Self-Repair" Capability for Military Structures". In Defence Post, 08 June 2022.

The majority of a military's carbon footprint is from vehicles and platform systems consuming fossil fuels. Land vehicles should be the easiest to convert, with the transition to renewables well underway in the civilian sector (although slower progress has been made with heavy vehicles). Maritime, air and space forces face more significant issues due to their inherently larger platforms. Options to significantly reduce emissions include sustainable mobility (the use of alternative fuels, alternative propulsion systems and improving fuel efficiency), unmanned platforms and synthetic training.

Global concerns over the impacts of climate change are driving innovation throughout the defence industry as militaries continue to pursue the electrification of vehicle fleets, with numerous major aerospace and defence companies investing proactively in emerging technologies. For example, the naval equipment designers *Saildrone* has developed unscrewed surface vehicles (USV) powered by renewable solar and wave energy. Saildrone's wing technology enables the USV to complete missions with a duration up to 12 months without the need for refueling or returning to land for maintenance, with an average speed between 2-6 knots, allowing it to reach most ocean locations within 30 days.

Due to their greatly reduced thermal and noise signatures when powered by batteries, electric cars can allow stealth mode capabilities that are more effective. Enhancing land-based electrification capabilities can also imply taking a step toward autonomous or semi-autonomous operations and better situational awareness via upgraded sensors. In addition to being good for the environment, using electric or hybrid propulsion can improve operating capabilities. Hybrid-electric propulsion vehicles have been the focus of programs in the U.S. and the UK, with the U.S. Army developing such platforms as the new M1A2 Abrams X main battle tank and the Joint Light Tactical Vehicle (JLTV) light armored vehicle. The British Army has companies including Supacat, General Dynamics and Magtec collaborating to produce hybrid-electric variants of the Jackal High Mobility Vehicles and Foxhound armored vehicles. Boeing has invested £ 370 million in the Wisk joint venture focused on electric Vertical Take-off and landing (eVTOL) platforms (Salerno-Garthwaite, 2022)¹⁹⁵.

Assuming that green hydrogen and a low carbon electricity grid is available, electrification together with hydrogen offer environmental benefits and potential operational gains in terms of signature reduction. Although there will be some limitations from the time frame for implementation. The reality is that electric and hydrogen will not be suitable for all types of platform within the near to medium

¹⁹⁵ Salerno-Garthwaite. "Environmental pressures are reshaping the defence industry". In *Naval Technology*, analysis, 12 November 2022.

term (next 30 years). There are clear areas where it is possible to achieve results more quickly. For example, Thales uses advanced flight simulators to reduce the need for live flying by 90%. Quantum computing, artificial intelligence and edge processing are among emerging technologies that will reduce the environmental impact computing in defence, lowering electricity use and reducing inefficiencies.

To sum it up, climate change will affect the military in many ways, including the need to decarbonize the Armed Forces themselves. Decarbonizing a military is an operation that does not have a long-established body of knowhow. The Defence Ministries would benefit both themselves and global military decarbonization efforts by setting up platforms to enable ongoing research and development and increase the knowledge base. This could be done in partnership with other militaries, for example from NATO countries.

The present chapter will explore different technological options for defence sector to become more environment friendly. It will also focus on NATO Single Fuel Policy and the evolution of alternative fuels including synfuels.

4.1 NATO Single Fuel Policy and alternative fuels

The aim of the Single Fuel Policy (SFP) is to maximize equipment interoperability through the use of a single fuel, namely F-34, on the battlefield for land based military aircraft, vehicles and equipment (NATO Logistics Handbook, 1997)¹⁹⁶. In 1986 agreement was reached on a common aviation turbine fuel for land based military aircraft, F-34 to replace F-40. A further development has been a reduction in the use of gasoline as NATO member-states phase-out gasoline-driven equipment in favor of diesel engines. Such a trend is not occurring at a uniform rate as this depends on national procurement policies for new military vehicles and equipment. The logistic benefits of a single fuel on the battlefield, and in out-of-area peace-keeping missions, are numerous, but a major benefit is a simplification of the fuel supply chain. Single Fuel Policy also ensures that the physical and chemical characteristics of the fuel are such that it can be introduced, stored, produced, transported and distributed by the fuel logistic systems.

Concerns over climate change, the finite nature of oil reserves, and concerns over security of supply from the oil producing regions have triggered a broad effort in the search for new sources and conversion processes for the production of alternative fuels. The increasing availability of liquid alternative fuels, and their mix-

¹⁹⁶ “NATO Logistics Handbook”, Chapter 15: Fuels, Oils, Lubricants and Petroleum Handling Equipment (1997).

ing with conventional petroleum distillate fuels, have led to the need for the military to more closely study and mitigate any negative effects of the introduction of such fuel blends on their systems (air, land or naval) as well as operational procedures. For these reasons, alternative hydrocarbons will also need to meet the standards set by NATO’s Single Fuel Policy (SFP). Options include blended and non-blended biofuels and synthetics. In the maritime domain, biofuel options include straight vegetable oil (SVO), biodiesel (first and second generations), biogas, bio-hydrogen and lignocellulose-based bio-oil. These are not new technologies and have been experimented within both the military and commercial sectors. For example, a Fischer Tropsch biofuel blend was tested on five U.S. Navy vessels on the Rim of the Pacific Exercise as early as 2012.

Biofuels are already playing an important role in civilian road transport with relatively good performance achieved by so-called “non-drop-in” solutions, which are fuels which require adaptation or special treatment to the engine fuel systems. However, it is unlikely that biofuels will continue to advance progressively on a global scale, given the disparity of available feedstock and development limited to a few countries such as Brazil and the U.S., although Australia, Canada, China, India and the EU have significant potential. Biofuels will need to guarantee environmental sustainability in the production chain, without competing with food production; be cost-competitive; achieve the necessary fuel quality and perform in engines comparably to fossil fuels; and meet NATO’s SFP standards. The lack of a “drop-in” solution without reduced performance, and access to appropriate biomass at scale, make such alternatives less useful in a military context. For this reason, biofuels are likely only to be a partial answer.

Table 10: Alternative fuels definitions

Drop-in Alternative Fuel	Non-drop-in Alternative Fuel
An alternative fuel that is completely interchangeable and compatible with a particular conventional (typically petroleum-derived) fuel. A perfect drop-in fuel does not require adaptation of the fuel distribution network or the vehicle or equipment engine fuel systems, and can be used “as is” in vehicles and engines that currently operate on that particular fuel. Some alternative fuels may become “drop-in” only after blending with conventional fuel to a certain prescribed proportion.	An alternative fuel that is not completely interchangeable and compatible with a particular conventional (typically petroleum-derived) fuel. A non-drop-in fuel requires adaptation of (or special treatment within) one or more components of the existing fuel distribution network or the current fleet or vehicle and equipment engine fuel systems. Some alternative fuels must be carefully segregated from conventional fuels, while others may be safely blended with conventional fuels. Some alternative fuels may remain “non-drop-in” even after blending with conventional fuel.

Source: Adapted from the study: “Green Defence: the defence and military implications of climate change for Europe” by the International Institute for Strategic Studies, 2022.

The use of synthetic fuel is likely to be a better option. These are liquid fuels that basically have the same properties as fossil fuels but are produced artificially. A great advantage of synthetic fuels is that they can be tailored to superior properties in several respects, such as thermal stability (enhanced heat sink potential), freezing point (improved operability at higher altitudes), flash point (improved safety), reduced propensity to soot (infrared and smoke signature reduction) and energy density (range and payload characteristics). Gasification of “low quality” (cheap) primary fuels, biomass or even waste (e.g. refinery residues), and in some cases also the reforming of “high quality” fuel, natural gas is used for generation of so-called syngas. Syngas from gasification (after cleaning) contains about 25-50% hydrogen (H₂) and 35-65% carbon monoxide (CO), as the combustible components. The name syngas is related to the initial typical use for chemical synthesis of basic chemicals (methanol, ammonia, etc.) as well as synthetic liquid fuels (Fischer-Tropsch). The Fischer-Tropsch process¹⁹⁷ is a collection of chemical reactions that converts a mixture of carbon monoxide and hydrogen, known as syngas, into liquid hydrocarbons. These reactions occur in the presence of metal catalysts, typically at temperatures of 150-300 degrees Celsius and pressures of one to several tens of atmospheres. Besides the reforming of natural gas, which is only applied for chemical synthesis, syngas is typically generated in gasifiers by partial oxidation of carbon containing solid or liquid feedstock. In order to reduce the gasifier size and the typical requirement of a pressurized syngas, the gasification is done under elevated pressures. Typical pressure levels are about 20-80 bar, depending on the process type and feedstock.

At present, there are three methods for the production of renewable syngas: (1) biofuels, which are produced from biomass, (2) e-fuels, which are produced with renewable electricity, and (3) solar fuels, which are produced with solar heat. That is why these three methods are sometimes also referred to as “*Biomass-to-Liquid*”, “*Power-to-Liquid*”, and “*Sun-to-Liquid*”. Renewable synthetic fuels are generally seen as a technology that will play an important role to reach net zero in the transportation sector. Although there are important differences between the various types of synthetic fuels regarding their production, scalability, and sustainability.

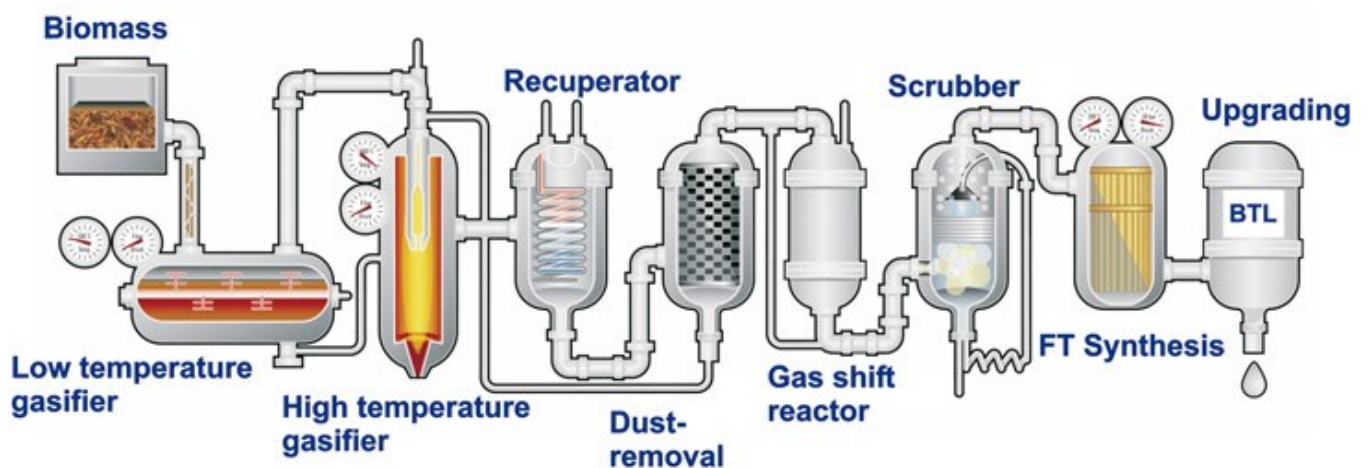
The production of synthetic fuels from biomass via Fischer-Tropsch, otherwise known as *biomass-to-liquids* (BTL) process, constitutes one of the most promising routes for sustainable fuels. Biomass to Liquids (BTL) processes are being designed based on the thermo-chemical platform for converting biomass to biofuels. In an indirect liquefaction process, synthesis gas (syngas, CO+H₂) is first produced

¹⁹⁷ Fischer-Tropsch synthesis, a technology invented by Franz Fischer and Hans Tropsch during 1920s and adopted during World War II in Germany.

via gasification of solid biomass or liquid bio-oil produced by the fast pyrolysis of biomass. Syngas can be converted to synthetic gasoline, jet-fuel or diesel using Fischer-Tropsch synthesis of hydrocarbons or synthetic alcohols, such as ethanol, through different catalytic processes. The *gas to liquids* (GTL) technologies, previously utilizing coal or low-cost, remote natural gas as feedstock for liquid fuels production can be adapted for the conversion of biomass to liquids.

In order to reduce the cost of biomass transportation, the BTL process can be decoupled into two steps. In the first step, the biomass is converted to a liquid form via fast pyrolysis at distributed facilities close to the source of biomass. The liquefied biomass, commonly called bio-oil, is then transported to a much larger central facility where it is gasified/reformed into synthesis gas at high pressure. The syngas is subsequently cleaned/upgraded and then converted into liquid fuels. The advantages of this two- step process are lower cost of transporting biomass feedstock and significant reduction of power requirement for producing high pressure synthesis gas. In addition, compared to its biomass source, bio-oil contains significantly lower ash, sulphur and nitrogen compounds, which are poisonous for the GTL reaction catalysts. The synthesis gas cleaning step at the centralized facility can thus be made significantly less strenuous.

Figure 11. The first biomass-to-liquid process was developed in 1996 by CHOREN Industries in Germany, with a plant capacity of 0.015 million tons of liquid fuel per year.

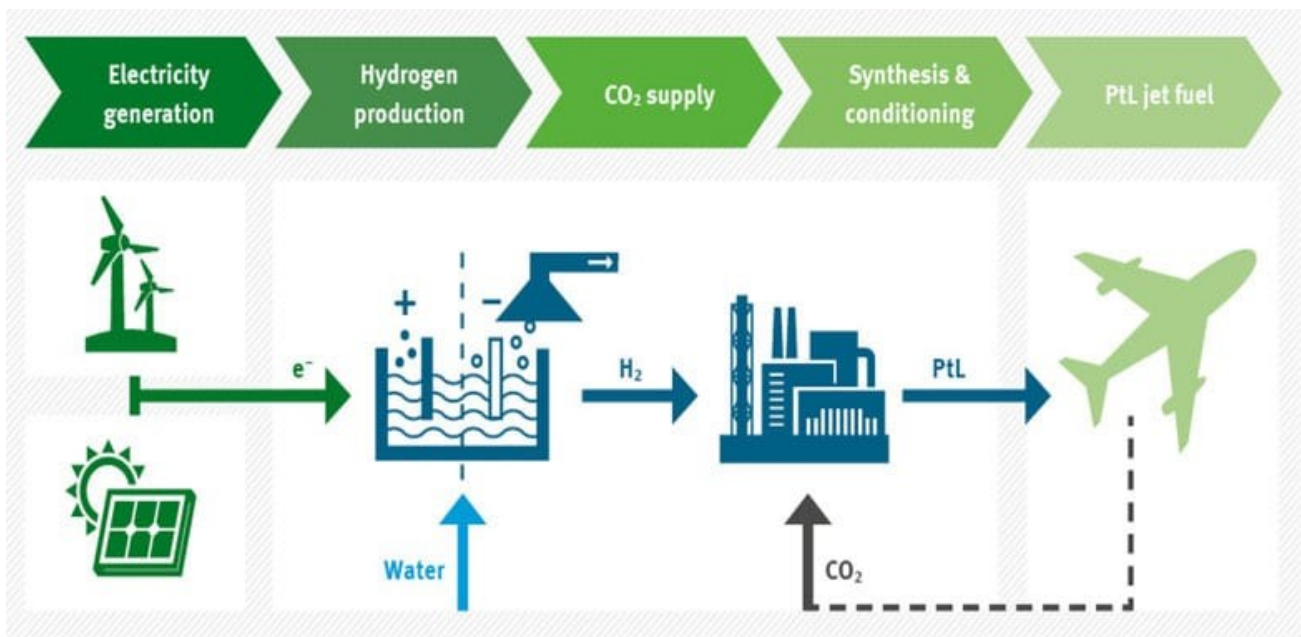


Source: Choren, 2011.

Aviation is at crossroads as the climate change targets require massive greenhouse gas emissions reductions in all sectors by the middle of this century. Future innovative – or even disruptive aviation propulsion systems may become important in the long run. *Power-to-Liquids* (PtL) is a production pathway for liquid hydrocarbons based on electric energy, water and CO₂ as resources. There are two principle pathways to produce renewable PtL: Fischer-Tropsch synthesis (FT) and methanol

(MeOH) synthesis and conversion. PtL production comprises three main steps: (1) hydrogen production from renewable electricity using the electrolysis of water; (2) provision of renewable CO₂ and conversion; (3) synthesis to liquid hydrocarbons with subsequent upgrading/conversion to refined fuels. Both PtL pathways (via Fischer-Tropsch or methanol) offer a high level of technology readiness. PtL can be produced from concentrated renewable CO₂ sources using established industrial-scale processes. PtL full system integration is currently significantly progressed with the Fischer-Tropsch pathway demonstration plant by Sunfire in Dresden, Germany (German Environment Agency, 2016)¹⁹⁸. The term *Power-to-Liquids* (PtL) denotes the conversion of sustainable hydrogen or syngas into liquid energy carriers such as methanol, oxymethylene ethers (OME) or ammonia. They will be used as platform molecules for the chemical industry, as energy carriers or as clean fuels for combustion engines and turbines in order to reduce both CO₂ and soot/NO_x emissions. There are several projects planned, but to date no industrial e-fuel plant exists, which also means that e-fuels are not yet available on the market.

Figure 12. Power-to-Liquid production.



Source: Adapted from H₂ International, 2017.

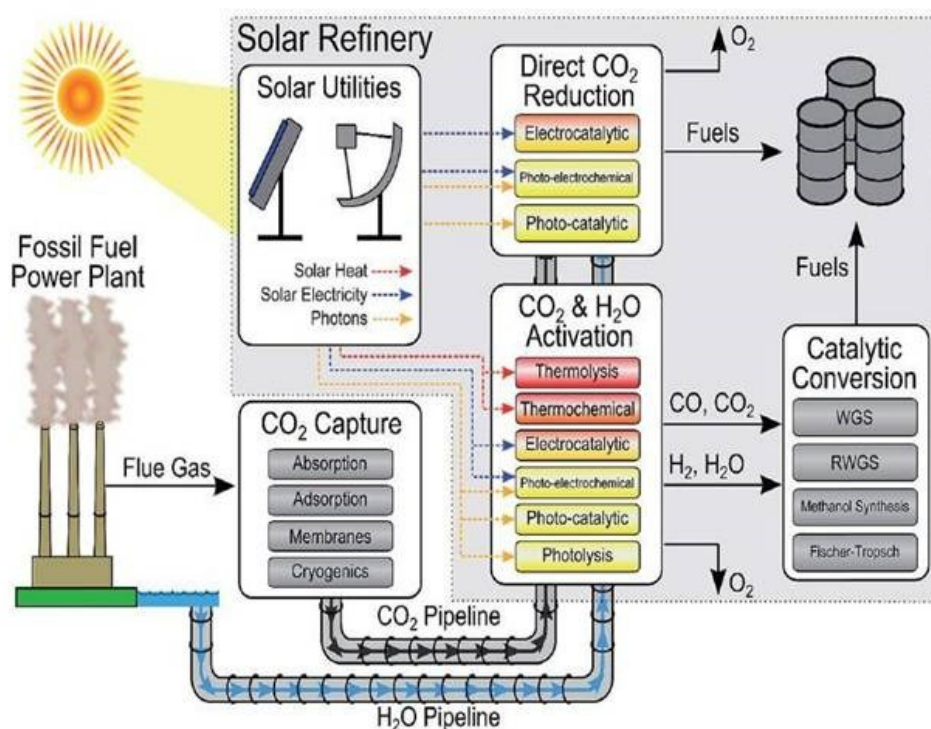
The conversion of carbon dioxide and water into fuels in a solar refinery presents a potential solution for reducing greenhouse gas emissions, while providing a sustainable source of fuels and chemicals. Solar energy can be used to convert basic chemical feedstocks such as carbon dioxide and water into clean alternative fuels that offer greater grid stability, energy security, and environmental benefits. *Solar fuels* technologies use sunlight, water, carbon dioxide, and nitrogen from the air

¹⁹⁸ German Environment Agency (2016). “Background paper: Power-to-Liquids Potentials and perspectives for the Future Supply of Renewable Aviation Fuel”.

to produce fuels that can readily be used in the existing energy infrastructure. Solar fuels technologies are analogous to natural photosynthesis – plants make fuels (biomass) from sunlight. However, the fastest growing crops store less than 1% of the sunlight they receive as biomass. To be compatible with current infrastructure, the primary biomass made by plants – lignocellulose – must be converted into ethanol, biodiesel, or gasoline. Converting crops to fuels raises significant land-use concerns, specifically with regard to trading food for fuel. The Lewis Group at California Institute of Technology has led the development of solar fuels technologies that produce hydrogen gas directly from sunlight and water. Carbon-containing fuels such as natural gas (methane) or liquid fuels such as methanol or ethanol might be produced from sunlight, water, and carbon dioxide. Ammonia for use as fertilizer in agriculture can be made indirectly from solar hydrogen or directly as a solar fuel from sunlight, water, and nitrogen in the air.

Similarly to e-fuels, solar fuels are not yet available on the market. Sunny regions offer ideal conditions for the production of solar fuels, in particular deserts and semi-arid regions with high solar radiation. The solar heat generated during the day can be stored by inexpensive thermal energy storage to enable round-the clock production of fuels. Storage makes solar fuel plants self-sufficient and independent from any grid, giving them the potential to be scaled quickly and broadly. A number of prototypes have been demonstrated but at present stage, these cannot compete with existing energy technologies nor provide long-term stability.

Figure 13. Sun-to-Liquid production of solar fuels.



Source: Adapted from the article "A general framework for the assessment of solar fuels technologies" published in Energy & Environmental Science, Issue 1, 2015.

The adoption of synthetic fuels is described in several military and NATO standards. To be eligible for use, “new alternative” jet fuels must undergo a full approval process defined by the ASTM D4054 standard (Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives). France, Germany and the UK all see tangible benefit in the use of synthetic aviation fuel due to the advantage of being able to “drop-in” to current platforms. Possessing similar physical and chemical properties as hydrocarbons, synthetics can be used without sacrificing the performance of proven combustion engines. There is no need to adopt alternative propulsion systems or re-design logistic chains. As a result, Germany plans to establish a new research center for fossil-free fuels in Cottbus. The UK Royal Air Force (RAF’s) successful experimentation flight of an Ikarus C42 micro-flight in 2021 was the first to use 100% synthetic aviation fuel. Rolls Royce’s EJ200 combat engine, which powers the Eurofighter Typhoon, and the MT30 gas turbine, in service with the US, UK and other militaries’ naval ships, are already compatible with synthetic fuels (Bell, 2021)¹⁹⁹.

4.2 Maritime

The naval sector is rarely mentioned in the discourse about decarbonization. Due to their unique purpose, naval vessels, and in particular combat vessels must meet a number of special requirements that set them apart from commercial ships. They must be able to operate under direct threat, at high speeds and for extended periods with the only possibility for refueling actually at sea. Independence, endurance, low detectability, high agility and maneuverability even in a damaged condition are of vital importance. The choice of fuel must account for the size, mission and payload of the given ship type, the range and the power demand of the military systems on board – such as radars and weapons – and potential exposure of fuel to hostile fire. All these requirements complicate the search for sustainable propulsion technologies.

Introducing electric propulsion motors to vessels, either in the form of an integrated electric drive (IED) or hybrid electric drive (HED) propulsion system, allows replacement of the relatively low efficiency gas turbines. Although gas turbines are power dense and fairly efficient at full load, their fuel efficiency decreases drastically at the lower levels used when slower speeds are required to accomplish the ship’s mission. An emerging global macro-trend in naval engineering over the last fifteen years has been a decisive move towards “more electric” propulsion due to progressively increasing electrical load demand and a focus on affordability.

¹⁹⁹ Bell (2021). “Rolls-Royce executive: “Decarbonization is a warfighting opportunity for industry and its customers”, 6 December 2021.

For example, the US Navy's 2019-2037 technology roadmap for naval power and energy systems calls naval electrification critical based on its electrification needs for high-power radars and networks, directed energy-weapons for counter-unmanned systems and missiles, and prime mover propulsion for silent running. Electricity allows moving large amounts of energy from one place to another, controllably and quickly, making the energy resource (power generated by prime movers) extremely fungible. The trend towards electrification of warfighting capability take advantage of, and relies upon, the fungible nature of electricity. An integrated energy system involves converting energy to the electric weapon or sensor's needs. The vision of integrated power and energy systems carries this further, with the end-goal of linking all energy consumers with all energy sources in a single electrical network to maximize flexibility in affecting the ship's functions (Rosenberg, 2021)²⁰⁰.

The future of keeping navies at sea for longer, further from home ports and with resilience is by making them as operationally efficient as possible. Hybrid propulsion systems combine both electrical and mechanical equipment to turn the ship's propellers throughout the speed operating range. The hybrid configuration is a versatile propulsion solution and is particularly suited to the fluctuating operational scenarios encountered by naval warships and auxiliary vessels. Using electric propulsion motors powered by the ship's generating sets to turn the propeller saves fuel, reduces emissions and reduces maintenance costs of the main engines, which can be shut down. The generating sets are running to meet other electrical needs of the ship anyway, so the overall number of hours run by the various diesel engines onboard is reduced (General Electric, 2014)²⁰¹. In October 2014, the amphibious assault ship USS America (LHA6) was commissioned – the first of its class – with a hybrid electric propulsion system. France's multi-mission frigate anti-submarine warfare version also uses an HED which has allowed it to optimize fuel consumption and reduce exhaust emissions. There are other benefits, including increased operational efficiencies throughout the ship's operating profile, as electrical equipment is operated nearer to its peak efficiency.

There are currently solar- and wind-powered maritime vehicles which could be operationally effective, particularly in the case of smaller unmanned vehicles. In December 2021, the U.S. announced it had begun operationally testing a sailboat-style drone (wind-powered with solar sensors) which could provide the U.S. Navy with a relatively inexpensive way to expand its sightline (Ziezulewicz, 2021)²⁰². Boe-

²⁰⁰ Rosenberg (2021). "The roadmap for naval electrification". In *Breaking Defence*, 08 November 2021.

²⁰¹ General Electric (2014). "Norwegian Navy Embraces Electrification in Choosing GE's Energy Efficient Hybrid Propulsion Drive Technology". Press release, 20 May 2014.

²⁰² Ziezulewicz. "The Navy is testing this adorable sailboat drone". In *Defence News*, 13 December 2021.

ing had developed a similar unmanned asset, which harvests its energy from wave and solar power, for intelligence, surveillance and reconnaissance (ISR) missions²⁰³.

Often overlooked as an energy source that can play an integral role in the energy transition and a cleaner future is the small modular reactor (SMR). It typically produces less than 300 MW compared with up to 1,600 MW for traditional reactors. Their smaller size means they provide an option to fulfil the need for flexible and affordable power and heat generation for a much wider range of users and applications, in addition to the possibility of combining nuclear with alternative energy sources, including renewables.

SMRs can also be subdivided into different categories. Some institutions and energy companies employ a wide variety of terms, including “micro modular reactors” (MMRs) and “very small modular nuclear reactors” (vSMRs) to describe SMRs that have the capacity to generate up to 10-25 MW energy per module. The use of small reactors for reliable power is not actually a new concept. SMRs have been used in the military since the 1950s, especially in vessels such as icebreakers and aircraft carriers that need to be at sea for long periods without refueling, or for powerful submarine propulsion (Trakimavičius, 2021)²⁰⁴.

Nuclear-powered surface and sub-surface vehicles remain an option for some – particularly for aircraft carriers and larger submarines. Nuclear propulsion has been used by the U.S., British, Russian, French and Chinese navies for decades because of the speed and endurance it gives to combat vessels, especially submarines. It is in essence carbon-free but extremely expensive. Notwithstanding the strategic and tactical advantages, demand remains low since radioactive waste is seen as an environmental threat and public opposition. Therefore, the nuclear option is limited for most navies; safety issues, high operating costs and investment in infrastructure and disposal options are prohibitive. On the other hand, submarines “have taken” the lead in terms of the adoption of alternative fuels thanks to the emergence of the air-independent propulsion (AIP) system in the mid-20th century. AIP systems are compatible with alternative fuels and fuel cells and considered as a viable alternative to nuclear propulsion.

Over the past decade, air-independent propulsion (AIP) for submarines has spread rapidly around the world. The technology, which allows conventionally powered submarines to operate without access to outside air, has the potential to shift the balance from the big nuclear attack submarines (SSNs) that have dominated un-

²⁰³ See Boeing “Wave Glider”, <https://www.boeing.com/defence/autonomous-systems/wave-glider/>.

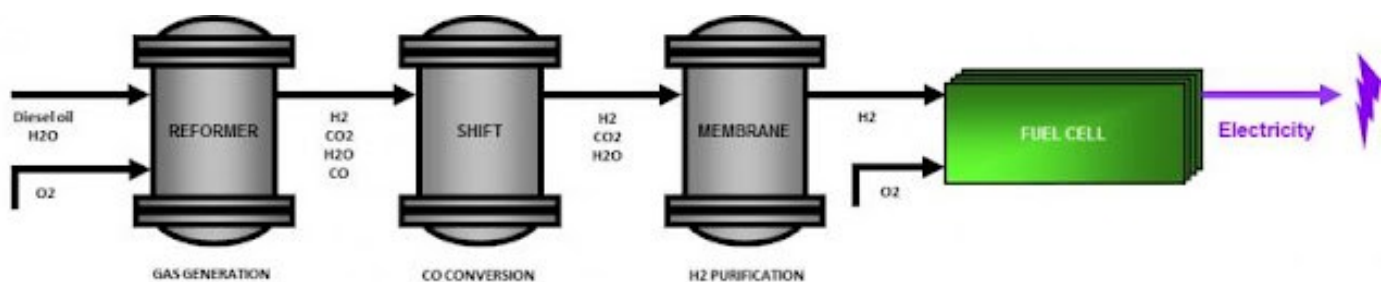
²⁰⁴ Trakimavičius (2021). “Is small really beautiful? The modular nuclear reactors (SMRs) in the military”. In *Energy Highlights*, No 15, NATO Energy Security Center of Excellence.

dersea warfare since the 1950s, and back towards small conventional boats. In global terms, this might again make submarines the great strategic equalizer; small cheap weapons that can destroy the expensive warships of the world's most powerful navies. In the mid-2000s, converging technological developments enabled several major submarine producers globally to begin to develop practical AIP systems. France, Germany, Japan, Sweden and China all laid down AIP capable boats, in some cases exporting those submarines around the world.

There are three main types of AIP found in extant diesel-electric submarines: (1) Closed cycle steam turbines; (2) Stirling cycle; and (3) Fuel cells.

Closed cycle steam turbines are used on French-built submarines and they mimic the energy production process found on nuclear subs (where a nuclear reactor provides heat that turns water into steam) by mixing oxygen and ethanol. This system is complex, generates a lot of power, but is somewhat less efficient than the alternatives. A Stirling cycle engine uses diesel to heat a fluid permanently contained in the engine, which in turn drives a piston and generates electricity. The exhaust is then released into the seawater. This is slightly more efficient, and somewhat less complicated, than the French variant, and is used on Japanese, Swedish and Chinese boats. Fuel cell technology is probably the state of the art in AIP. A fuel cell uses hydrogen and oxygen to generate electricity, and has almost no moving parts. They can generate a lot of energy with minimal waste product, and are very quiet. German-built submarines have successfully taken advantage of fuel cell technology, and the French, Russians and Indians are also moving in this direction (Farley, 2021)²⁰⁵.

Figure 14. Fuel cell submarines – principles of device



Source: Adapted from the article "Submarines Matter" by Naval Group, 2019.

²⁰⁵ Farley (2021). "AIP: The Stealth Submarines the US Navy Doesn't Have". Article, 17 November 2021.

Alternative fuels are the most effective measure to fully decarbonize in the future, but practical considerations such as logistics, fuel availability, and fuel change flexibility of the different low- or zero-carbon fuels matter for the naval segment. While the number of naval ships running on alternative fuels remains rather small, biofuels are seen as a more realistic option for naval ships than ammonia, methanol, hydrocarbons or other power sources, especially since drop-in biofuels do not require any retrofits. Probably non-combat vessels will be the first to embrace alternative fuels, rather than fighting vessels such as frigates and destroyers with their highly specialized needs (DNV, 2022)²⁰⁶.

4.3 Land

Electric vehicles (EVs) have the potential to transform the capabilities of armored vehicles and logistical and tactical trucks. Their adoption into the Armed Forces is quickly becoming a reality and whilst there are technical stumbling blocks to be resolved before EVs are used in combat setting, new technology is already being utilized in some barracks. Electrification is likely to be critical to the integration of emerging war-fighting capabilities such as high-power communications, high-power jamming, vehicle-centric microgrids and directed-energy weapons²⁰⁷. Greening strategies that are being implemented by many Armed Forces are driving the move towards EV integration into the current fleet. EVs produce low emission levels compared to traditional internal combustion engines. The UK, the U.S., NATO and the Environmental Defence Fund (EDF) are amongst those currently looking to reduce the environmental impact of their activities on the environment. Additionally, the alternate benefits of greening strategies, such as reduced cost and fewer vulnerable supply chains, will also encourage militaries to reduce their environmental impact.

Given the progress in the civilian sector over the last decade, it is not unrealistic to expect hybrid-electric drive (HED)²⁰⁸ and electric technology to work for land applications; it is best suited to lighter vehicles. Hybridization offers potential for tracked vehicles but seems more applicable to wheeled types; increasing range and functionality, as well as improving torque and therefore traction/off-road abil-

²⁰⁶ DNV (2022). “Decarbonization perspectives for navies”. Whitepaper, 11 May 2022.

²⁰⁷ A direct energy weapon (DEW) is a ranged weapon that damages its target with highly focused energy without a solid projectile, including lasers, microwaves, particle beams, and sound beams. Potential applications of this technology include weapons that target personnel, missiles, vehicles, and optical devices.

²⁰⁸ Hybrid electric vehicles are powered by an internal combustion engine and one or more electric motors, which uses energy stored in batteries. A hybrid electric vehicles cannot be plugged in to charge the battery. Instead, the battery is charged through regenerative braking and by the internal combustion engine.

ity. The UK and U.S. armies have independently commissioned the development of hybrid vehicles. The U.S. Army awarded the University of Wisconsin a contract to research how hybrid power trains can be integrated into the fleet. Furthermore, the electric light reconnaissance vehicle (eLRV) being explored by the U.S. Army will likely be initially equipped with a hybrid system before moving to full electrification. The same can be said about the UK's Protected Mobility Engineering & Technical Support (PMETS) program to electrify the MAN SV, Jackal and Foxhound vehicles. These seemed to be initial steps towards achieving environmental goals, while demonstrating that acceptable operational capability can be maintained²⁰⁹. The British army is assessing the benefits of hybrid military vehicles; the hybrid Jackal reconnaissance vehicle has electric drives on its wheels, a battery and a diesel engine that tops up the battery. The vehicles offered better stealth, capability and no noise and were better for the crew. BAE Systems is also heavily focusing on producing hybrid vehicles including heavy-duty trucks and buses. The reasoning behind the development of hybrid vehicles before full electrification is that some of the benefits of EVs can be gained before some of the hurdles of full electrification are overcome.

Other nations are starting to follow suit, and it can be seen that climate change is starting to become a new staple at military exhibitions and conferences, where industry is becoming more attuned to the growing demand for green solutions. For example, France is aiming to build an HED Griffon multi-role armored vehicle demonstrator by 2025. There are clearly significant benefits for combat service support-logistic vehicles – including unmanned or autonomous versions – where a hybrid option will reduce operational costs and fossil fuel consumption (IISS, 2022)²¹⁰.

Developments of hydrogen technology continue to be a source of debate, whether it be in relation to production methods or the use of hydrogen as an energy carrier. Hydrogen fuel cells have been around for many years, and continue to be the focus of investment and development for many of the world's leading motor manufacturers and system providers. Many believe that fuel cells are more ideally matched to higher power requirements involving applications that move greater loads across larger distances, such as heavy freight, ships, rail and aviation, with doubts remaining over the commercial viability of their widespread adoption for

²⁰⁹ In 2020, the UK's MAN SV Foxhound and Jackal vehicles were HED tested. See also The International Institute for Strategic Studies (2022). "Green Defence: the defence and military implications of climate change for Europe".

²¹⁰ International Institute for Strategic Studies (IISS). "Green Defence: the defence and military implications of climate change for Europe". February 2022.

smaller ground vehicles. Affordability for passenger car applications is often cited as a potential inhibitor to fuel cells becoming the successor to the internal combustion engine. Fuel-cell vehicles powered by hydrogen, by contrast do not suffer from the same payload challenges as batteries and possess all the advantages of HED vehicles, but with the additional benefits of rapid fueling and very low fuel consumption at idle. Examples already in development include General Motor's ZH₂ hydrogen fuel-cell-powered electric pick-up truck²¹¹. However, hydrogen vehicles are more complex and therefore more costly. Although, for well-matched applications, it can be seen that fuel cells being adopted at ever-increasing rate. This will inevitably result in increased demand for hydrogen production, storage and distribution, and need for suitable technologies to support these requirements. Using methanol as a bulk hydrogen carrier that can be reformed into hydrogen on demand is seen as an answer to some of the transport and safety challenges.

Battery technology will continue to evolve, and this may continue to represent the most viable and effective solution for lighter vehicles that operate over shorter distances. Demand for rare earth metals and materials essential for battery manufacturing will increase and inevitably, and solutions will need to be found, for the widespread recycling of lithium battery technology to satisfy demand and meet green objectives. Nevertheless, a full-electric driven land system is more challenging. Currently, batteries are heavy, slow to charge and offer limited range; removable, swappable batteries might solve issues with charging time, while ongoing improvements in lightweight and energy-dense materials will make batteries more competitive in terms of weight. In 2021, the Netherlands announced it was testing an electric truck to assess its operational feasibility. However, full-electric and HED options will both need extremely high-powered charging stations (likely greater than 10 megawatts) for sustainability requirements during missions. In more contested environments, the protection of such stations will be a clear operational requirement.

It may be that electrified heavy armour will need a period of development before some of the key technologies are validated to a point at which military users are satisfied that they could rely on them as a mainstay of their force deployed in a tactical or combat environment. The near-term route to military use of electric vehicles may be at the lighter end of the scale. At the same time, there are real challenges to overcome for armoured vehicles. The current tanks of the UK, U.S. and many other NATO countries weigh 60-70 tons and the German MoD had currently assessed that propulsion systems based on batteries or fuel cells alone will not be able to achieve the special requirements of armoured vehicle fleets. Moreover, for

²¹¹ "General Motors introduced a hydrogen fuel cell-powered pick-up truck". In *Plug-In Magazine*, 18 October 2016.

heavier and some medium-weight combat support vehicles –such as missile launchers, bridge-layers and recovery vehicles – the cost of conversion is difficult to recoup over the vehicles’ lifetime.

One of the more niche, but nonetheless important, trends is the development of mini nuclear reactors. These are being actively developed by countries including the U.S., UK, Canada, and China in an attempt to find a solution to the question of how to charge EVs in the field. In instances where no power grid access is available, or until a lightweight solution to carrying batteries is found, the mini nuclear reactors could offer an alternative source of power. The U.S. Department of Defence is running Project Pele to develop a forward deployable reactor. The timeline aims for a prototype to be ready for the end of 2023²¹². The reactors will be able to provide large amounts of energy, which could reduce the need for long and vulnerable supply chains to the front line. Furthermore, they would be transportable and deployable and would be able to cool without the need for water electricity in case of emergency (Neumann, 2021)²¹³.

Key technological pillars of future defence vehicle will be electrification, autonomy, and cybersecurity – that latter being an area in which an adversary has the potential to wreak havoc in new and innovative ways and with previously unachievable consequences. Designers will need to address security and safety from new perspectives. In addition, to cyber threats, they will need to consider theft or hijack of unmanned systems and varying impacts on public safety (Wilkins, 2021)²¹⁴.

4.4. Air and Space

The investigation of aviation alternative fuels and energies has increased significantly in recent years in an effort to reduce the environment and climate impact by aviation. Special requirements have to be met for qualifying as a suitable aviation fuel or an alternative power source. The fuel has to be high in energy content per unit of mass and volume, thermally stable and avoiding freezing at low temperatures. There are also many other special requirements on viscosity, ignition properties and computability with the typical aviation materials. There are quite a few contending alternative fuels, which can be derived from natural gas and biomass. As a result, much research efforts are required to realize the aircraft alternative fuels and energies.

²¹² The companies currently involved in Project Pele are Bwx Technologies, Westinghouse Government Services, and X-Energy.

²¹³ Neumann (2021). “Easy EV: Challenges and benefits of land vehicle electrification”. In *Defence Technology*, December 2021.

²¹⁴ Wilkins. “Powering Future Defence Vehicles”. In *Military Technology* No 6, 2021.

Despite the challenges, there have been notable developments in the air and space domains in alternative propulsion. For example, Elroy Air are working on Chaparral hybrid-electric autonomous vertical take-off and landing (VTOL) aircraft for cargo deliveries and LIFT Aircraft on an optionally piloted amphibious all electric version called Hexa²¹⁵. Battery-powered small uninhabited aerial vehicles (UAVs) are already a reality and in military use globally by state and non-state actors. Due to current weight considerations, a scalable battery-driven aircraft for fast jet, bomber or transport operations is not possible in the near term if offset against lighter construction materials.

Table 15. Summary of sustainable mobility options

Examples	Types	Maritime	Land	Air and Space
Improving fuel efficiency	<ul style="list-style-type: none"> Improved engine-management software for platform efficiency. Aids to vehicle drivers, pilots and ship bridge crew in reducing fuel consumption. Adjust flight, ship and vehicle route planning. 			
Fuels	<p>Biofuels</p> <p>Synthetics</p>	<p>Biofuels: SVO, bio-diesel, biogas, bio-hydrogen and lignocellulose-based bio-oil testing and experimentation in the commercial and military sectors.</p> <p>Synthetics: Rolls-Royce MT30, marine gas turbine engine is compatible.</p>	<p>Biofuels: civilian “non-drop-in” solutions being tested/used. Military tests: US TARDEC tests on caterpillar C7 engine successful.</p>	<p>Biofuels: SAF – 50% blended and 100% unblended. The Netherlands Air Force F-16 fighters fly on a mix containing 5% SAF.</p>
Benefits	<p>Synthetics are “drop-in” solutions to current platforms:</p> <ul style="list-style-type: none"> Used on proven combustion-engine technology. No need to adopt alternative propulsion systems or to re-design logistic chains. Does not sacrifice performance. 			
Challenges	<p>Biofuels:</p> <ul style="list-style-type: none"> Inaccessibility. Limited access to biomass at scale and disparity of feedstock. Expensive to produce, and “non-drop-in” solutions are costly. Environmental sustainability in production chain and could be in competition with food production. Fuel quality and performance. Difficulties in meeting NATO Single Fuel Policy. 			

²¹⁵ See more information at the websites: www.elroyair.com; www.liftaircraft.com/ownership

The effective application of low carbon technologies, such as electric and hydrogen propulsion are unlikely to be in widespread use until 2040 or later. This means that Sustainable Aviation Fuel (SAF) provides the only viable way to reduce aviation emissions significantly in the short to medium-term. SAF can be made from renewable sources, such as used cooking oil, municipal waste and woody biomass. It is safe, proven fuel, which has the potential to reduce lifecycle emissions by up to 80%, compared with conventional aviation fuel. SAF is also a drop-in fuel, which can be blended in a ration of up to 50% with conventional jet fuel for use in aircraft operating today. However, the SAF type currently predominant (i.e. biofuels) faces real availability and scalability challenges, as well as supply chain bottlenecks and questions over the sustainability of feedstocks.

The UK's Royal Air Force is already using sustainable aviation fuel (SAF) which is a 50% blend and is developing a 100% SAF for flight in 2022. SAF gives an impressive reduction of up to 80% in carbon emissions over the lifecycle of the fuel compared to traditional jet fuel it replaces, depending on the sustainable feedstock used, production method and the supply chain to the airfield. However, currently, SAF is relatively inaccessible and expensive. In terms of unblended biofuels, high-profile bio-jet-fuel tests on F-18 and Gripen fighters have already taken place. Sweden has conducted biofuel testing in the Gripen RM-12 engine. The Netherlands also has a pilot project underway to mix kerosene with biofuel for use in F-16 aircraft at Leeuwarden Air Base (Voegele, 2019)²¹⁶.

Part of the problem is standardization. Jet fuel is a kerosene-grade fuel formulated to meet stringent commercial or military performance standards, including energy content, combustion quality, stability, lubricity, fluidity, volatility, noncorrosivity and cleanliness. The most widely recognized commercial performance standards are ASTM International's D1655 Standard Specification for Aviation Turbine Fuels in the US²¹⁷ and Defence Standard 91-91 in the UK²¹⁸. To be utilized in flight, sustainable aviation fuel (SAF) must be thoroughly tested and must meet the same rigorous standards as petroleum-derived fuels.

Thus, finding a sustainable aviation fuel is likely to remain a long-term problem owing to energy content, usability and technical viability compared with jet fuel. To achieve significant scale-up an exponential expansion of e-fuels or power-to-liquid will be needed. E-fuels are produced using low carbon hydrogen

²¹⁶ Voegele (2019). "The Netherlands announces plans to fuel air force with biofuels". In Biomass Magazine, 24 January 2019.

²¹⁷ ASTM D1655-18a. "Standard Specification for Aviation Turbine Fuels". ASTM International accessed 09 November 2022, <https://www.astm.org/standards>.

²¹⁸ Civil Jet Fuel, Grades and Specifications". Royal Dutch Shell PLC, accessed 09 November 2022, <https://www.shell.com/business-customers/aviation/aviation-fuel/civil-jet-fuel-grades>.

(produced from biogas or renewable/nuclear electricity electrolysis) and captured CO₂. As such, lifecycle carbon savings from e-fuel can achieve over 90% compared with fossil jet fuel (A1). In theory, e-fuels have far higher supply potential than other SAF types, given that electricity and CO₂ are not restricted by feedstock availability in the same way. Although, e-fuels are highly energy-intensive to produce, very expensive and dependent on the rapid expansion of clean electricity production (renewable and/or nuclear) and carbon capture technology globally.

Investment in and development of hydrogen cell propulsion for aircraft is well underway. At the lighter scale, hydrogen-powered UAVs are smaller and have greater endurance than existing battery-propelled options. They offer the benefit of low-noise and low-vibration, of particular importance for Intelligence, Surveillance, and Reconnaissance (ISR) mission. Major companies such as Boeing and Airbus are developing hydrogen-powered aircraft for small UAVs such as the ScanEagle3, but also for the next generation of single-aisle jets from the mid-2030s²¹⁹. Airbus has sought to lead in the transition to greener aviation, demonstrating zero-emission aircraft concepts in 2020 (eschewing batteries in favor of hydrogen) which it said could enter service in 2035. Boeing has been more cautious in its public statements regarding the long-term switch to battery and hydrogen-powered aircraft. The company's focus remains on SAF.

In parallel with the maritime domain, solar and wind-powered energy options are readily available and offer niche/specific capabilities in certain areas of air power. In the past, gliders have been put to military use in transporting troops and heavy equipment but have had no proven operational utility since 1945. Solar power can be used for small UAVs; and for powering aerostats in forward operating bases. However, harnessing solar power for military effect may be most feasible in the space domain. For example, Chinese advances in space-based solar power, include a concept using power-beaming technology to transmit solar energy to receive on earth (Brown, 2019)²²⁰.

Wireless power transmission envisioned by Nikola Tesla a century ago is feasible today. Microwave beams can propagate power efficiently along lines-of-sight over long distances. Orbiting microwave reflectors could form the basis of a global electric grid. After decades of alternating between optimism and abandonment, power beaming is finally becoming a reality, thanks to research led by space and military agencies, and attention from startups and the private sector. Beaming could

²¹⁹ “Airbus and Boeing to embrace hydrogen from mid-2030s”. In Engineering and Technology, <https://eandt.theiet.org/content/articles/2021/airbus-and-boeing-to-embrace-hydrogen-from-mid-2030s/> 2 December 2021

²²⁰ Brown. “How China’s Space-Bound Station Will Beam Power Down to Earth”, 19 February 2019.

also transfer power from remote renewables sites such as offshore wind farms. Other areas where power beaming could revolutionize energy solutions include re-fueling space missions and satellites, and 5G provision.

In September 2022, the defence company Emrod demonstrated its technology for Space-Based Solar Power (SBSP) applications in collaboration with the European Space Agency (ESA), Airbus and Technocarbon. The companies believe that commercial Space-Based Solar Power, using satellites to capture solar energy in space where it is in abundance 24/7 and beaming it wirelessly to the ground, could support the transition to sustainable energy. While the concept of Space-Based Solar Power is based on existing technological principles, challenges to date has been how to cost-effectively deliver the energy generated in space to earth for use (Emrod, 2022)²²¹.

4.5 Military installations

Military installations differ in terms of their existing infrastructure and potential vulnerabilities. A number of coastal military installations already routinely experience hide-tide flooding, and storm surge, disrupted operations and caused extensive damage to infrastructure. Likewise, infrastructure outside of military installations, (e.g. mission critical access roads) can be impeded by sea-level rise, further impeding military operations. The US Navy, for example, has identified effects, such as rising sea levels, that could negatively affect quays and melting polar ice that could open new navigable sea-lanes (Congressional Research Service, 2019)²²². Typically, these issues are seen mainly as challenges for the country that operates the bases. Many defence energy and climate strategies also focus on army installations such as producing a fleet of purpose-built, hybrid-drive tactical vehicles and providing 100% carbon free electricity. This is also consistent with minimizing the risks to bases, making them better, more sustainable, safer places to live and train. Climate strategies, especially in the U.S. and UK allow opportunities for “smart, 21st century bases” that are prepared for modern threats.

The role of military bases, and the way they project national power, appears to be changing. In the past, bases provided staging grounds for military actions, serving as safe havens against threats and helping defend critical territory. Increasingly however, bases are part of multi-domain battlespaces – both physical and cyber. New tasks generally essential to modern military operations – such as resup-

²²¹ “Emrod successfully demonstrates power beaming technology to unlock space-based solar power”. Press release, 28 September 2022.

²²² Congressional Research Service (2019). “Military Installations and Sea-Level rise”, 26 July 2019.

plying forces on the moves with exactly what they need and repairing critical components before they fail – tend to require huge volumes of data be stored, analyzed, and viewed in a single place. By harnessing the advanced digital platforms now emerging in smart cities, the modern smart base can be that place.

With the smart-cities movement gaining more traction, and the convergence of the IoT, the successes of smart city initiatives may be directly applicable to military installations. This extrapolation and enthusiasm are further fueled as technology disruptors shift their focus to relevant smart-city innovations. The U.S. military is already adopting “smart city” solutions and approaches for use in military installations. During 2016, the U.S. army has installed a 250 acre smart solar energy farm on Fort Stewart, Georgia, which can allow the base to operate independent of the local power grid in case of emergency, and is also making use of renewable energy. Nearby, Fort Bragg North Carolina, the biggest military base in the world is testing driverless vehicles for the transportation of wounded personnel, with the aim of later using them on actual battlefields as well (Martinidis, 2017)²²³.

Military bases function as small cities, they face a lot of the same challenges municipalities face. The evolution of technology continues to improve our way of life in many ways such as adjusting supply to demand levels, identifying faults that require repair, tailoring information to the user, and gathering utilization statistics to improve services. The base is reliant on the critical infrastructure (e.g. power, gas, water, transportation) provided by commercial industry, just as the civilian city. Military bases have the opportunity to use proven methods, technology and principles from smart city implementation to design and build smart bases (Nolan, 2021)²²⁴. Figure 16 depicts an effective smart base implementation that results in a secured intelligent infrastructure, energy efficient buildings, efficient transportation, cost-effective operations, and higher quality of life for the inhabitants of the base.

A smart base employs technologies – artificial intelligence, the Internet of Things (IoT), machine automation and robotics, and data analysis to name a few – to improve the quality and speed of its functions and services. Taken together, they collect and process large amounts of data that enable more economical operations and help military staffers make better decisions. At present, because of the IoT, the number of interconnected sensors has exploded. It has only been a few years, however, this data transformation of networked sensors is already being taken for granted.

²²³ Martinidis. “Smart Cities provide the model for Smart Military Bases”. In *Smart Cities Solutions*, 22 February 2017.

²²⁴ Nolan (2021). “Building the smart base of the future: the Integration of Smart Technologies for a More Efficient and Secure Base”. National Strategic Research Institute, University of Nebraska.

A connected machine does not become “smart” from single sensor, or modem, or network, or application alone. It is a combination of all of these pieces coming together that creates added intelligence. Smart bases are essentially the integration of networks with IoT components and data analytics to present users with situational intelligence or a common operating picture. Typical base-level shortfalls that smart bases may remedy are increased safety and security, lower operating costs, resiliency, and infrastructure and energy efficiencies (Johnson, 2017)²²⁵. While these can be massive benefits for each functional community (finance, logistics, operations, etc.), greater and less-often discussed non-tangible benefits are increased mission assurance and mission command through enhanced, holistic sense-making, and situational awareness. However, legacy bases today are for the most part not “smart-enabled” because they are not optimized for IoT and data analytics and this causes inefficiencies.

Installing and integrating network-connected sensors into the everyday operations of a military installation will drive efficiencies, feed and automate analytics, bolster antiterrorism and force protection measures, and improve processes. Smart sensors that distinguish between base personnel and transient visitors can help reduce congestion in the base during rush hours or during large public events that attract visitors. Smart sensors in garbage cars or on the shelves of stores can facilitate waste management and automate inventory requests for new items. At the same time, smart technology and the use of smart devices for military installations carries risks, as digital infrastructure can be a major target for hacking attacks.

At the same time one of the major vulnerabilities is that the military bases are integrated with Industrial Control and Data Acquisition (SCADA) networks which control a variety of power, water, communication, and transportation infrastructure stateside. Currently in the USA these bases are linked to the state and municipal ICS²²⁶/SCADA grid systems, with backup power via short-term fossil fuel stockpiles running generators (Marquese et al., 2017)²²⁷. The reliance on ad-hoc ICS/SCADA systems and public energy is dangerous because an attack on these systems could disrupt US military operations across the globe. Therefore, extra security measures and rigorous security protocols, however, can more than offset these difficulties.

²²⁵ Johnson (2017). “Smart City Tech Would Make Military Bases Safer”, retrieved from <http://www.wired.com/2017/02/smart-city-tech-make-military-bases-safer/>

²²⁶ ICS is Information and Communications Services.

²²⁷ Marquese, Schultz & Robyn (2017). “Power begins at home: Assured energy for U.S. military bases”.

Figure 16. Smart military base



Source: Adapted from the article “Smart Military Bases. Now is the time” by Deloitte USA, 2016.

The IoT and smart-base era is just beginning, and many aspects of securing it remains a work in progress. By approaching the IoT strategically, and with security at the core of every connected device, military installations can begin to capture new value through the smart-base concept – while keeping potential risks in check.

Over the last decade, European governments have been considering ways how to make their installations more carbon neutral. In 2018, Austria stated that it would strive for higher energy self-sufficiency on military properties by reducing energy consumption, increasing the use of renewables such as installing photovoltaic panels on buildings²²⁸. Many nations have set tangible goals to create “net-zero” camps. By 2025, France expects to create a sustainable camp on operations, while RAF Leeming will be the first net-zero airbase in the UK and Rolls Royce’s Bristol site will achieve net zero in 2022 (Bell, 2021)²²⁹. Powered by solar, geothermal and hydrogen energies, future bases will include the use of ground-source heat pump technology for runway maintenance and solar-cell installation. Several other countries have similar plans, including Slovenia.

²²⁸ Austrian Federal Ministry of Defence. “Nachhaltigkeitsbericht 2018 des Bundesministerium für Landesverteidigung [Sustainability Report 2018 of the Federal Ministries of Defence].

²²⁹ Bell (2021). “Rolls Royce executive: Decarbonization is a warfighting opportunity for industry and its customers”. In *Defence News*.

4.6 Decentralized power generation and microgrids

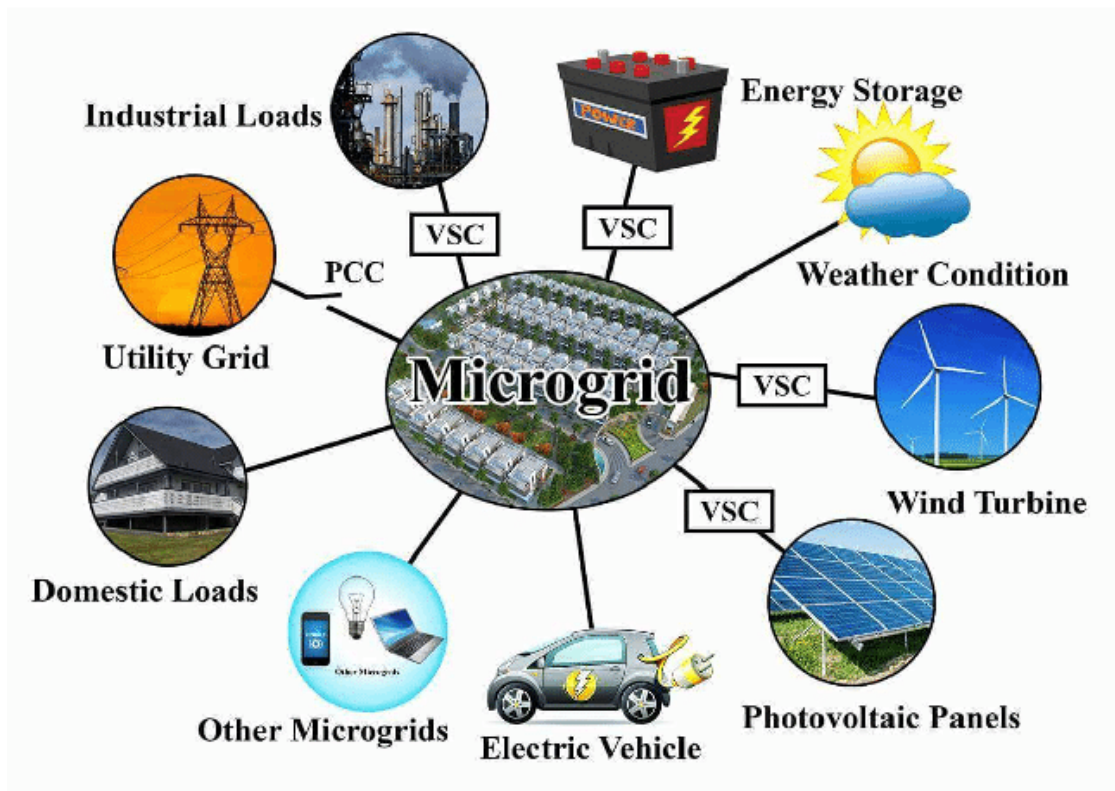
Most power generation systems worldwide have been designed to provide energy in a centralized distribution manner, regardless of how energy is derived. New and more advanced systems are beginning to take shape throughout the world, which are laying the foundation for decentralized and distributed energy systems. In the last decade, distributed energy resources (DERs) have been integrated into transmission and distribution power networks to reduce the amount of carbon emissions worldwide and to meet the increasing demands of power systems. A microgrid is one of the leading features of a smart grid power network for integrating DERs within a distribution network. The main platform of how these are taking shape is through the creation of microgrids. The idea behind this type of grid is that it is a group of smaller generation, storage, and load management systems that are either linked to the main electricity grid or islanded from it. A networked microgrid is an advanced microgrid concept in which a network is formed using several adjacent microgrids. Figure 17 illustrates a typical networked microgrid in a distribution network.

The microgrid concept comes from a 2004 research paper by Robert Lasseter and Paolo Piagi. They proposed that increasing levels of distributed generation could cause problems with the traditional electric grid and that a solution lay in a new approach that views localized generation and associated loads as a subsystem or “microgrid”. It is a power supply system composed of distributed energy sources; it primarily includes biomass energy, fuel cells, geothermal power, wind power, gas turbines, and compound internal combustion engines. Microgrids are often used for an entire region, combining local distributed energy sources and connecting with the utility power source network to supply power. Operationally, microgrids can be divided into the grid-connected mode and the islanded-mode. Loads can be differentiated as critical loads cannot be cut off and non-critical loads that can be cut off.

Microgrids have one unique characteristic, that is, all power sources and loads in the network can be cut off or closed at any time. Therefore, plans and adjustments can immediately respond to power supply and load demand, significantly increasing power consumption efficiency. The plug and play function in the microgrid’s power supply and load is primarily because of the breakers installed on each component in the microgrid. By controlling the breaker’s power using external signals, each component can adjust to and compensate for the state of the overall network.

In addition to using renewable energy as the primary source of power generation and the ability to cut off or integrated with the utility power source system at any time, microgrids can also add smart meters in the future, allowing users to obtain information regarding power consumption at any time to instantly manage their power efficiency. Furthermore, multiple microgrid systems can communicate and interact, achieving even more comprehensive applications.

Figure 17. An illustration of an islanded microgrid



Source: Adapted from the article "A Comparative Study of High Performance Robust PID Controller for Grid Voltage" by Sarker, Badal & Das, 2018.

Microgrids are found at both the macro (military installation or hospital) and micro scale (deployment or field hospital). There are generally two different methods, spot generation and consolidated generation. Spot generation is where each node (a tent in this instance) has a dedicated generator. Consolidated generation shows how one generator may link to provide power to multiple tents in a row. The introduction of microgrid systems that store electricity from renewable sources, as well as deployable hybrid microgrid systems to provide general-purpose power could offer self-sufficiency for defence.

The purposes for which microgrids are developed vary. Military microgrids are built to cater to the requirements of military bases, boost energy supply for power-intensive military operations and eliminate dependence on the grid. This type of microgrids are also made to be physically and digitally immune to attacks that may put down the civilian grids. As they operate independently from the grid,

they also enhance physical security and cybersecurity – which are significant concerns to the military. As systems become interconnected to monitor and make more efficient systems, more vulnerabilities present in the military. The internet of things (IoT) has created more efficient monitoring of equipment at different stages, however, it has also allowed hackers to find many different entry points to affect the grid. Sometimes microgrids also exchange power with the macro-grid or other microgrids. Renewable-based military microgrids eliminate the reliance on external fuel supply which could be a vulnerable link in the chain of operations. This is because transportation equipment could be attacked at any point on a long supply route, and fuel transport is always inherently risky.

Microgrids are also systems that can increase the resilience of military facilities to provide power during interruptions by providing multiple redundant local power sources and infrastructure independent of the larger electric utility. Microgrids can be simple or complex in nature. Microgrids consist of connected loads and energy generation sources (e.g. diesel generators, photovoltaics (PVs), etc.) with a variety of potential control systems and operating philosophies that often include energy storage systems (e.g., chemical batteries, thermal storage). Initially, the data gathering such as energy usage and defining critical infrastructure are crucial to designing a properly sized system. The identification of loads is crucial in designing the system. Under sizing the system could cause mission failure because it will not handle the load, comparatively, significantly oversizing the system may cause poor performance and cause the system lifespan to shorten. Microgrid technology also makes the traditional grid more resilient and efficient by improving power quality and reducing transmission and distribution losses.

The U.S. Army has recently developed a mobile microgrid concept. This is a fast-forming, secure and intelligent vehicle-centric microgrid prototype that will power next-generation warfighting capabilities. Integrating power generation directly onto tactical vehicle platforms, this type of microgrids are designed to provide on-the-move power for next-generation warfighting capabilities, such as directed energy and missile defence systems. Conforming to the Tactical Microgrid Standard, vehicle-centric microgrids can distribute power between vehicles and connect to other tactical microgrid systems compliant power generation, storage and distribution systems under development by the U.S. Department of Defence. It is not only a microgrid, it is also a smart grid. A centralized controller can increase or decrease the number of powered vehicles automatically for optimal efficiency/resilience across the microgrid. It is expected that in future around 10-20% of tactical vehicles will have vehicle-centric microgrid (Vergun, 2021)²³⁰.

²³⁰ Vergun (2021). “DOD Demonstrates Mobile Microgrid Technology”. In *DOD News*, 30 June 2021.

In European countries which own large defence estates, there are also immediate opportunities to generate energy from erecting renewable energy farms – such as solar, wind and wave on sites. The Netherlands established solar fields at the Vliehors and Eindhoven air bases in 2018 and 2019 respectively. Renewables could be a key component of microgrids but also have the potential for income-generation by supplying surplus energy. Training areas could also offset military emissions elsewhere through the development of carbon sinks. The UK, for example, has pledged to plant two million trees on training areas over the next decade.

Although deliberate attacks on microgrids are not typical, military microgrids can be a more attractive and likely target due to the importance of their mission and national security value (Battis et al., 2018)²³¹. Threats to a military base’s energy security result from a variety of sources, including disruption of power from the utility’s grid, reliability of components on the base, damage to the grid due to accidents or natural disasters, and deliberate attack (both physical and cyber). In 2017, a research report by Prehoda et al²³² shows that the U.S. electric grid is highly vulnerable to natural disasters, physical attacks and cyberattacks. The researchers found that the “traditional power grid infrastructure is incapable of withstanding intentional physical attacks”. Damage caused by sabotage, bombing or terrorism can be long-lasting and expensive because grid infrastructure components such as large transformers are often custom-built and are difficult to source and move. The researchers reported that the technical community and energy industry recommend that the military harden itself from these threats with distributed solar + battery energy storage microgrids. Solar energy is free to operate, requires almost no maintenance, and is not vulnerable to supply chain disruption. Battery energy storage makes intermittent renewables like solar fully dispatchable, allowing stored solar energy to be used whenever it is needed.

4.7 Challenges

Whilst the current infrastructure of European armed forces offers quick-win opportunities, there are significant infrastructure challenges, which will need to be overcome, particularly in energy-storage facilities. In the maritime domain, even without the requirement to reduce emissions, current power systems will soon lack the capacity to withstand the increasing demand placed on them, including through

²³¹ Battis, Kurtovich, and O’Donnell. “A Security and Resilience for California Electric Distribution Infrastructure: Regulatory and Industry Response to SB 699”. Technical Report; California Public Utilities Commission Safety and Enforcement Division Risk Assessment and Safety Advisory Section: San Francisco, CA, USA, 2018.

²³² Prehoda, Schelly and .Pearce. “U.S strategic solar photovoltaic-powered microgrid development for enhanced national security”. In *Renewable and Sustainable Energy Reviews*, volume 78, October 2017, pp. 167-175.

the future integration of directed-energy weapons, advanced electronic-warfare systems, electromagnetic rail guns and radiated energy systems such as radars. Ships will need to develop better energy storage systems to support future sensors and weapons, as well as housing renewable energy sources themselves. If hydrogen is part of the solution, coolant systems may also be a key consideration. On land, it is necessary to invest significantly in storage systems and e-charging points. The Norwegian Armed Forces are already investing in electrical energy storage (partnered with Energy Nest). The U.S. is doing the same and looking for domestic sources for lithium (used in batteries) to ensure self-sufficiency. The protection of critical energy storage facilities should be a key planning consideration for European armed forces – this will be particularly important in the cyber domain.

Key to all plans will be ability to map the carbon emissions of armed forces. This will assist in measuring the effectiveness of decarbonization options as they are introduced. It will also assist in promoting awareness and in making the behavioral changes required amongst military personnel. Addressing the emissions involved in defence supply chain will also be critical. The defence sector needs to think hard about these challenging issues, identify the resilience and sustainability efforts it should be taking to adapt to a changing climate, and how these should be balanced with sustaining defence operations and capabilities. The full spectrum of defence activities including travel and training will need to reduce unnecessary emissions. Increasing the proportion of training in simulated environments would go some way towards this objective.

Barracks, docks, airfields and training areas offer considerable opportunities to reduce emissions, generate renewable energy and sequester carbon. This could help offset the emissions from elsewhere in the defence system, particularly in those areas where emissions are more difficult to reduce, such as from maritime and aviation fuels. Such measures would have the operational advantage of making bases more energy independent, thus increasing resilience against external power-supply interruptions. This threat is not only more likely as a result of increasingly unstable European weather, but is also a potential outcome of cross-border cyber-attacks, such as the Russian attack on Ukraine's electricity grid in December 2015.

Conclusions

The challenges of the 21st century are many and complex. Still, there is a growing recognition that climate change is one of humankind's most pressing issues. The defence agencies and armed forces globally are preparing for and addressing climate issues. In order to cope with the new reality, they have to build resilience to climate change as well as the ability to react to climate change-induced or exacerbated risk and disaster. Nevertheless, there is an array of benefits of a military green transition, including cost savings as well as enhanced autonomy, agility and range of forces due to increased energy efficiency and resilience.

Defence has a significant carbon and environmental impact. The UK Ministry of Defence, for example, accounts for half of central government's greenhouse gas emissions, two-thirds of water use and 56 percent of waste. The burden of moving huge volumes of fuel has led most defence organizations to find innovative new ways to reduce their carbon footprint, ranging from personal solar generation to small-scale nuclear reactors. The other solutions for the sector are transitioning to alternative green fuels, increasing fuel efficiency and electrification.

Yet, defence organizations themselves typically prioritize performance over all considerations. The defence footprint also extends into many parts of industry via major defence manufacturers at home and abroad, increasing these companies' indirect carbon emissions, use of scarce resources and pollution. As a result, most defence companies are trying to reduce their carbon footprint across facilities by creating smart buildings, constructing and operating smart manufacturing facilities, and utilizing power efficiently. Curbing these impacts is a significant challenge, given that defence involves sectors with some of the toughest decarbonization challenges – notably aviation and maritime – as well as ageing, energy-efficient estates. Thus, moving away from fossil fuel makes sense not just from the climate point of view but also for the military survivability. The potential for interruption in fuel supply, whether from shortage or hostile action, is an Achilles' heel of military operations. Therefore, NATO and European armies can gain a strategic advantage when moving on fast with decarbonizing military infrastructure and its supply chain. Mitigation is essential to armed forces, not only to reduce logistic vulnerability but also to gain operational advantages and catalyze innovation at a broader scale.

Reducing the Defence Forces' carbon footprint starts with benchmarking. This requires developing a methodology to accurately measure and track greenhouse gas emissions from all defence activities. A standardized methodology and comprehensive assessment framework for greenhouse gas emissions, including

those embedded in products across their life cycles are needed. Although much can be drawn from other industries, military-specific environments and circumstances must be considered.

There are two major gaps. First, the day-to-day footprint of militaries themselves must include the emissions associated with the management of bases and estates –from providing infrastructure, cement and food to feed and house the troops. Second, a reckoning need on the impacts of infrastructure damage, land-use changes. Breaking down emissions by technology sectors will help to prioritize actions and targets. Studies on feasibility of adopting low-carbon technologies are key. Software that creates a barcode that can be scanned to reveal a product’s emissions data might be helpful; this is already used in the private sector to track emissions throughout a supply chain, for example in food and agriculture initiatives. Such data can inform declarations of emissions for processes, products or services.

Once reporting mechanisms are in place, plans for decarbonizing the military must be assessed and improved. Militaries will need support from researchers to do this effectively. One major challenge is “lock-in” emissions from military equipment are fixed for decades, owing to procurement processes and lifespans. For example, F-16 fighter planes entered service with the U.S. Air Force in 1979 and are not due to be retired until about 2040. Despite proposals to electrify land vehicles, and to promote synthetic fuels for aviation, fossil fuel use in global militaries will continue to rise for many years to come.

Warships, combat aircraft and ground vehicles must become more fuel-efficient and take advantage of renewable energy. For reconnaissance, lightweight craft, such as drones, and satellite data should be used more often. Solar photovoltaic arrays and electric vehicles should become the norm in military bases. The United Kingdom’s Ministry of Defence and its Defence Innovation Fund ideas scheme, the VITAL Living Lab develop and harness solar, geothermal, hydrogen and electric energy for use on the Royal Air Force’s (RAF) Leeming base as a testbed. This project will develop and harness full-scale experiments, exploring the application of cutting-edge solar technology, carbon sequestration techniques and geothermal, hydrogen and electric as potential energy sources for the Royal Air Force Leeming base. Critically, it will establish a carbon baseline and life cycle assessments at RAF Leeming base so that changes made to the estates and infrastructure are understood in a sustainability context (Newcastle University, 2021)²³³.

²³³ “Newcastle University supports RAF’s pathway to Net Zero”, press release, 18 November 2021.

Life-cycle impacts and raw material requirements are another black box. There could be unintended consequences when switching technologies, such as lithium-ion batteries, large amounts of energy – and subsequent emissions – are required in the supply chain. Using a new technology might increase reliance on rare earth materials, such as cobalt or antimony.

Viewing operations with a climate lens can often uncover emerging needs and demands, such as new mechanisms to crunch massive climate data, new materials to reduce corrosion as sea levels rise, and new means of generating power for expedition teams. As militaries work with industries to address these needs, they could create wholly new technologies that have the potential of commercial spillover. The military has produced important climate-related innovations but has seen relatively slow adoption of them. To reduce its reliance on diesel generators for power – and the often targeted fuel convoys that feed them – the U.S. Marine Corps has moved into the forefront of tactical solar generation (Sawislak et al, 2022)²³⁴. For example, in 2018, the Marine Corps even fully fielded a mobile solar power array designed to power an entire battalion command post. Green technologies have been receiving much attention globally over the past two decades, driven mainly by ever-increasing demands for more efficient and sustainable uses of resources. Doing nothing is not an option. A failure to decarbonize could leave defence budgets highly exposed to carbon taxes and reliant on fossil fuels, which may become increasingly expensive as the world transitions to alternative energy sources. This could impair the ability to invest in key capabilities.

To sum it up, militaries have a significant presence within their countries and are controlled environments – making them ideal places to generate, launch a scale new ideas. This includes ideas about climate change. By modeling the use of climate considerations to enhance operations as well as promote innovation, defence forces can encourage societies at large to view integrating climate as critical mission success.

²³⁴ Sawislak et al (2022). “Climate –forward defence”. Deloitte U.S., article, 15 September 2022.

APPENDIX 1: Military emissions accounting data in Denmark

Data	Units	2016	2017	2018	2019	2020
Master Data						
Personnel	Man-years	22.902	22.806	23.061	23.078	23.966
Building Mass	[m ²]	2.419.630	2.457.466	2.477.061	2.590.498	2.454.516
Heated Building Mass	[m ²]	1.750.609	1.773.788	1.702.231	1.789.966	1.687.209
Estates						
Water consumption	[m ³]	513.405	479.002	470.236	472.678	234.185
Electricity consumed	[kWh]	119.931.253	119.662.864	121.502.336	123.944.927	117.048.796
CO ₂ e	[tons]	30.552	22.289	23.691	17.836	14.093
District Heating – Actual consumption	[kWh]	108.062.231	113.564.672	105.543.226	105.076.564	103.521.744
CO ₂ e	[tons]	15.223	24.257	13.162	13.263	12.688
Individual Heating – Actual Consumption	[kWh]	82.937.428	80.652.598	91.195.539	80.506.550	42.501.576
CO ₂ e	[tons]	15.268	14.572	16.226	14.246	8.282
Total Heating – Actual Consumption	[kWh]	190.999.659	194.217.270	196.738.765	185.583.114	146.023.320
Total Heating – Heating normalized by degree days	[kWh]	211.794.285	217.111.576	224.533.204	215.206.476	194.649.687
CO ₂ -e from Estates	[tons]	61.043	51.118	53.078	45.345	35.063
Total Energy Consumption	[kWh]	331.725.538	336.774.440	346.035.540	339.151.403	311.698.483
Cooling- and Extinguishing Agents						
CO ₂ from Cooling- and Extinguishing Agents	[tons]	14.203	7.677	9.077	6.150	3.750
Fuels						
Fuel consumption	[liters]	81.212.425	80.066.940	94.193.282	73.987.124	71.485.880
CO ₂ e from Fuels	[tons]	211.621	210.706	244.565	191.594	187.624
Energy consumption	[kWh]	797.676.534	788.713.768	922.005.978	728.282.436	702.681.390
Travels total		94.110.922	101.219.499	103.336.581	99.779.905	42.819.654
Travels by plane	[km]	75.301.472	77.615.193	78.929.444	73.497.920	24.158.829
Travels by car	[km]	18.809.450	23.604.306	24.407.137	26.281.985	18.660.825
CO ₂	[tons]	12.575	10.650	10.641	10.678	4.844
Key Figures						
Energy Consumption from Estates and Fuels	[kWh]	1.129.402.072	1.125.488.208	1.268.041.518	1.067.433.839	1.014.379.872
CO ₂ e total	[tons]	299.442	280.152	317.361	253.767	231.281
CO ₂ e total	[tons CO ₂ e/man-year]	13	12	14	11	10

Source: Danish Ministry of Defence (2021). "Carbon Account 2020"

APPENDIX 2: Military emissions accounting data in the United Kingdom

	Emission Sources	Ref	2019-20	2020-21	2021-22
Non-Financial indicators tCO ₂ e 000s	Defence Carbon Footprint (Scope 1,2,3)		3650	2,889	3,341
	Estate Emission and Business Travel UK only(covered by GGC 2025) and Capability Energy (b+d+f+k)		3,084	2,527	2,901
	Estate Emissions and Business travel UK only (covered by GGC 2025) (b+f+k)		1,097	1,043	956
	Scope 1		2,621	2,152	2,538
	Estate Direct Emission (UK and overseas)	A	596	633	558
	of which GGC (UK only)	B	553	597	522
	Capability Energy	C	1,987	1,485	1,945
	Fugitive emissions	D	38	34	35
	Scope 2		496	421	399
	Estate electricity and heat (UK and overseas)	E	496	421	399
	Of which GGC (UK only)	F	465	395	375
	Scope 3		533	316	403
	Waste generated	G	4	3	3
	Employee commuting	H	58	41	50
	Service Family Accommodation	I	186	184	183
Duty travel (UK and overseas)	J	285	87	168	
Of which GGC (UK only)	K	79	51	58	
Related Energy Consumption KWh 000s	Electricity: Non-renewable		1,788,171	1,661,414	1,726,487
	Electricity: Renewable		18,748	21,401	20,261
	Natural Gas		2,562,547	2,740,139	2,471,064
	LPG		80,331	91,811	82,106
	Other		417,683	428,035	343,735
Related Equipment Energy Consumption Litres 000s	Aviation fuel		472,029	384,998	424,391
	Ground fuel		57,074	21,654	32,999
	Maritime fuel		200,065	141,458	245,307
	Other fuel		180	190	287
Financial Indicators GBP	Expenditure on energy		347,132	317,890	336,155
	Expenditure on official business travel		156,985	80,651	78,647
	Expenditure on equipment energy (fuel)		323,339	287,702	278,592

APPENDIX 3: Water and Waste Data in the United Kingdom MoD

Water data		2019-20	2020-21	2021-22
Non-Financial Indicators 000s m ³	Water consumption ²³⁵	15,618	15,306	15,235
Financial indicators £000s	Water and Wastewater supply costs (GB estate within GGC scope)	62,286	63,839	65,374

Waste Data ²³⁶		2019-20	2020-21	2021-22
	Total waste	56	47	46
	Landfill	2	2	1
	Recycled	18	12	14
	Reused	0	0	1
	Composted	5	5	5
	Incinerated with energy efficiency	34	32	32
	Incinerated without energy recovery	2	0	0

²³⁵ Water consumption represents the new Greening Government Commitments (GGC 2021-25) scope which includes approximately 2,400 private company's Aquatrine sites (based on the Government's Private Finance Initiatives (PFI) the company provides water and wastewater services). The UK MoD has been a pioneer in service contracts and outsourcing those contracts. Furthermore, the new GGC scope excludes Distribution Losses and Service Family.

²³⁶ Waste data follows the new GGC2021-25 Scopes which include all MoD UK estates waste generated. The new Scopes elude military end of life equipment, hazardous waste, waste generated from Service Family Accommodation, sanitary and clinical waste.

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