The Hague Centre
for Strategic Studies

Resilient and Robust

Climate-Proofing the Military for Increased Military Effectiveness

Irina Patrahau, Laura Birkman, Michel Rademaker, Tom Middendorp and Ella MacLaughlin

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Solar panels power tank battalion compound,
WikiMedia Commons

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THE GOVERNMENT
OF THE GRAND DUCHY OF LUXEMBOURG
Ministry of Foreign and European Affairs

Directorate of Defence

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Introduction

Armed forces have protected their countries' national security interests for centuries. The Russian invasion of Ukraine in February 2022 restored concerns over protecting territorial integrity that were side-lined by European countries after the Cold War. The need to enhance military operational effectiveness materialized into significant increases in European defence budgets, totalling an estimated additional defence spending of €200 billion over the next years.[1] Capabilities that have been weakened over time need to be revitalized and modernized to respond to the changing geopolitical setting. The crisis in Ukraine also highlighted the importance of securing global supply lines. Energy security and the energy transition became priority areas within NATO and the European Union (EU). These challenges should be seen in the context of climate-related changes to the operational environment.

Until now, climate-related discussions hardly affected military force requirements. That changed at the Chicago Summit in 2012, when NATO members unanimously agreed to improve the energy efficiency of their military forces. While it was widely recognised that this measure would also significantly reduce the carbon footprint of the armed forces, it was not explicitly motivated by climate change.[2] Rather, it was driven by the need to decrease costs of transporting fuel to battlefields and reduce the risks of these supply lines being targeted by adversaries.[3]

Today, the rationale behind this agreement remains, albeit with a stronger awareness and understanding of the importance of climate proofing the armed forces as a precondition for operational effectiveness, rather than a positive side effect.

Focusing on existing technologies and policies, this report offers a range of potential opportunities for armed forces to become more self-sufficient in their operations. It shows how new technologies can help armed forces reduce their carbon and logistical footprint, while maintaining - or even strengthening - their operational effectiveness. It divides the lines of effort between military installations and operations, providing examples of dual-use and military technologies that can support the decarbonization of armed forces.

A multi-method approach was used to develop the paper including desk research, game-driven analysis, and expert interviews. The research was conducted within the context of the 2022 Warsaw Security Forum, where the topic of climate-proofing defence was the focus of a roundtable expert meeting and two tabletop exercises of the 'Climate Security Industry for Defence' serious game, co-organized by *The Hague* Centre for Strategic Studies (HCSS).

1 Paul Taylor, 'How to Spend Europe's Defense Bonanza Intelligently', *POLITICO* (blog), 2 September 2022, https://www.politico.eu/article/european-union-defense-russia-ukraine-invasion-intelligent-budget/.

2 'Emissions Savings', IEA, accessed 16 December 2022, https://www.iea.org/reports/multiple-benefits-of-energy-efficiency/emissions-savings.

3 Expert Group of the International Military Council on Climate and Security et al., 'The World Climate and Security Report 2022: Decarbonized Defense - Combating Climate Change and Increasing Operational Effectiveness with Clean Military Power, The Need for Clean Military Power in the Age of Climate Change'.

The first section highlights technologies that can be used to mitigate the climate impact of armed forces and improve self-sufficiency. The second section offers some initial insights into areas where disruptive green technologies can support military climate adaptation programs and strengthen the resilience of capabilities.[4] The final section offers food for thought on some enablers of climate action in the armed forces like: policy frameworks and institutions; funding and procurement; innovation and public-private collaboration; and human capital and behavioural change. These factors can accelerate climate action in the military and are necessary to ensure the adoption of new low-carbon and climate neutral technologies.

4 This topic is briefly addressed but requires further in-depth investigation.

Managing mitigation for military resilience

Decarbonizing installations: a low hanging fruit

Military installations offer immediate opportunities to decarbonize and become self-sufficient in their energy supply. At the centre lie dual-use technologies. In the past, the military sector was the primary domain for dual-use innovation and testing. Now the civilian domain is at the forefront of most dual-use green innovation, driven by private endeavours. The military can reap the benefits from well-established product development processes and enormous investments. A list of existing technologies that can be used for climate mitigation by the armed forces is available in Appendix II.

Due to the extensive opportunities for dual use, military installations can follow the lead of civilian climate plans, including the European Union's (EU) target to reduce greenhouse gas (GHG) emissions by 55% by 2030[5] and net zero by 2050[6]. They offer win-win opportunities for civil-military cooperation in the fields of energy production, conversion and storage. Installations include all technologies, equipment, and facilities used by the employees of defence organisations, as well as those for the sheltering, residence and training of troops.[7] They do not need to be mobile and are located in secure areas. The characteristics of the required energy system is quite similar to the characteristics of a village or a large civil installation. They have similar requirements for their water supply, air conditioning, heating systems. This offers the opportunity for defence forces to intersect with civilian technologies and take advantage of rapid civil innovations as a 'smart follower'.

The lowest hanging fruit to reduce the carbon footprint of defence are electricity and heat generation methods in civilian offices and vehicles, military bases and training centres for which technology is already available now (Figure 1 and Figure 2).[8] Well-insulated buildings require less energy for heating in the winter and cooling in the summer. Installing reflective insulation and sealing air leaks are two ways in which building insulation can be improved.[9] Innovative materials such as Y-Warm[10] can lower energy consumption and reduce costs even further. Funds can be redirected and used to strengthen other military capabilities, increasing operational effectiveness.

5 European Commission, '"Fit for 55": Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality', 14 July 2021, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550.

6 European Commission, 'A European Green Deal', Text, Priotities 2019-2024 - European Commission, 2020, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

7 See Appendix I for the complete definitions used throughout this paper.

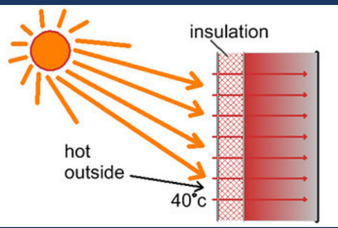
8 Harry Bowcott et al., 'Decarbonizing Defense: Imperative and Opportunity' (McKinsey & Company, 2021), 4, https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/decarbonizing-defense-imperative-and-opportunity.

9 'How Does Insulation Conserve Energy?', Home Guides | SF Gate, accessed 12 September 2022, https://homeguides.sfgate.com/insulation-conserve-energy-78704.html.

10 'New Insulation Material Y-Warm Helps Reducing Carbon Emissions', Big News Network.com, accessed 12 September 2022, https://www.bignewsnetwork.com/news/264284196/new-insulation-material-y-warm-helps-reducing-carbon-emissions.

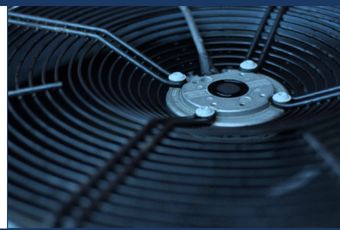
Low-carbon heating and cooling systems

New Y-Warm thermal insulation material for internal and external building insulation



(Singal, flickr)

Solareast R32 Three-in One-air source heat pumps for external heat absorption into buildings



(Niklas Morberg, flickr)

Figure 1. Low carbon heating and cooling systems and insulator materials

Moreover, microgrids offer important opportunities to decrease reliance on fossil fuels. Microgrids are local energy grids with the ability to operate autonomously.[11] Research suggests that hydro-powered microgrids in a military setting are more reliable than those powered by wind or solar power, because water is highly controllable and the amount required to run the grids is so minimal that hydropower is still obtainable in drought-stricken regions, e.g., through the use of grey water.[12]

The ability to use smart technologies can furthermore reduce energy use and waste. Smart meters include both gas and electricity data on the same meter and update regularly. Smart meters increase the cost-effectiveness of energy consumption and ensure the efficiency of energy allocation across military functions.[13] In combination with smart meters, large-scale batteries can store excess energy and reallocate it once required. In this way military installations and vehicles used outside contested territories can become more self-sufficient and less dependent on foreign energy sources.

Using synthetic fuels as well as increasing energy efficiency – is already a priority for various armed forces investing in emerging technologies.[14] This reduces dependency on fossil fuels while also enhancing the strategic autonomy of European armed forces as they become self-sufficient rather than dependent on foreign powers. The military airbase in Leeuwarden, the Netherlands, for example, is installing a solar park in combination with electrolysers to produce hydrogen for use in heavy duty transport, fleet and ground equipment. The solar park is expected to enter into operation in 2024,[15] followed by the production of green hydrogen for heavy transport within 5 years, for heating buildings within 10 years, and for producing synthetic kerosene after more than 10 years.[16]

11 'Army Engineer: Microgrids Are the Future of U.S. Energy Security', www.army.mil, accessed 12 September 2022, https://www.army.mil/article/207563/army_engineer_microgrids_are_the_future_of_u_s_energy_security.

12 'Army Engineer'.

13 'Smart Meters: A Guide for Households', GOV.UK, accessed 12 September 2022, https://www.gov.uk/guidance/smart-meters-how-they-work.

14 NATO, 'Climate Change & Security Impact Assessment', 2022.

15 'Leeuwarden Solar PV Park, Netherlands', *Power Technology* (blog), 17 February 2022, https://www.power-technology.com/marketdata/leeuwarden-solar-pv-park-netherlands/.

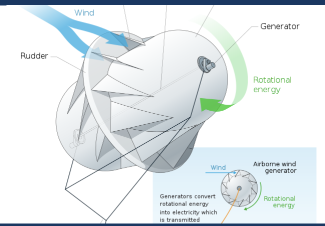
16 Peter de Laat, 'Overview of Hydrogen Projects in the Netherlands', 71, https://www.topsectorenergie.nl/sites/default/files/uploads/TKI%20Gas/publicaties/Overview%20Hydrogen%20projects%20in%20the%20Netherlands%20-%20version%2018%20May%202021.pdf.

Low-carbon electricity generation in military installations

Photovoltaic roof tiles and solar panels on building roofs (home-base) or mobile command centers (expeditionary)

(U.S. Department of Energy, flickr)

Airborne wind energy generated from flying blades, tethered to the ground or directly to an installation



(James Provost, Wikimedia Commons)

Solar and wind based battery management systems for vehicle maintenance

(Ivan Radic, Wikimedia Commons)

Canadus HD-1224 battery reconditioner or desulfator combined with solar technology for vehicle battery maintenance

(Defence Imagery, flickr)

Figure 2. Opportunities for low-carbon electricity generation in military installations

Smarter and Leaner Operations

Green technologies can increase operational independence by reducing the required logistical support, the dependence on local resources, and the need to allocate forces to secure those supply lines. Operational energy consumption by armed forces is dominated by transportation, with jet fuel accounting for 70% of energy used in training, moving and sustaining military forces and platforms in the United States, followed by diesel for vehicles, ships and passenger fleets.[17] Clear benefits can be derived from shortening supply chains in conflict areas. By bypassing the transportation of large amounts of fuel across long distances in hostile terrain, the chances that energy sources would be sabotaged decrease.[18]

In 2012, the US Army delivered Advanced Medium Mobile Power Systems (AMMPS) to Afghanistan in order to decrease the chances of fuel convoys being targeted by roadside attacks, cutting fuel consumption by 21%.[19] James Mattis, a retired US Marine Corps four star general and former US secretary of defence, argued in 2012 that "the military must be unleashed from the tether of fuel".[20] More than 3000 American troops and civilian contractors were killed or wounded in 2009 protecting convoys, 80% of which were transporting fuel.[21] The high risk of sabotage during the transportation of fuel means that soldiers, heavily armoured vehicles, and other resources are required to deter attackers. With a self-sufficient energy grid, the personnel and resources required to protect this logistic supply chain could be redirected to enhance capabilities in other areas.

17 Bowcott et al., 'Decarbonizing Defense: Imperative and Opportunity', 3; Neta C. Crawford, 'Pentagon Fuel Use, Climate Change and the Costs of War' (Boston University, 2019), 7–8, https://watson.brown.edu/costsofwar/papers/ClimateChangeandCostofWar.

18 Ben Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe' (IISS, 2022).

19 Nancy Jones-Bonbrest, 'Army to Deliver Fuel-Efficient Generators to Afghanistan', www.army.mil, 2012, https://www.army.mil/article/81578/army_to_deliver_fuel_efficient_generators_to_afghanistan.

20 Greg Doquet, '"Unleash Us from the Tether of Fuel"', *Atlantic Council* (blog), 11 January 2017, https://www.atlanticcouncil.org/content-series/defense-industrialist/unleash-us-from-the-tether-of-fuel/.

21 Doquet.

In the operational environment many civil disruptive innovations can still be used, but they need to meet extremely high reliability standards. In other words, they cannot be used as they are. They need to be improved and integrated in existing military capabilities and platforms. They need to be cyber-proof and be able to operate in harsh operational conditions such as time sensitive and violent mobile situations, and extreme temperatures. In the operational domain armed forces cannot be just a smart follower of civil green innovation, they need to be a smart integrator and user of these technologies.

When it comes to heavy operational capabilities like tanks, vessels and airplanes, lowering emissions and achieving self-sufficiency is a challenge. Technologies must pass the so-called 'SWaP challenge' – size, weight and power – to be adopted in the military. For instance, manoeuvrability (understood as the ratio between thrust and size) is essential for the air force. A low-carbon fuel (blend) must allow fighter jets to move with the same ease and speed as they can currently in order to maintain operational effectiveness. Currently, liquid hydrocarbons (diesel, kerosene) still have the highest energy density out of all fuels, allowing troops to travel farther distances with less fuel – an essential capability when operating in hostile or isolated areas.

Incremental change is necessary for heavy operational capabilities because green technologies still lack the maturity to match existing ones. In the short term, in-between solutions such as biofuel blends obtained from organic waste or the use of alternative fuels outside of contested territories, could be adopted to reduce the carbon footprint. Both heavy and light carrier systems and vehicles often rely on the same motors or are identical to civilian counterparts. Moreover, the fact that certain ships and planes engines can run on biofuels without modifications would easily support emissions reductions (Figure 3).

Box 1. Atmospheric water generators for remote locations[24]

Genaq is a Spanish company that developed a portable atmospheric water generator (AWG) in response to water accessibility challenges. Water for drinking, cooking, hygiene or cleaning in remote areas can be produced through their AWG with no waste and without the necessity of water supply. The machines can be integrated with solar panels to produce water in a sustainable and cost-effective way.

Genaq also developed an emergency response unit which can provide water in crisis situations like earthquakes or floods. This unit can also be rapidly deployed in civil or military camps. It was designed in a way that transportation does not alter its functioning and brings great opportunities for armed forces.

24 'Atmospheric Water Generator by GENAQ', GENAQ, accessed 2 February 2023, https://www.genaq.com/.

Opportunities to decarbonize shipping and aviation

Airbus A380 100% biofuel powered passenger jet

(Mottl, Wikimedia Commons)

GoodFuels 100% biofuel inland container vessel

(OLionnain, flickr)

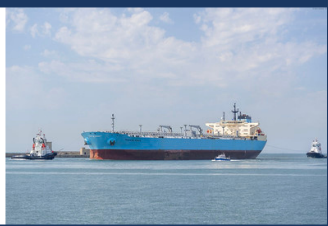
US "Green Hornet" Naval Fighter jet with GE F414 engine and noise reduction kit

(Sullivan, flickr)

NYK 100% biofuel Capsize Bulker

(Eddie, flickr)

BP/Maersk tankers with non-modified main and auxiliary engines and boiler



(Prevot, flickr)

Boskalis 100% biofuel dredging vessel

(Torn, flickr)

Figure 3. Opportunities to decarbonize shipping and aviation

Conventional biofuels made of food crops like sugar cane, corn and soybeans are not sustainable in the long term. Instead, advanced biofuels produced from waste, cellulosic ethanol and biomass-based Fischer Tropsch technologies are increasingly mandated through legislation.[23] For armed forces' to reduce their climate footprint in a sustainable way, advanced biofuels should be pursued.

In the longer term the armed forces should focus R&D efforts on developing (technologies for) next generation heavy capabilities that have a net-zero footprint and a high level of self-sufficiency. This requires a more intense cooperation not just with defence industries, but also with small and medium enterprises (SME) that bring disruptive technologies to the table, and the wider civil maritime and aviation sectors that face similar challenges.

In addition to heavy operational capabilities, the decarbonization of light capabilities brings operational advantages. Light operational capabilities include small military weapons, carrier systems and transport vehicles, as well as light reconnaissance and attack equipment like unmanned aerial vehicles (UAVs) and smaller drones. For example, electric vehicles can increase stealth as they produce less noise and have a lower heat signature.[24] Passive sensors are robust to electronic warfare because they do not emit energy.[25] Examples are illustrated in Figure 4.

23 'Biofuels', IEA, 2022, https://www.iea.org/reports/biofuels.

24 Top Sector HTSM, 'Roadmap Security', May 2018, https://hollandhightech.nl/_asset/_public/Innovatie/Technologieen/z_pdf_roadmaps/Roadmap-Security-2018-2025.pdf.

25 Top Sector HTSM.

Hybrid electric systems

General Motors unmanned Silent Utility Rover Universal Superstructure (SURUS)

(GM Authority)

Alia-250 electrical vertical take-off and landing aircraft

(BETA Technologies, Wikimedia Commons)

Hybrid propulsion systems for diesel-powered ships

(U.S. Navy, flickr)

ST-35 Silent Thunder battery-powered loitering munition drone

(Athlon-Avia Unmanned Solutions)

Figure 4. Low carbon operational capabilities

A push toward digitalization and semi-autonomous systems would support decarbonization by reducing the weight on board (less people, equipment, food etc.) and thus the demand for fuel. Synthetic environments for simulations are another way of decarbonizing. By allowing the Air Force to train and experiment in realistic and immersive environments, they can improve their operational capability without burning fuels. For instance, French military pilot trainings include virtual simulations of energy-efficient operations.[26] Military training can support the development of climate literacy and energy efficient behaviours in missions.

Additionally, interchangeability and flexibility are strengths of military technologies that can serve climate-proofing goals. Modular designs ensure that the technology consists of smaller parts that can be independently created, modified or replaced. Modular designs can thus enhance circularity and recycling.[27] Products will have a longer life cycle given that damaged or faulty components can be replaced individually.

26 Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe'.

27 Natália Machado and Sandra Naomi Morioka, 'Contributions of Modularity to the Circular Economy: A Systematic Review of Literature', *Journal of Building Engineering* 44 (1 December 2021): 103322, https://doi.org/10.1016/j.jobe.2021.103322.

Integrating adaptation capabilities

Climate proofing the military entails efforts of climate adaptation and resilience in addition to climate mitigation. Extreme weather conditions, global warming and sea level rise are already affecting military installations and operations around the world. In 2016, the engines of UK's Type 45 destroyers broke down in the very warm seas of the Persian Gulf, requiring a GBP 160 million multi-year program to modify the engines.[28] The diesel generators became overloaded because of the temperature and failed, leaving the ships without any power. The role of armed forces is also evolving as a result of increasingly threatening climate events. In support of disaster relief, NATO provided helicopters, pilots, crewmembers, and mechanics to various Mediterranean countries during the large-scale wildfires in the summer of 2022.[29]

Adaptation efforts are closely intertwined with climate mitigation. Reducing fuel consumption decreases logistic requirements.[30] When operations rely on self-produced electricity and purified water, they are less dependent on vulnerable supply chains and local infrastructure. This not only helps operations adapt to a new environmental reality, but it also makes them more resilient to the effects of environmental crises on their logistical capacity. An integrated approach of mitigation, adaptation and resilience is key to climate proof the military while maintaining and/or increasing operational effectiveness.

Preparing for extreme events such as forest fires, cyclones and flooding is essential to ensure the uninterrupted functioning of installations.[31] The most straight-forward solution for climate adaptation and resilience is to build new installations in areas that are least vulnerable to climate change. However, it is strategically disadvantageous to locate all installations in similar areas (for example, areas high above sea level). Existing installations will remain in vulnerable areas, and new buildings will require resilience to the novel climate conditions.[32]

The design knowledge and technology required for adapting installations has been developed over time, as the weather conditions caused by climate change have long been present in certain regions of the world. Design principles such as high ceilings, light-coloured roofs, and minimized openings on the east and west sides of buildings can be adopted and coupled with new technologies that increase resilience to climate change even further.[33] Based on the foreseen environmental threats, comprehensive climate resilience plans can be developed for installations to ensure their sustainment over the intended lifespan of the infrastructure.[34]

28 George Allison, 'Type 45 Destroyer Propulsion Fix "Going Well"', *UK Defence Journal* (blog), 4 October 2022, https://ukdefencejournal.org.uk/type-45-destroyer-propulsion-fix-going-well/.

29 NATO, 'NATO Allies Stand Together against Wildfires', NATO, accessed 26 August 2022, https://www.nato.int/cps/en/natohq/news_186029.htm.

30 Lucia Retter et al., 'Crisis Response in a Changing Climate: Implications of Climate Change for UK Defence Logistics in Humanitarian Assistance and Disaster Relief (HADR)and Military Aid to the Civil Authorities (MACA) Operations', n.d., 86.

31 U. N. Environment, 'A Practical Guide to Climate-Resilient Buildings & Communities', UNEP - UN Environment Programme, 7 May 2021, http://www.unep.org/resources/practical-guide-climate-resilient-buildings.

32 Sara Schonhardt News E&E, 'Military Operations Will Be Strained by Climate Change', Scientific American, accessed 21 October 2022, https://www.scientificamerican.com/article/military-operations-will-be-strained-by-climate-change/.

33 Environment, 'A Practical Guide to Climate-Resilient Buildings & Communities'.

34 'Department of Defense Climate Adaptation Plan' (U.S. Department of Defense, 2021).

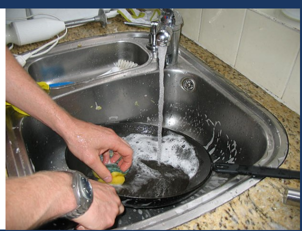
Extreme weather events will require armed forces to be more proactive in water management processes. For coastal installations, rising sea levels and increased risk of flooding can be addressed with elevated buildings. In cases where there is a risk of extreme flash flooding, buildings can be made buoyant, resting on pillars with buoyant tanks that rise during floods.[35] Meanwhile, for installations in areas at risk of drought, methods must be adapted to store, filter, and purify water. Water may be obtained through harvesting rainwater, retaining groundwater, and accumulating water from the atmosphere. Transportable skid-mounted water treatment systems can treat sea-, brackish, and freshwater, as well as water contaminated with nuclear, biological, and chemical warfare agents.[36] Used or contaminated water may be purified and re-used with technologies detailed in Figure 5. These technologies not only increase resilience to climate change, but they also boost operational effectiveness by reducing reliance on water delivery systems and preventing poisoning and disease from contaminated water sources.

Additionally, buildings should be made resilient to strong winds, including cyclones where relevant. Buildings could include frangible architecture: design that allows for small breakages (e.g. a roof above a patio breaking off) in order to prevent more intense structural damage. Roofs may be built or modelled to have very strong connections to building foundations, multiple slopes, and central shafts that take in outside air, which will reduce the pressure of wind on the roof.[37]

In the last few years, European armed forces have also become more active in supporting civilian efforts of humanitarian assistance and disaster relief (HADR) following environmental crises. In 2017, Dutch and French troops supported the response effort in Sint Maarten following Hurricane Irma.[38] This had already become an established practice in South Asian countries since the 1990s. For instance, Japanese armed forces rapidly engaged with recovery efforts

Opportunities for water purification and re-use

Re-use of grey water can lead to a 65% reduction in necessary base water supply.



(Secretariat, Wikimedia Commons)

Membrane bioreactors (MBR) can provide automated wastewater treatment to produce water requiring minimal disinfection.

(Hoots, Wikimedia Commons)

Reverse osmosis (e.g. Reverse Osmosis Systems from Pure Aqua) can provide portable clean water treatment.

(Staff Sgt. Jorge Intriago, Wikimedia Commons)

Wastewater Electrochemical Treatment Technology can treat highly contaminated water and is automated and maintenance-free.

(US Army Environmental Command, Flickr)

Figure 5. Opportunities for water purification and re-use

35 Environment, 'A Practical Guide to Climate-Resilient Buildings & Communities'.

36 'Military Portable Water Purification Systems | MECO', accessed 12 September 2022, https://www.meco.com/industries/defense/.

37 Environment, 'A Practical Guide to Climate-Resilient Buildings & Communities'.

38 See Catherine Mukosa, 'What to Know About Hurricane Irma in St. Maarten/St. Martin?', https://www.sint-maarten.net, 4 October 2022, https://www.sint-maarten.net/climate/hurricane/irma.

after the 2011 earthquake and tsunami, and the US military provided extensive humanitarian aid in the aftermath of Typhoon Haiyan in the Philippines in 2013.[39]

As extreme weather events become more prevalent, military HADR could develop from being occasional and ad-hoc to being a core part of operations. For instance, following Hurricane Dorian, the British Royal Navy support ship RFA Mounts Bay is now tasked to be present in the Caribbean every year in case of disasters; and following Typhoon Haiyan, the US maintained their operational bases in the Philippines and increased collaboration with the Filipino armed forces for HADR via the Enhanced Defense Cooperation Act.[40]

Heat stress is a direct threat to human health that significantly affects physical and mental performance. It can be a determining factor for the success of operations, either directly by causing heat strokes or indirectly by reducing troop effectiveness.[41] Especially in the case of short-notice deployment of troops, there is little time for personnel to acclimatize with the existing climate conditions on the ground.[42] Military troops have been training in extreme conditions for a long time, but those conditions are constantly and rapidly changing. For instance, the Arctic region is increasingly at the forefront of defence and political institutions. In 2022, NATO organized the 'Cold Response' exercise to test the ability of 30,000 troops to work together in cold weather conditions in preparation for operating in the Arctic environment.[43]

39 Deon V. Canyon, Benjamin J. Ryan, and Frederick M. Burkle, 'Rationale for Military Involvement in Humanitarian Assistance and Disaster Relief', *Prehospital and Disaster Medicine* 35, no. 1 (February 2020): 92–97, https://doi.org/10.1017/S1049023X19005168.

40 'Ministry of Defence Climate Change and Sustainability Strategic Approach', n.d., 15.

41 Iain T. Parsons, Michael J. Stacey, and David R. Woods, 'Heat Adaptation in Military Personnel: Mitigating Risk, Maximizing Performance', *Frontiers in Physiology* 10 (2019), https://www.frontiersin.org/articles/10.3389/fphys.2019.01485.

42 Parsons, Stacey, and Woods.

43 NATO, 'Exercise Cold Response 2022 – NATO and Partner Forces Face the Freeze in Norway', NATO, 2022, https://www.nato.int/cps/en/natohq/news_192351.htm.

Box 2. Harvesting fresh water in the desert[46]

SunGlacier and Ap Verheggen: Emerging technology for harvesting water from air in dry environments

SunGlacier technologies and designer Ap Verheggen have developed cutting edge technology to produce fresh water in a desert climate with very little solar energy. During the Dubai World Expo 2020, SunGlacier technology was exhibited at the Netherlands' pavilion where it was able to produce 1200 litres of water per day used both as drinking water and for the irrigation of vegetation. Water is produced by capturing air moisture and putting it through a condensation process that relies on solar power. This innovative technology increases the availability of fresh water even in desert heat, giving significant opportunities for the sustainable production of water in challenging hot environments. If scaled up and used in a military context, dependence on local resources and supply chains is removed. So is the need of supplying bottled water, which therefore also significantly reduces (plastic) waste.

46 Giovanni Prati, 'The Netherlands Expo Pavilion Makes Its Own Water to Grow Food in the Desert Heat', CNN, February 2022, https://www.cnn.com/travel/article/netherlands-pavilion-expo-2020-dubai-spc-intl/index.html; 'SunGlacier', accessed 19 December 2022, https://sunglacier.nl/.

Enabling factors

Four factors are essential to create an enabling environment for climate-proofing the military: (1) policy frameworks and institutions; (2) funding and procurement; (3) innovation and public-private collaboration; and (4) human capital and behavioural change. If these factors are not tailored to support climate action, they could be actively constraining climate action in the military.

Policy frameworks and Institutions

International organizations can be trendsetters, leading by example. NATO has a successful track record as a standard-setter due to its normative influence and its ability to enhance interoperability between various defence organisations, doctrines and equipment.[45] While NATO plans cannot be legally enforced, reputational costs are high if a member refuses to adhere to such goals.

NATO's Action Plan on Climate Change and Security was adopted in 2021, contributing to raising awareness, developing a methodology on measuring greenhouse gas emissions and setting targets to reduce these emissions by 45% in 2030 and net zero by 2050.[46] Moreover, the NATO Climate Change and Security Centre of Excellence (CASCOE) has been under development since 2022, at the initiative of the Canadian government. The Centre aims to facilitate the joint development of capabilities, knowledge sharing and best practices to reduce the climate impact of NATO's military activities.[47]

NATO's Single Fuels Concept changed the way armed forced use fuels. To maximize interoperability and simplify the fuel supply chain, all NATO forces are required to use the same fuel for aircraft, tanks and electricity generation. If NATO were to pursue similar goals for green technologies, member states would likely adhere to common defence goals. Interoperability will be more difficult to achieve in the case of green technologies than it was for fossil fuels, but a standardisation process by NATO would reduce barriers of adoption.

Even when climate-related discussions do not directly address the armed forces, they may still have a major influence on climate-proofing the defence sector. For instance, the EU will ban the sale of new internal combustion engine cars as of 2035.[48] This change will increase the market share of low-carbon cars and therefore decrease their costs, not only for regular civilian consumers but also for military use. Even if the armed forces were exempt from this

45 Expert Group of the International Military Council on Climate and Security et al., 'The World Climate and Security Report 2022: Decarbonized Defense - Combating Climate Change and Increasing Operational Effectiveness with Clean Military Power, The Need for Clean Military Power in the Age of Climate Change'.

46 NATO, 'Climate Change & Security Impact Assessment'.

47 'NATO Climate Change and Security Centre of Excellence', Government of Canada, 21 March 2022, https://www.international.gc.ca/world-monde/international_relations-relations_internationales/nato-otan/centre-excellence.aspx?lang=eng.

48 Kate Abnett, 'EU Approves Effective Ban on New Fossil Fuel Cars from 2035', *Reuters*, 28 October 2022, sec. European Markets, https://www.reuters.com/markets/europe/eu-approves-effective-ban-new-fossil-fuel-cars-2035-2022-10-27/.

ban, which does not seem likely,[49] electric vehicles will still become a more cost-effective option. Therefore, policies affecting the civilian sector shape low-carbon markets and can thus influence the procurement of climate-proof military technology.[50]

Leadership and consistency in driving change is key to ensure the implementation of green initiatives.[51] The UK, US and Austria and the Netherlands, among others, have already presented their national military decarbonization plans. The UK Ministry of Defence set a net-zero target for 2050,[52] while the Royal Air Force aims for 2040.[53] Other countries are active but have not set emissions targets. The French 2020 Defence Energy Strategy includes energy efficiency requirements to armaments programmes and especially focuses on reducing fossil fuel dependence.[54] The US similarly aims to increase efficiency and improve supply chain security for energy storage.[55] Some more detailed targets exist for instance in the Netherlands, aiming to generate 50% of energy in installations from renewable sources in 2030.[56] An overview of enabling policy frameworks for climate action in the military is provided in Appendix III.

Often, defence organisations in allied countries cooperate more closely with each other than with other departments in their home country, given that they face similar issues and can develop and pursue similar solutions.[32] Strengthening horizontal cooperation between defence organisations could lead to knowledge sharing and innovation. This applies to European institutions like the European Defence Agency but it could also open new avenues for dialogue with non-allied countries to share concerns about climate-related migration and conflict, energy crises or food shortages.

49 'Gevolgen van EU-ban ICE's voor Defensie', 1 November 2022, https://www.energievoorinzet.nl/europese-gevolgen-voor-defensie.
50 Abnett, 'EU Approves Effective Ban on New Fossil Fuel Cars from 2035'.
51 HCSS interview with Sharon Burke, 2022.
52 'Ministry of Defence Climate Change and Sustainability Strategic Approach'.
53 Royal Air Force, 'A Net Zero RAF by 2040', Royal Air Force, 23 November 2021, https://www.raf.mod.uk/news/articles/a-net-zero-raf-by-2040/.
54 Ministère des Armées, 'Stratégie énergétique de défense', 2020, https://www.defense.gouv.fr/ministere/politique-defense/strategie-energetique-defense.
55 'Department of Defense Climate Adaptation Plan'.
56 Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe'.

Box 3. Key policy considerations for climate mitigation by the armed forces

- Ambitious plans from large-scale norm-setting international organisations like NATO and EU
- Methodology and clear requirements to measure military emissions
- Long-term national (military) decarbonization plans and concrete targets
- Horizontal cooperation between armed forces in both allied and non-allied countries (e.g., joint R&D, joint procurement, pooling and sharing of future capabilities)

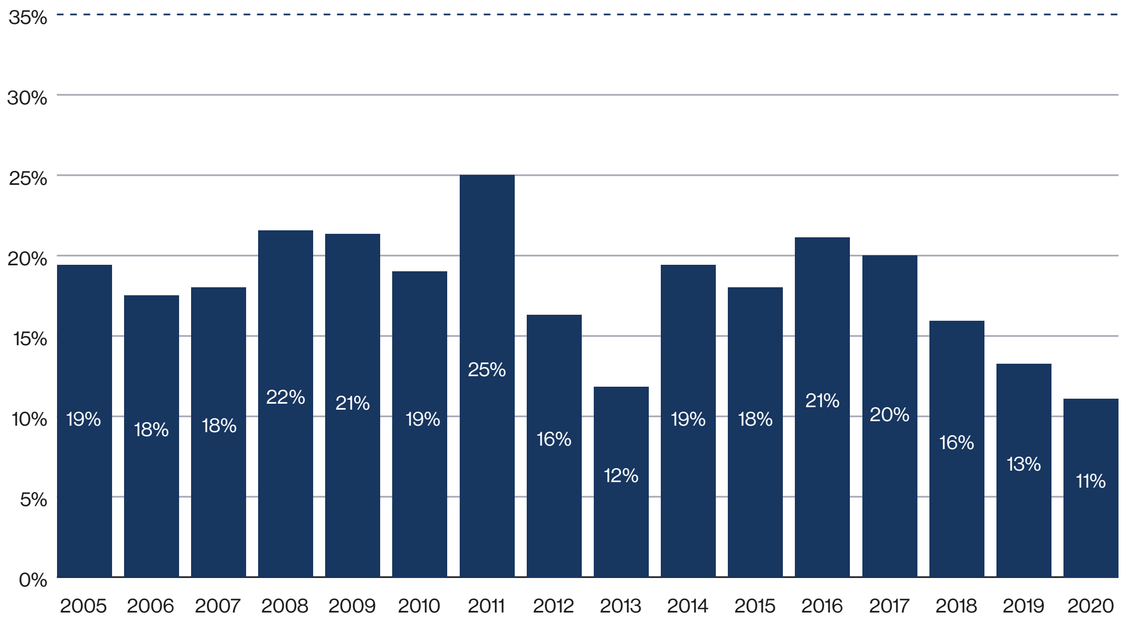
Funding and Procurement

The EU and its member states announced significant increases in their defence budgets following the invasion of Ukraine in 2022. The European Commission estimates that member states announced additional defence spending of €200 billion over the next years.[57] Germany alone will invest €100 billion to provide heavy transport helicopters, F-35 fighter aircrafts, U12 submarines, combat vehicles as well as personal equipment for soldiers.[58] Poland adopted the Homeland Defence Act in February 2022 with the aim of strengthening and modernizing national armed forces.[59]

Nonetheless, sustainability principles have thus far not been integrated in all European countries' defence procurement processes or across supply chains. There is not only a lack of frameworks, regulations and directives to ensure that armed forces themselves emit less, but also a lack of rules directing their industry partners, contractors and supply chains to take climate action.

Although the commitment under the Permanent Structure Cooperation (PESCO) is to deepen defence collaboration between EU states, this remains limited. In 2020, only 11% of equipment procurement took place in collaboration with other countries, compared to the commitment of 35% (Figure 6).[60] This makes it difficult to converge efforts and leads to the development of parallel, competing technologies.

Figure 6. European collaborative defence equipment procurement as percentage of total defence equipment procurement[63]



57 Taylor, 'How to Spend Europe's Defense Bonanza Intelligently'.

58 Peter Hille and Nina Werkhauser, 'How Will the German Military Spend €100 Billion?', DW.COM, June 2022, https://www.dw.com/en/how-will-the-german-military-spend-100-billion/a-62020972.

59 'More Troops and More Money for Defence – the Council of Ministers Adopted a Draft Homeland Defence Act', gov.pl, February 2022, https://www.gov.pl/web/primeminister/more-troops-and-more-money-for-defence--the-council-of-ministers-adopted-a-draft-homeland-defence-act.

60 'Defence Data 2019-2020: Key findings and analysis' (European Defence Agency, 2021), https://eda.europa.eu/docs/default-source/brochures/eda---defence-data-report-2019-2020.pdf.

61 Defence Data 2019-2020: Key Findings and Analysis

To ensure that defence spending from now on is done in a sustainable way, procurement processes must be updated. This is where calculations of scope 1, 2 and 3 emissions come into play. The military itself produces emissions (scope 1 in the case of, for instance, emissions produced by vehicles or ships; and scope 2 in terms of purchased electricity, heating or cooling), but so do the actors involved in procurement and supply chains (scope 3). Emissions may relate to transporting equipment from manufacturing to operating sites and to equipment maintenance and disposal.[62] As such, strict rules can scrutinize military acquisition and ensure that not only the armed forces but also their suppliers decarbonize.

Large institutional players like the European Defence Fund (EDF) and NATO could play a pivotal role in climate-proofing armed forces moving forward. NATO launched in 2022 its €1 billion Innovation Fund, aimed at start-ups and other venture capital funds developing relevant dual-use technologies in fields including artificial intelligence, novel materials, energy.[63] The European Investment Bank's (EIB) Strategic European Security Initiative is offering up to €6 billion by 2027 for dual-use cutting-edge technology.[64] While the EIB is not able to lend to the defence sector directly, this is an opportunity to overcome structural constraints associated with R&D funding for the defence sector and encourage inter-sectoral cooperation.[65] For EDF energy and climate remain a low priority, despite some recent progress. In 2022, out of the €924 million budget, only €20 million went to the research of green technologies, specifically to sustainable components for underwater applications.[66]

62 Bowcott et al., 'Decarbonizing Defense: Imperative and Opportunity'.

63 NATO, 'NATO Launches Innovation Fund', NATO, 2022, https://www.nato.int/cps/en/natohq/news_197494.htm.

64 'EIB Approves Strategic European Security Initiative, Confirms Ukraine Disbursement and Backs €543 Million Business and Clean Energy Investment', European Investment Bank, 2022, https://www.eib.org/en/press/all/2022-122-eib-approves-strategic-european-security-initiative-confirms-ukraine-disbursement-and-backs-eur543-million-business-and-clean-energy-investment.

65 European Commission, 'Roadmap on Critical Technologies for Security and Defence' (Strasbourg: European Commission, 15 February 2022).

66 'Factsheet on EDF Calls 2022', Defence Industry and Space, 2022, https://defence-industry-space.ec.europa.eu/eu-defence-industry/european-defence-fund-edf_en.

Box 4. Key financial factors for climate mitigation by the armed forces

- Integrate sustainability principles in all European countries' defence procurement and supply chains to accelerate action.
- Match the demand for green effective military technologies with funding initiatives like NATO's Innovation Fund, European Defence Fund's calls for proposals and, in the case of non-lethal equipment, European Investment Bank's Strategic European Security Initiative.

Innovation and Public-private collaboration

To successfully climate-proof armed forces, the need to decarbonise at all costs must be replaced with better incentives for green innovation to reduce costs and improve operational capability.

Once clear targets for European defence are set and funding is allocated, public-private cooperation with the European defence industry can facilitate the process of climate-proofing the armed forces. The defence industry must be incentivized to allocate funding and human capital to develop green and climate neutral military technologies and engage in climate action. Innovation should be encouraged so that technology push factors are replaced by pull factors.

Public-private collaboration on military green technologies needs to be further facilitated across Europe. Both pre-existing and emerging technologies have great potential for climate-proofing the military. Existing cutting-edge technology from the civilian sector should be adopted by the military as soon as possible. Being a fast follower of new commercial technologies, the military can reap the benefits from years long product development processes and enormous investments. Further, dual-use innovation should be explicitly pursued within partnerships between the defence industry, military, civilian private sector technologies, universities, and other relevant actors. Many of these technologies can be combined and integrated in new concepts for military compounds or for main weapon platforms. Using living labs within the armed forces has proven to be a very fruitful way of bringing together technology partners and research centres around certain central themes like future self-sustaining military bases. Armed forces can act as a platform for innovation, providing the conditions for successful development of new concepts and technologies through public-private cooperation.

For specific military technologies, the largest potential for civil and military sectors to overlap occurs in the early stages, during research and development (R&D).[67] Applications and standards start diverging eventually, but there is a lot to gain in the early development stages, nonetheless. NATO's Defence Innovation Accelerator for the North Atlantic (DIANA) focuses on developing test and innovation centres as a cooperative platform between national organizations, while also supporting the interconnection of private sector innovators with military end users to facilitate technology development.[68]

The European defence market, however, is quite fragmented, divided into a few large companies and many small and medium enterprises. Even between the large defence companies there are huge differences in market share. The yearly turnover of the largest 31 companies is €3 billion on average, but it ranges from €0.5 billion to €23 billion.[69] BAE Systems in the UK is Europe's largest defence company, with yearly military equipment worth €23 billion, followed by Airbus with €13 billion, Finmeccanica with €8 billion and Thales with €7 billion.[70] These companies are geographically concentrated in a few European countries: the UK, France

67 Maaike Verbruggen, 'The Role of Civilian Innovation in the Development of Lethal Autonomous Weapon Systems', *Global Policy* 10, no. 3 (2019): 340, https://doi.org/10.1111/1758-5899.12663.

68 NATO, 'NATO Sharpens Technological Edge with Innovation Initiatives', NATO, accessed 26 August 2022, https://www.nato.int/cps/en/natohq/news_194587.htm.

69 Alexander Roth, 'The Size and Location of Europe's Defence Industry', Bruegel, 2017, https://www.bruegel.org/blog-post/size-and-location-europes-defence-industry.

70 Roth.

and Italy. The smaller companies are spread across the continent. Defence SMEs are thus discouraged from playing an active role in research and innovation.[71]

While SME's have valuable human capital for innovation, they often cannot invest as much in R&D because their budgets pale in comparison to the main defence companies. While the European Defence Fund publishes many funding openings, the threshold for applying is often high for SMEs given that they may lack the capacity to track and review all very detailed conditions and engage with very bureaucratic processes. Funding platforms such as the EDF could take action to increase the accessibility of their financing instruments to SMEs, by decreasing the bureaucratic and administrative burden of applying for funding and facilitating information sharing. Additionally, funding opportunities that incentivize large defence companies to collaborate with SMEs in R&D should be promoted in order to stimulate cooperation.

At the same time, construction processes for large-scale projects like building new ships could give more flexibility and time for innovation. A ship for the navy may require a decade to complete construction. While the engine is often one of the first parts of the ship installed, a more strategic option would leave the engine as the last feature installed.[72] A decade of innovation while building a ship may bring new options for a less energy intensive low carbon engine design.

Technological inventions that do not have an obvious dual use could still prove useful for climate action in the long run. For example, GPS technology was initially invented for naval navigation by the US Department of Defense,[73] and the military communications network ARPANET was a key technological foundation of the Internet.[74] In many instances, innovations from the defence sector may later be able to be adapted to and sold in the civilian sector. This possibility of future dual-use purposes should give further momentum to defence-led green technological developments.

71 European Commission, 'Roadmap on Critical Technologies for Security and Defence'.

72 HCSS interview with Richard Nugee, 2022.

73 'A Position in History: 25 Years of GPS', *Airforce Technology* (blog), 21 July 2020, https://www.airforce-technology.com/analysis/a-position-in-history-25-years-of-gps/.

74 'From ARPANET to the Internet | Science Museum', accessed 23 November 2022, https://www.sciencemuseum.org.uk/objects-and-stories/arpanet-internet.

Box 5. Key factors for successful public-private collaboration

- Cross-fertilise opportunities between the public and private sector for dual use technologies.
- Promote greater SME involvement in defence research and development.
- Streamline and mainstream European procurement of green defence technology.
- Embrace the potentials of modularity in long-term technology planning.
- The armed forces should act as a platform for public-private innovation creating thematic living labs.

Human capital and Behavioural change

Climate-proofing would imply that sustainability and climate neutrality are integral parts of every decision within the defence sector, whether it relates to procurement, resilient supply chains, designing installations that can withstand extreme climate conditions or establishing principles of intervention for humanitarian purposes. In other words, climate intelligent policy making requires climate-related concerns to inform policy decisions across all sectors.[75]

The military's organisational culture is rooted in mandates, regulations, and codes of conduct: as long as people are trained and instructed to do something, they will. In order to make structural changes to the current modus operandi, operators and technicians must learn how to handle, use and repair green technologies. Military training can support the development of climate literacy and energy efficient behaviours in missions. Behaviour training of sustainable practices could contribute to decarbonization, for instance by training staff to optimize fuel on a platform or, in the future, extend battery life.[76]

75 According to the World Economic Forum, climate intelligence is "historical, current and predictive information on our natural and built systems used to power insights for climate mitigation and adaptation." See 'What Is Climate Intelligence – and How Can It Help Out with Climate Change?', World Economic Forum, 2021, https://www.weforum.org/agenda/2021/12/climate-intelligence-climate-change/.

76 HCSS interview with Eric Engelbracht, 2022.

Box 6. Key behavioural factors for climate mitigation by armed forces

- Integrate sustainability and climate neutrality as objectives in military decision-making.
- Mainstream climate literacy in military trainings.

Conclusion

The climate security debate must shift to an understanding that (1) climate-related mitigation and adaptation measures in the military are urgent and inevitable; (2) existing dual-use innovative green technologies can bring important operational advantages to European armed forces; (3) massive investments into R&D for future capabilities are needed to climate-proof the armed forces and enhance their operational effectiveness; and (4) military procurement processes and trainings must be updated.

A stepwise approach to climate proofing the military is necessary. When looking at military installations, dual-use and military technologies already offer opportunities for armed forces to enhance their operational effectiveness and reduce their climate footprint. Efforts to climate proof military installations should begin immediately. Sustainable mobility and micro-grids, low-carbon electricity generation, insulation of buildings etc. can be used by armed forces in installations.

The possibilities for climate proofing operational capabilities depend upon the types of capabilities and the maturity of the required green innovations. A quick start is possible on the area of (operational) infrastructure and minimizing supply chains. In this area armed forces can integrate existing civil technologies and use civil best practices to build self-sufficiency. A next step would be focusing on the light operational capabilities like reconnaissance vehicles, unmanned systems and light vessels. Here the armed forces can adapt existing civil technologies and integrate them in upgrade programs for existing capabilities.

The hardest part concerns heavy capabilities like tanks, frigates and fighter jets requiring a more sophisticated range of green technologies that are not yet readily available. Here the focus should be on the R&D of next generation zero-footprint capabilities in cooperation with the private sector. This can be an area where armed forces and defence industries can lead the way for the private sector by designing heavy vehicles, ships and airplanes running on low-carbon energy. In the meantime, hybrid solutions such as energy efficiency, biofuel blends (obtained from organic waste), hybrid electric vehicles and platforms, sensors and drones, and modular applications can support the partial decarbonization of operations with the current generation of heavy platforms.

To accelerate action, an enabling environment that consists of favourable policy frameworks, targeted funding and procurement, innovation, public-private collaboration as well as behavioural change is essential. European governments supported by their membership in NATO and the EU must set the framework in which the defence industry can operate. NATO is a strong enabler that can support the exchange of good practices, standardization of processes and integration of emissions measurement methods. Accelerators like NATO's DIANA and financing platforms like the European Defence Fund and NATO's Innovation Fund must facilitate dialogue between allies and encourage coordinated action.

At the national level, concrete targets for reducing military emissions and updated sustainable procurement processes are required to create incentives for the defence industry to make green R&D the main pillar for new military technology.

It is important that European defence industries open their supply chains to start-ups and small and medium enterprises that bring scalable innovative ideas and technologies. Through cross-sector collaboration, the use of civil and military technologies can be maximized through dual use applications. If fit for purpose, the opportunities offered by green civil technology would be enhanced by their modification and integration in the military sector. Still, armed forces should not only aim to be a fast follower, but can also act as a platform for innovation in areas where green innovations have not yet sufficiently matured.

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Appendix

Appendix I. Definitions

Home-base Installations - Includes all technologies and equipment used for the sustenance and maintenance of the permanent, non-expeditionary, locations of troops, their sheltering, residence and training. Includes the facilities necessary for sleep, sanitation, nutrition, training and storage which intersect with civilian technology.

Expeditionary Installations - Includes elements of military material and informational supply-chains which support the procurement, distribution, implementation, and maintenance of heavy and light equipment operations including air and water conditioning and cleaning systems, heating systems, temporary constructions for encampment and waste management systems.

Light Equipment Operations - Includes the use of small military weapons as well as carrier systems and transport vehicles. Further includes light reconnaissance and attack equipment like UAVs and smaller drones.

Heavy Equipment Operations - Includes the use of large military weapons systems and technologies like tanks, helicopters, fighter and transport planes, submarines and warships which are used for direct combat and facilitation of military functions like transportation of people and equipment.

Climate adaptation: 'Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative efforts' (US Department of Defense). Examples of climate adaptation include the construction of flood barriers around a city and the development of drought-resistant agriculture.

Climate mitigation: 'Measures to reduce the amount and speed of future climate change by reducing national emissions of heat-trapping gases or removing carbon dioxide from the atmosphere' (US Department of Defense). Examples of climate mitigation include the use of renewable energy sources like solar or wind power and the use of smart technologies to improve efficiency and decrease consumption.

Resilience: 'The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions' (US Department of Defense). A measure enhancing resilience could be a hospital or school foreseeing possible electricity outages and thus building an alternative energy source to rely on if necessary, such as a solar roof. Resilience could also include building appropriate infrastructure that allows for the quick evacuation of populations in the event of a natural disaster.

Operational Effectiveness: 'Measure of the overall ability of a system to accomplish a mission when used by representative personnel in the environment planned or expected for operational employment of the system considering organization, doctrine, tactics, supportability, survivability, vulnerability, and threat' (Glossary of Defense Acquisition).

Scope 1 Emissions: Greenhouse gas emissions produced *directly* by an organisation or company, e.g. by vehicles or ships.

Scope 2 Emissions: Greenhouse gas emissions produced *indirectly* by an organisation or company, e.g. purchased electricity, heating or cooling.

Scope 3 Emissions: Greenhouse gas emissions *associated* with an organisation or company, e.g. procurement and supply chains.

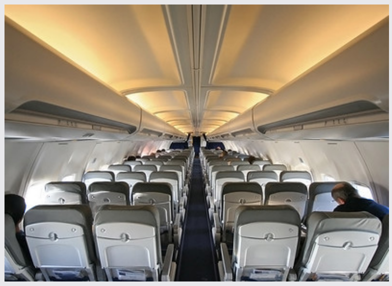
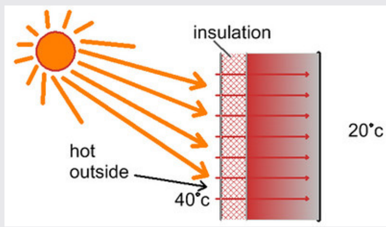
Sources: US Department of Defense[77] and the Glossary of Defense Acquisition[78]

77 'Department of Defense Climate Adaptation Plan'.

78 'Operational Effectiveness', accessed 11 November 2022, https://www.dau.edu/glossary/Pages/Glossary.aspx#!both|O|28081.

Appendix II. Technologies for climate mitigation

Technology	Examples	Pictures
Bio and synthetic fuels	Airbus A380 passenger jet (Rolls-Royce Trent 900 Engine)	Boskalis Dredging Vessel
	GoodFuels Inland Container Vessel (non-modified engine)	
	NYK Capesize Bulker (non-modified engine)	
	Boskalis Dredging Vessel (non-modified engine)	(Torn, flickr)
Bio and synthetic fuel blends	"Green Hornet" Naval Fighter (GE F414 Engine with noise reduction kit)	Green Hornet
	BP/Maersk Tankers (non-modified main engine, auxiliary engine and boiler)	 (Sullivan, flickr)
Alternative propulsion systems	Airbus ZEROe (hydrogen[2] fuel cells powering modified gas turbine engines)	USS Ford-class aircraft carrier
	Light, solid-state, aircraft and drones propelled by ionic wind (electro-aerodynamic propulsion)	
	Hydrogen vehicles capable of powering electric motor through electricity generated onboard	
	UK Royal Navy Type 45 Destroyer with full electric power and propulsion	
	USS Ford-class aircraft carrier with nuclear marine propulsion	
	USSR Kirov class guided missile cruiser with combined nuclear and steam propulsion	(US Navy, flickr)
Sustainable generation of electricity	Solar powered conceptual aircraft like the NASA Helios prototype	
	Photovoltaic roof tiles and solar panels	
	Wave energy converters, tidal energy hydro-generators and blue energy pressure retarded osmosis or reverse electro dialysis for seagoing vessels	
	Canadus HD-1224 battery reconditioner or desulfator combined with solar technology for vehicle battery maintenance	
	Skydweller Aero solar powered larger unmanned aircraft	
	Solar powered small reconnaissance drones	(USFWS, flickr)
	Cargo ships with electrical grids powered by solar panels on decks	
	Airborne wind energy for installations	
	Partly or fully solar powered tanks	(Unten, flickr)

<table>
<tr><th>Technology</th><th>Examples</th><th>Pictures</th></tr>
<tr><td rowspan="6">Hybrid electric systems</td><td>Alia-250 electrical vertical take-off and landing and other battery powered aircraft</td><td rowspan="6">
(GM Media, Wikimedia Commons)</td></tr>
<tr><td>Hybrid propulsion systems for diesel-powered ships</td></tr>
<tr><td>General Motors unmanned Silent Utility Rover Universal Superstructure (SURUS)</td></tr>
<tr><td>ST-35 Silent Thunder battery-powered loitering munition</td></tr>
<tr><td>Hybrid and electric powered civilian boats</td></tr>
<tr><td>French Arquus Scarabee hybrid all terrain vehicle</td></tr>
<tr><td>Atmospheric water accumulation</td><td>Atmospheric water harvesting through passive techniques and electric generators which use dehumidification</td><td>
(Wirth, flickr)</td></tr>
<tr><td>Altitudinal cooling</td><td>Electrical Environmental Control System which process external air for cabin pressurization and air conditioning in airplanes</td><td>
(Aibusky, flickr)</td></tr>
<tr><td>Durable and sustainable components</td><td>Longevity of equipment can be tracked through military condition tags</td><td></td></tr>
<tr><td rowspan="4">Low carbon temperature control and insulation</td><td>Solareast R32 Three in One air source heat pumps for external heat absorption into buildings</td><td rowspan="4">

(Singal, flickr)</td></tr>
<tr><td>Boilers, hybrid heat pumps, direct electric heating, solar technologies</td></tr>
<tr><td>Y-Warm thermal insulation</td></tr>
<tr><td>Well insulated buildings (reflective and containing insulation)</td></tr>
<tr><td rowspan="3">Water purification</td><td>Reverse Osmosis.</td><td rowspan="3">
(Hoots, Wikimedia Commons)</td></tr>
<tr><td>Membrane bioreactors</td></tr>
<tr><td>Wastewater Electrochemical Treatment Technology (on land and water)</td></tr>
</table>

Technology	Examples	Pictures
Water re-use	Grey water re-use	
Portable water filtering systems	MECO water filtration system is lightweight and mobile.	
Waste processing	Portable filtration systems for motor oils, hydraulic oils or other industrial fluids	 (Dvorty, Wikimedia Commons)
	Ompeco portable Converter (mechanical shredding)	
	Terragon's Micro Auto Gasification System (on land and water)	
	Biodigester	
	Composting	
Energy-efficient foods	Light-weight, high-calorie foods such as macadamia nuts and pecans	
Alternative energy grids	Domestically, decarbonized energy grids	 (Porter, Wikimedia Commons)
	Abroad, microgrids (2030-2040)	
Biodegradable and reusable solutions	Biodegradable tents	 (Jamain, Wikimedia Commons)
	Lightweight and compostable packaging for ready-to-eat meals.	
Smart technologies	Smart meters	 (Kleinholz, Wikimedia Commons)
	Building automation (towards 2030)	
	Energy-efficient training through simulations	

Appendix III. Policies enabling climate mitigation in the military

Policy	Description	Examples
Objective for military carbon neutrality	Set an objective for the military to become carbon neutral.	NATO aims to be carbon neutral by 2050.
		The EU committed to becoming climate neutral by 2050 with the European Climate Law.
Objective for military emission reduction	Set an objective for military emission reduction.	France aims to cut military emissions by 40% by 2030.
		The Netherlands aims to cut military emissions by 20% by 2030.
Develop a universal military emissions measuring framework	Use a 'carbon footprint' approach to monitor and report on military emissions.	The US and Canada have the most comprehensive frameworks.
		The United Kingdom, Denmark, the Netherlands, Germany, France, Luxembourg, Norway all have some level of reporting. This includes tracking direct (onsite), indirect (offsite), and induced (supply chain) emissions.
Investment in research and development	Ensure yearly investment in research and development within the climate security industry.	France and the US invest in dual-use application technology.
Decarbonize energy grids	Set an objective for bases to rely on decarbonized energy grids.	In the US, all defence agency buildings are required to consume a minimum of 7.5% renewable energy.
Objective for biofuel and synthetic fuel blends	Set an objective for the percentage of fuel use to be based on biofuel and synthetic fuel blends.	The UK allows for biofuel substitution in up to 50% of military aircraft.
		The Royal Netherlands Air Force aims for 20% added biofuels by 2030 and 70% biofuel blend by 2050 for all aircraft.
Investment in biofuels and synthetic fuels	Finance biofuel and synthetic fuel production plants for military use.	The US is financing two companies to produce 10 million gallons per year for military specification biofuels.
Move away from single fuel policy	Set an objective to shift away from a single fuel policy.	NATO currently adheres to a single fuel policy to simplify logistics
Support for multilateral organizations	Support multilateral organizations in setting green guidelines.	NATO and the EU are both developing a common measuring and reporting framework.
		The EU is using existing frameworks such as PESCO.
		Funding for less developed militaries.
Integrate military emission and broader climate goals	Integrate military emission reduction goals with the European Green Deal, Fit for 55 etc. to increase accountability and ensure policy coherence.	-
Digitalize energy grids	Integrate digital technology and infrastructures in order to make processes more efficient and less resource intensive.	European Union SmartGrids Technology Platform for Electricity Networks of the Future initiated in 2005.
		United Kingdom Department of Energy and Climate Change initiated increasing roll-out of smart meters.
Collaborate with partner nations	Work with partner nations and communities to build shared resilience and adapt shared ecosystems to climate impacts.	-
Train climate-ready forces	Train militaries to assess and adjust requirements, needs and equipment and adapt to the changing climate conditions.	US Department of Defense Climate Adaptation Plan includes goal to 'Train and Equip a Climate-Ready Force'

Policy	Description	Examples
Circular economy	Introduce circularity objectives and clarify procedures to increase efficiency and decrease resource intensity.	2020 European Commission Circular Economy Action Plan put into effect as part of Green Deal.
		France requires the reuse, recycling or donation of unsold products.
		The Netherlands aims to have a fully circular economy by 2050.
Avoid unintended effects	Consider trade-offs and promote policy coherence between different areas to avoid unintended consequences of sustainable measures (e.g., energy efficiency in one area causing more consumption elsewhere).	-
Enhance the security of supply chains	Establish secure and efficient supply chains for climate-ready products.	-
Behavioural change	Change attitudes and behaviours in the defence sector to strengthen climate action.	Fully green bases of French Air Force.

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