INTERNATIONAL MILITARY COUNCIL ON CLIMATE & SECURITY
COUNCIL ON STRATEGIC RISKS

JULY 2024

WORLD CLIMATE AND SECURITY REPORT 2024

MILITARY INNOVATION AND THE CLIMATE CHALLENGE

A Product of the Expert Group of the International Military Council on Climate and Security

CENTER FOR CLIMATE & SECURITY
COUNCIL ON STRATEGIC RISKS

Planetary Security INITIATIVE

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The International Military Council on Climate and Security is a group of military leaders, security experts, and security institutions across the globe dedicated to anticipating, analyzing, and addressing the security risks of a changing climate. IMCCS is co-led by:

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Cover photo: A C-130J Hercules assigned to the 146th Airlift Wing, carrying the Modular Airborne FireFighting System, drops fire retardant chemicals onto a ridge line above Santa Barbara, Calif., on Dec. 13, 2017. (USAF Photo / J.M. Eddins Jr.)

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Marines based out of Marine Corps Base Camp Pendleton, Calif. dig to install additional solar panels to power radios, laptop computers, lighting, ventilation and other systems, July 26, 2010.

Source: USMC photo / Lance Cpl. Michael Nerl

Executive Summary

With climate impacts accelerating and the energy transition underway, militaries are increasingly considering the carbon footprint of their operations, infrastructure, and supply chains. Today, though there are gaps in measuring, reporting, and reducing these emissions, many countries already have initiatives to reduce their carbon footprint and improve the efficiency of their militaries.

This report analyzes the urgency of climate change for militaries and explores how military research and innovation might enable both emissions reduction and greater resilience of infrastructure and operations to climate impacts while improving the self-sufficiency of military units and facilities. While the report should be useful to militaries around the world, its recommendations focus on NATO member state militaries.

The report reveals a need for militaries to adopt a comprehensive approach to the climate challenge. This should include research and development (R&D) but also a wider range of policy and procurement changes. The climate crisis is not a challenge that can be solved by a single tool such as military R&D, but rather a broader set of partnerships, policies, and investments that make up a more complete sustainability toolbox.

There are, of course, limits to military research as a solution to climate mitigation and adaptation challenges. For example, when it comes to operational equipment, the decades-long lifecycle of this equipment means that large-scale implementation of new technologies will require an extended transition period. Progress is still important, but there is not a singular or immediate solution to meet emissions targets. Furthermore, military research focuses on mission-specific applications. While there are opportunities within this scope to explore resilience to climate impacts as a mission necessity (e.g. energy resilience on bases impacted by disasters), research on emissions reduction is much more likely to come out of commercial and civilian research efforts.

Yet, despite these constraints, addressing the environmental costs of militaries remains beneficial. Increased efficiency in energy use of platforms, even when incremental, has benefits both for operational capability and reduction of carbon footprint. Hybrid vehicles are a logical innovation that requires little to no change in supporting logistics systems and reduces the logistics burden. Artificial intelligence will increase efficiency, reduce costly accommodations for military personnel in vehicles, and potentially propel new avenues for research. It will be most effective to pursue decarbonization technologies that synergize with other advances that are occurring simultaneously. With these advances, gains in energy efficiency will also reduce the need to transport and secure fossil fuels, limit price volatility, increase self-sufficiency, and reduce environmental damages caused by fuel leaks or spills.

Research programs on technologies including, but not limited to, hybrid vehicles and energy use management by artificial intelligence provide pathways to innovations that will improve energy efficiency and the performance of systems in use. However, the best opportunities to reduce the military's carbon footprint will be found in innovative procurement and policy approaches. While military research does not represent as large a portion of the global research enterprise as it once did, military procurement budgets remain extremely influential, often representing the single largest customer in their respective nations. As a result, acquisition choices can catalyze and steer markets toward particular policy outcomes even while prioritizing military missions.

After analyzing the urgency of climate change for the world's militaries and assessing progress, shortfalls, and opportunities for emissions reduction and technology advancement in military operations, infrastructure, and supply chains, this report makes a few key recommendations.

1. **Approach military innovation in an integrated and time-sensitive way.** In addition to innovating to achieve energy efficiency, militaries must adapt to the impacts of climate change. Technologies that serve both purposes should be prioritized. Adopting these technologies

early will give militaries an edge in both operations and international and domestic reputation.

2. **Foster public-private partnerships to leverage civilian technological advances.** Many useful innovations for the military will be made in the civilian sector, and militaries should support those advances. For example, given that fuel use, especially for aviation, is one of the largest sources of operational emissions, militaries should send strong market signals for sustainable aviation fuel.

3. **Set targets for infrastructure decarbonization and strategies for emissions monitoring and sustainable procurement.** Clear emissions reduction targets and monitoring strategies are the first steps to achieving military infrastructure decarbonization, including for products in the military's supply chain (scope 3 emissions). A key way to achieve these targets is for militaries to procure carbon-free electricity for fixed installations. This can be done through targeted power purchase agreements or through the broader greening of the electric grid. Notably, the technologies that will enable this electricity shift already exist commercially.

4. **Leverage education and training for climate literacy.** Technological solutions are not enough: a climate-literate workforce is essential for transforming how militaries understand and respond to the opportunities and challenges arising from decarbonization. Given shared challenges and goals, there is an opportunity for NATO member state militaries, for example, to catalyze transnational cooperation on climate training.

5. **Incentivize the energy transition within military supply chains, leading to lower defense industry emissions.** Procurement preferences for and investments into lower embedded carbon levels in the products militaries purchase could accelerate this transition. For example, the EU could give companies that demonstrate a clear commitment to achieving net zero through realistic targets access to more credit by reforming their taxonomy and lending practices.

Many of these recommendations can be encapsulated in one central tenet—acquisition and procurement innovation. To address the climate challenge, militaries will need to think fundamentally differently about how and what they buy. This encompasses procurement policy, process, and requirements that meet both mission and sustainability requirements. Military acquisition leaders should send this market signal to civilian and commercial energy researchers and catalyze clean energy research by committing to purchase the products that are developed.

By broadening the framing of innovation to encompass not only research programs but a fundamentally different way of managing military and defense organizations, military innovation can help reduce its impact on carbon emissions and help militaries confront the climate challenge.

The report concludes that military innovation can indeed make a significant contribution to addressing the climate challenge, but militaries need stronger partnerships with other government agencies, policymakers, and private industry to do so in a manner that's adequately commensurate to the challenge.

Cadets Natalie Meyer and Andrew Putlock perform research in an electrical engineering lab at the U.S. Air Force Academy's Fairchild Hall, November 19, 2021.

Source: USAF Academy photo / Trevor Cokley

I. Introduction: Can Militaries Innovate their Way out of the Climate Challenge?

Author: **John Conger**

In a pattern the world has experienced repeatedly in recent years, 2023 was again the hottest year on record. The last ten years (2014-2023) have, in fact, been the ten hottest years on record, making it clear that the globe is continuing to warm.[1] Climate change impacts are increasingly visible across the globe and are poised to propel greater changes in the future. These impacts span not only environmental issues but economic, health, and, of course, security challenges. Earlier iterations of the IMCCS Expert Group's World Climate and Security Report explored the nature of these changes and how they impact security concerns—from human security to national security to regional and international security.[2] In 2022, the report turned to the idea of military decarbonization, exploring some of the policy and technological challenges that impede reductions in military emissions.[3]

In this volume, the World Climate and Security Report (WCSR) will delve deeper into the discussion of militaries and climate change, with a particular

1 NOAA National Centers for Environmental Information, "Monthly Global Climate Report for Annual 2023," published online January 2024, retrieved on March 20, 2024.

2 Steve Brock, Bastien Alex, Oliver-Leighton Barrett,, Francesco Femia, Shiloh Fetzek, Sherri Goodman, Deborah Loomis, Tom Middendorp, Michel Rademaker, Louise van Schaik, Julia Tasse, Caitlin Werrell, "The World Climate and Security Report 2020," Product of the Expert Group of the International Military Council on Climate and Security, eds. Francesco Femia and Caitlin Werrell, *The Center for Climate and Security, an institute of the Council on Strategic Risks*, Feb 2020.

3 Louise van Schaik, Pierre Laboué, Katarina Kertysova, Akash Ramnath, and Douwe van der Meer, "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," Eds. Erin Sikorsky and Francesco Femia, *Expert Group of the International Military Council on Climate and Security*, June 2022.

focus on how military research and innovation might enable both emissions reduction and greater resilience of infrastructure and operations to climate impacts. Put another way, can the military innovate itself out of this problem, and can its innovation provide benefits that will help address the broader climate challenge?

Missions and Emissions

While mission statements vary, the purpose of a military institution is generally to provide for the defense of its nation and its nation's interests, build the capacity to deter aggression, and, if necessary, fight and win the nation's wars. A military is a tool of national power and, as such, is focused primarily on accomplishing the missions assigned to it.

Climate change imposes itself on this system in multiple ways, but the reason that it has become a significant issue in military forums is, first and foremost, its impact on mission. This can manifest in direct impacts to security forces and infrastructure, in constraints on operations, in the prompting of new missions and requirements, and in the feeding of instability and conflict. To military audiences, it isn't always clear that it is climate change that is impacting them, but they feel the effects and will need to execute their missions despite the constraints that the climate imposes.

At the same time, militaries are often the largest single organization in their respective national governments and, as a consequence, will be the entity with one of the largest, if not the largest, carbon footprint. Military emissions are driven by fossil fuel use—either from the energy used to power fixed infrastructure or from the fuel used to drive most military vehicles. If one is willing to widen the aperture to a broader view, there are additional emissions associated with procurement and the defense industry, broader supply chain impacts, and, of course, conflict itself. So, even as militaries begin to incorporate the impacts of climate change on their operations and missions, they must recognize that they are also contributing to the impacts with which they contend.

While many catastrophic climate impacts are less immediate and more diffuse than the imperative of fulfilling their current missions, climate impacts, from hurricanes and heat to fire to flood raising costs and risk to military missions. Investments, including the research investments upon which this report focuses, prioritize missions over emissions, though smart investments can address both without imposing a trade-off. In essence, the military must be able to "walk and chew gum at the same time," when it comes to reducing climate risk and meeting mission requirements. Both are necessary. Furthermore, a longer-term look at mission requirements reveals that reducing climate impacts that may exacerbate future security risks is itself an important contribution to mission success.

Climate Impacts on Mission

Among the earliest national security figures who perceived the impact of climate change were Sherri Goodman, the Pentagon's first Deputy Undersecretary of Defense (Environmental Security) and senior military leaders who had experienced climate stress as part of military operations around the world. Sherri Goodman is the Secretary General of the International Military Advisory Council on Climate & Security and founder of the Center for Naval Analyses Military Advisory Board, the first group of senior military leaders to assess the national security implications of climate change. The landmark 2007 report, *National Security and the Threat of Climate Change* characterized climate change as a "threat multiplier" for instability in both fragile and stable regions, amplified by the stresses that a nation or region was enduring.[4] This was followed by a number of other assessments by military experts, including those published by the Center for Climate and Security.[5] Years later, former US Secretary of Defense James Mattis noted that climate

4 "National Security and the Threat of Climate Change," *The CNA Corporation*, 2007.

5 See for example, "Military Expert Panel Report: Sea Level Rise and the U.S. Military's Mission," *the Center for Climate and Security*, 1st edition (2016) and 2nd edition (2018)

change "can be a driver of instability" and that it impacts "stability in areas of the world where our troops are operating today."[6] In his 2022 address to the NATO Public Forum, NATO Secretary General Jens Stoltenberg asserted that "Climate change is a crisis multiplier" that fuels tensions and conflict and that "Climate change is not a threat that exists far beyond the horizon, or long into the future. We see its impact on our security right now."[7]

From an operational and operator perspective, the effects of climate change on the global security situation are a priority. Militaries are concerned about accelerating instability and increasing risks of conflict that may compel the deployment of a nation's forces.

In the 2020 edition of the World Climate and Security Report, the IMCCS Expert Group identified the highest global risks due to ecosystem loss and associated failures in food and water systems needed to support populations; increased tempo and severity of natural disasters; water security issues including droughts, flooding and sea level rise; and finally the disruptions associated with forced relocation and involuntary migration.[8] Each of these has the potential to drive instability and catalyze conflict. Moreover, in regions where survival resources have become more scarce, and governments are challenged to support their populations, violent extremist organizations have sometimes taken advantage of the situation to take control of food and water to exert influence and to recruit members. For example, in an interview, IMCCS Chair Tom Middendorp shared that, "In Somalia, we were fighting piracy on the seas, but in fact, we were fighting farmers and fishermen who had been pushed away from their homelands by droughts and cattle failure and needed

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6 Andrew Revkin, "Trump's Defense Secretary Cites Climate Change as National Security Challenge," *ProPublica*, March 14, 2017.

7 "Opening Speech by NATO Secretary General Jens Stoltenberg at the High-Level Dialogue on Climate and Security, NATO Public Forum," *NATO*, June 28, 2022, updated July 28, 2022.

8 Steve Brock, Bastien Alex, Oliver-Leighton Barrett, Francesco Femia, Shiloh Fetzek, Sherri Goodman, Deborah Loomis, Tom Middendorp, Michel Rademaker, Louise van Schaik, Julia Tasse, and Caitlin Werrell, "The World Climate and Security Report 2020," Eds. Francesco Femia and Caitlin Werrell, *the Center for Climate and Security, an institute of the Council on Strategic Risks*, February 2020.

to sustain their families. We were fighting the symptoms without addressing the root causes."[9]

The next set of impacts that have concerned military stakeholders involves the effect of climate change on fixed infrastructure. While operable aircraft and ships can usually[10] move out of the way of an approaching storm in order to avoid damage, infrastructure cannot. The most visible of these impacts involve natural disasters and complete mission disruptions at particular locations. These include extreme weather and storms that damage facilities and disrupt mission capability, resulting in impacts that can range from power outages and water shutdowns to mandatory evacuations. Damage from the worst of these events has imposed billions of dollars of costs in addition to forcing personnel and missions to relocate. Within the United States, frequently cited examples are hurricane damage at Tyndall Air Force Base (AFB) in Florida[11] and flood damage at Offutt AFB in Nebraska.[12] More recent examples include the impact of Hurricane Sally on Pensacola Naval Air Station[13] and Typhoon Mawar, which did more than 10 billion dollars of damage to military installations across Guam.[14]

Additional impacts include recurring flooding associated with sea level rise, coastal erosion impacting nearby infrastructure, power outages driven by high winds, extreme heat driving higher power requirements, thawing permafrost in Arctic installations, and increased wildfire risk augmented by drought

9 Elsa Barron, "The Making of a Climate General: An Interview with IMCCS Chair, Retired General Tom Middendorp," *The International Military Council on Climate and Security*, August 4, 2022.

10 It is not always possible to move aircraft or ships out of the way of extreme weather events, particularly when they are not ready to be operated. See John Conger, "Three Takeaways from Hurricane Michael's Impact on Tyndall Air Force Base," *The Center for Climate and Security*, October 19, 2018

11 Phil McKenna, "Hurricane Michael Cost this Military Base About $5 Billion, Just One of 2018's Weather Disasters," *Inside Climate News*, February 6, 2019.

12 Greg Hadley, "Cost of Rebuilding Offutt Will Top $1B, Congressman Says," *Air and Space Forces Magazine*, January 5, 2022.

13 Jared Morgan, "Hurricane Sally inflicts wind, water damage at NAS Pensacola; Florida Guard aiding aftermath," *Military Times*, September 18, 2020.

14 David Roza, "Air Force Needs $10 Billion to Repair Guam After 2023 Typhoon," *Air & Space Forces Magazine*, May 7, 2024.

conditions.[15] As a result of these and other physical climate risks, increased installation resilience has been a significant focus of investments.[16]

Training missions have also faced increased disruptions. Climate change not only changes the natural infrastructure of training ranges but also creates conditions in which personnel cannot exert themselves without facing heat-related injuries. Again, given the difficulty of relocating missions away from fixed infrastructure, changes in a local climate impose new constraints and challenges on those missions.

Operators will face new missions and new climate regimes as a result of climate change. While military forces generally maintain the ability to operate in many climates, both the increasing temperatures observed in North Africa and the Middle East and the extreme cold in the opening Arctic pose challenges to existing platforms, equipment, and outfitting for military personnel. One official in the US Department of Defense has argued that the military needs to "own the heat like they own the night." The ability to operate in conditions that would otherwise be outside the operating specifications of existing equipment—and generally uninhabitable for unprotected personnel—will be a growing focus of military efforts.[17]

With Arctic ice receding but not gone, the ability to operate surface ships at higher latitudes will also impose challenges to existing naval vessels. For example, the *US Navy's Arctic Strategy—A Blue Arctic* specifically references the fact that it needs to prepare for a "more navigable Arctic Region" and cites the fact that "the Beaufort, Chukchi, and Bering Seas are experiencing rapid sea ice loss."[18] It cites emerging requirements for the Blue Arctic era,

15 "Report on Effects of a Changing Climate to the Department of Defense," *U.S. Office of the Under Secretary of Defense for Acquisition and Sustainment*, January 2019.

16 "Defense Budget Overview: United States Department of Defense Fiscal Year 2025 Budget Request," p. 3-31, *Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer*, March 2024.

17 Patrick Tucker, "'We Need to Own the Heat The Way We Now Own Night,' Pentagon Climate Leader Says," *Defense One*, August 24, 2022.

18 "A Strategic Blueprint for the Arctic," *U.S. Department of the Navy*, 2021.

such as improved domain awareness and communications in polar latitudes and incorporating the ability to operate in freezing conditions into new platform requirements. The 2023 NATO Climate Impact Assessment also highlights the high north, citing easier access to the Arctic's natural resources and increased economic activity due to thawing sea ice, infrastructure damage from melting permafrost, and threats to Indigenous communities and subsistence traditions as significant climate impacts in the region with implications for NATO.[19]

Even as climate change forces militaries to respond to climate impacts on military infrastructure and shifting operational conditions to perform their traditional defense missions, militaries are also increasingly called upon to respond to climate-related disasters hitting communities within and around their borders. The Military Responses to Climate Hazards (MiRCH) tracker has identified over 250 instances of militaries responding to climate-related disasters around the world since June 2022, and this is likely a conservative estimate.[20] In a speech presented at the conference, "Integrating Climate Change into Professional Military Education," US Deputy Undersecretary of Defense Caroline Baxter shared that the personnel days spent by the US National Guard combatting forest fires increased more than twelve-fold in a period of five years, "from 14,000 personnel days in 2016 to 176,000 personnel days in 2021."[21]

Increasing demands to respond to natural disasters often require a unique set of knowledge and skills that may not always be prioritized in traditional defense training. Understanding the degree of demand for these skills today and its potential to increase even further in the future underscores the significance of climate change to military operations and the need to think seriously about both immediate disaster response and pre-emptive adaptation planning.

19 "NATO Climate Change and Security Assessment," p. 20, *NATO*, 2023.

20 "Military Responses to Climate Hazards (MiRCH) Tracker," *The Center for Climate and Security, an institute of the Council on Strategic Risks*, last updated February 28, 2024.

21 "DASD Caroline Baxter On Integrating Climate Change into Professional Military Education," *The Center for Climate and Security*, March 7, 2024.

The bottom line is that climate change makes it harder for militaries to fulfill their missions. It increases costs and undermines military capacity and capability. As climate solutions are considered to address climate constraints, they should not impose parallel or more burdensome constraints. In other words, climate solutions will need to make it easier for militaries to fulfill their missions. Moreover, viewing climate responses through a mission frame, the ideal solutions will reduce cost and increase military capacity and capability.

Military Emissions Impacting Climate

As noted above, climate challenges to the military extend beyond the impacts that climate change has on armed services and their missions to the fact that military capability has been enabled by a steady supply of fossil fuels.

In the WCSR 2022, the IMCCS Expert Group highlighted the fact that military data is not always available on emissions and carbon footprint.[22] This is a result of both inadequate record-keeping and the fear that releasing information will provide insight to adversaries. Nonetheless, even without specific accounting data, the carbon emissions of military forces can generally be attributed to the burning of fossil fuels by its operations. This occurs in two primary ways. First is the burning of fuel by aircraft, ships, and tactical ground vehicles. While there are a limited number of nuclear-powered ships in naval fleets and a smaller number of electric vehicles in tactical inventories, the preponderance of operational energy still involves burning petroleum. Second is the use of power by fixed installations and infrastructure, largely in the form of electricity and gas.

22 Louise van Schaik, Pierre Laboué, Katarina Kertysova, Akash Ramnath, and Douwe van der Meer, "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," Eds. Erin Sikorsky and Francesco Femia, *Center for Climate and Security, an Institute of the Council on Strategic Risks*, June 2022.

Several militaries have published information on their emissions and fuel use, and think tanks have developed models to derive unreported emissions based on available data, such as the total number of military personnel.

In 2023, the US Department of Defense published its Plan to Reduce Greenhouse Gas Emissions, which reported emissions of 51 million metric tons of carbon dioxide equivalent ($MMTCO_2e$) in 2021.[23] Of this total, it reported 19 $MMTCO_2e$ from installations, and 32 $MMTCO_2e$ from operational or mobile sources. Notably, jet fuel represented the single largest source of emissions, at 80% of operational emissions and 50% of total emissions. From the installation perspective, 60% of emissions came from purchased electricity, and another 28% came from fuel combustion for heat in buildings.

The report also indicates these totals represent roughly 1 percent of total US emissions. This aligns with at least one non-governmental estimate of global military emissions, which cited its "best estimate" of operational GHG emissions (which included fixed infrastructure) was 1.0% of global GHGs.[24]

Several other nations publish military-related greenhouse gas emissions information to varying degrees. Within the United Kingdom, the Ministry of Defense reported 2.7 $MMTCO_2e$ for estate and capability emissions in 2022, with capability energy representing 64% of the total.[25] An NGO assessment of EU nations' military emissions found very few were complete, though it assessed the total reported emissions to be 4.5 $MMTCO_2e$.[26] The assessment includes data that Germany reported to the UNFCCC in 2018, indicating it

23 "Department of Defense Plan to Reduce Greenhouse Gas Emissions," *U.S. Office of the Under Secretary of Defense for Acquisition and Sustainment*, April 2023.

24 Stuart Parkinson and Linsey Cottrell, "Estimating the Military's Global Greenhouse Gas Emissions," p. 8, *Scientists for Global Responsibility and the Conflict and Environment Observatory*, November 2022.

25 "UK Ministry of Defence Annual Report and Accounts 2022-23," p. 204, *House of Commons*, July 2023.

26 Stuart Parkinson and Linsey Cottrell, "Under the Radar: The Carbon Footprint of Europe's Military Sectors," *Scientists for Global Responsibility and the Conflict and Environment Observatory*, February 2021.

emitted 0.75 $MMTCO_2e$ with 59% being from stationary and infrastructure sources and 41% from mobile and transportation sources.

Even without complete emissions reporting, the EU and NATO have taken steps toward understanding and reducing carbon emissions. A component of the EU's Climate and Defence Roadmap is "gathering data on the energy consumption of the armed forces of Member States to help Member States find joint approaches to enhancing energy efficiency and sustainability," pledging 133 million euros in 2021 to energy transition and resilience.[27] The roadmap also calls for member states to produce national plans, which some, including France[28] and Germany[29] have already published.

NATO made measurable commitments to reduce its organizational emissions at the 2022 NATO Summit with a statement that "By 2030, we will reduce emissions by at least 45%, reducing to net zero by 2050."[30] While this commitment did not extend to NATO member state militaries and only the operations of the central organization, NATO published its Greenhouse Gases Emission Mapping and Analytical Methodology as a resource for member states to measure and reduce their own emissions.[31]

Beyond the emissions that these organizations control, some models and analyses have attempted to assess an expanded carbon footprint by projecting Scope 3 emissions associated with military organizations. There is a wide variance in what should be counted toward this total. The UK MOD, for example, reports its Scope 3 emissions to be 0.4 $MMTCO_2e$,[32] resulting in

27 "The EU's Climate Change and Defence Roadmap," *European Union External Action*, March 2022.

28 "Climate & Defence Strategy," *Ministry of Armed Forces of France*, April 2022.

29 "Strategy on Defence and Climate Change," *German Federal Ministry of Defence*, March 2024.

30 "Opening Speech by NATO Secretary General Jens Stoltenberg at the High-Level Dialogue on Climate and Security, NATO Public Forum," *NATO*, June 28, 2022, updated July 28, 2022.

31 "The NATO Greenhouse Gases Emission Mapping and Analytical Methodology," *NATO*, 2023.

32 "UK Ministry of Defence Annual Report and Accounts 2022-23," p. 204, *House of Commons*, July 2023.

a total of 3.1 $MMTCO_2e$. However, others have modeled this with a more expansive definition of carbon footprint, projecting a figure that would be 5.8 times the direct emissions footprint.[33] This number implies a decision to attribute a very broad range of industrial activities to be part of a carbon footprint, though the boundaries are not specified, and it is unclear what activities are incorporated into the figure. Nonetheless, it is significant enough to prompt exploration of supply chain and defense industry contributions in this assessment and to explore whether military innovation might offer opportunities to lower these emissions as well.

Finally, while these figures represent recurring or annualized emissions, the non-recurring emissions from active conflicts are also important to note, both from the increased operational tempo and fuel use and from the costs associated with physical destruction, reconstruction, population migration, aid delivery, and other war-related activities that have carbon impacts. Recent monitoring and analysis of the ongoing wars in Ukraine and Gaza have led to a better understanding of the degree and significance of military emissions during active conflict. While each instance of conflict is unique and should be considered independently, the real-time monitoring of climate impacts of these two instances provides insight into the often unconsidered climate costs of war.

An assessment of the carbon impacts of war in Ukraine from February 24, 2022, to September 1, 2023, estimates 150 $MMTCO_2e$.[34] Within this total, the majority of emissions are attributable to categories unrelated to the actual military campaign, including fire, the closure of airspace for civil aviation, and yet-to-be-realized post-war reconstruction. Emissions from military operations, mostly fuel use, are estimated at 37 million tons, only a quarter of the total. These figures reveal two realities. First, warfare emissions can cause a

33 Stuart Parkinson and Linsey Cottrell, "Estimating the Military's Global Greenhouse Gas Emissions," p. 7, Scientists for Global Responsibility and the Conflict and Environment Observatory, November 2022

34 Lennard de Klerk, Mykola Shlapak, Anatolii Shmurak, Olga Gassan-zade, Oleksii Mykhalenko, Adriaan Korthuis, Yevheniia Zasiadko, Andriy Andrusevych, and Ivan Horodyskyy, "Climate Damage of Russia's War in Ukraine," *Initiative on GHG accounting of war*, December 1, 2023.

sizable spike in military emissions from fuel use itself. Second, reducing the emissions output of technologies actively engaged in warfare alone will not eliminate wartime emissions, especially since the majority of emissions come from the impacts of warfare like disrupted air traffic and destroyed infrastructure. Therefore, one cannot eliminate the expanded carbon emissions caused by conflict by greening the military alone. Furthermore, even non-mechanized warfare can create significant carbon emissions through environmental and infrastructure destruction.

Initial analysis of Israel's war in Gaza confirms similar themes. Immediate emissions from the first 60 days of conflict are estimated around 280,000 tons of carbon dioxide. However, estimates of the reconstruction costs in Gaza from these same initial 60 days overwhelm this figure at 30 million tons.[35] When considering the emissions impacts of conflict, it is important to consider both the immediate costs of fueling the war, and the longer-term costs of environmental destruction, including the built environment.

The Potential and Promise of Military Innovation and Investment

World War II spurred investments in military research, and new innovations had a corresponding impact on the outcome of the war. As a result, military research garnered increased support. By 1960, defense-related R&D in the US alone represented 36% of *global* research in all sectors.[36] In the era of defense research dominance, its investments drove many new technologies, including the Internet and global navigation services.

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35 Neimark, Benjamin and Bigger, Patrick and Otu-Larbi, Frederick and Larbi, Reuben, "A Multitemporal Snapshot of Greenhouse Gas Emissions from the Israel-Gaza Conflict," *SSRN*, January 5, 2024.

36 John F. Sargent Jr. and Marcy E. Gallo, "The Global Research and Development Landscape and Implications for the Department of Defense," *Congressional Research Service*, June 28, 2021.

In the decades that followed, however, a transformation of the R&D sector occurred and commercial companies saw the benefit of their own investment. As a result, by 2019, US defense research fell to 3 percent of global R&D.[37] With a technology and economic ecosystem that has shifted significantly away from defense, many of the most important technological advances are now initiated in the commercial sector. In fact, the top ten corporate R&D investors alone exceeded $200 billion euros, the majority of which is focused on information and communications technology.[38]

As the dominance of military research budgets have receded, the practical impact has been that military research is focused more on capabilities directly applicable to military requirements. The explosion in research by private industry means, in part, that the defense research enterprise can and does leverage private sector progress, which is also true of innovations connected to the green energy transition.

Focusing on the energy transition and the kinds of technologies that will have a broad impact on the climate crisis, the bulk of these advances are likely to come from outside the military as well. Looking at the US budget again as an example, there are billions of dollars of clean energy investments funded through the annual Department of Energy budget,[39] along with large targeted investments through non-recurring funding allocations. Specifically, in the US, the Infrastructure Investment and Jobs Act provided "$21.5 billion for clean energy demonstration projects in clean hydrogen, energy storage, carbon capture, advanced nuclear, direct air capture, and other technologies; and the Inflation Reduction Act (IRA) provided billions of dollars in deployment

37 *Ibid.*

38 Nindl, E., Confraria, H., Rentocchini, F., Napolitano, L., Georgakaki, A., Ince, E., Fako, P., Tuebke, A., Gavigan, J., Hernandez Guevara, H., Pinero Mira, P., Rueda Cantuche, J., Banacloche Sanchez, S., De Prato, G. and Calza, E., "The 2023 EU Industrial RandD Investment Scoreboard," *Publications Office of the European Union*, December 14, 2023.

39 The White House Office of Management and Budget, "Analytical Perspectives: Budget of the U.S. Government," *U.S. Government Publishing Office*, 2023.

for carbon capture and storage, carbon dioxide removal, and hydrogen."[40] This includes $500 million for the Defense Production Act to support the manufacturing of clean energy technologies.[41] The IRA, however, did not provide any funding to the military, even for decarbonization efforts.

The European Green Deal is another significant driver of clean energy investment with similar impacts on military emissions, including legally binding targets for emissions reductions.[42] The REPowerEU Plan is mobilizing close to 300 billion euros in investments to boost the share of renewables in the European energy mix and reduce dependency on Russian gas.[43] The ReFuelEU Aviation initiative similarly seeks to promote alternative fuel sources such as synthetic fuels, with potential for military applications.[44] The increased need for more military equipment in Europe has spurred the EU to develop a EU Defence Industrial Strategy.[45] It is a comprehensive set of policy proposals aimed at shoring up European defense industry production capacity and promote further innovation. It contains passages specifically calling for the exploration of green procurement and production practices in line with the EU net-zero goals.

The biggest investments that militaries are making in R&D are focused either on development of new platforms or on a subset of military-applicable technologies. This exacerbates structural challenges facing energy use in military operations: both the length of time it takes to procure a system and the length of time a

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40 "Mission Innovation: National Innovation Pathway of the United States," *White House Office of Science and Technology Policy, United States Department of Energy, and United States Department of State*, April 2023.

41 "IRA Section 30001—Enhanced Use of the Defense Production Act of 1950," *Sabin Center for Climate Change Law*, 2024.

42 "Delivering the European Green Deal," *European Commission*, Accessed March 29, 2024.

43 "REPowerEU: Affordable, secure and sustainable energy for Europe," *European Commission,* Accessed March 29, 2024.

44 Jaan Soone, "ReFuelEU Aviation Initiative," *European Parliamentary Research Service*, November 2023.

45 "First Ever Defence Industrial Strategy and a New Defence Industry Programme to Enhance Europe's Readiness and Security," *European Comission*, March 5, 2024.

system remains in operation. Systems are being developed and procured today that use fossil fuels, potentially locking in their emissions profile for decades.

The US Defense Department released a National Defense Science and Technology Strategy in 2023 that highlights fourteen critical technology areas—one of which is renewable energy and storage.[46] Still, the preponderance of energy research at DoD is focused on directed energy rather than logistics, with much smaller budgets devoted to installations and operational platform energy efforts.[47] Within the DoD's Strategic Environmental Research and Development Program, there are relatively small investments being dedicated to anticipating climate change impacts, coastal resilience, wildland fire, and permafrost thaw. Due to its modest budget, these efforts are focused more on models and providing tools, although the funding could be increased to support investment in promising military energy technologies.45 The companion Environmental Security Technology Certification Program, provides funding to demonstrate and validate promising energy and environmental technologies.[48]

The EU is supporting R&D aimed at addressing energy resilience issues. For the EU, strategic autonomy has become pivotal to the Union's sense of security, especially regarding energy.[49] It has directed institutions such as the European Defence Agency to undertake research to support innovations in this domain, and to encourage further R&D and procurement collaboration among its member states.[50] In addition, NATO has created the Defense Innovation Accelerator for the North Atlantic (DIANA), to nurture innovative start-ups developing dual-use technologies. One of its key initial focus areas is energy resilience.[51]

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46 "Critical Technology Areas," *U.S. Undersecretary of Defense for Research and Engineering*, Accessed March 21, 2024.

47 Richard Kidd, Interview by John Conger, January 5, 2024.

48 Kevin Hiers, Interview by John Conger, January 19, 2024.

49 "A Strategic Compass for Security and Defence," *Council of the European Union*, March 21, 2022.

50 "EDF | Developing tomorrow's defence capabilities," *European Commission*, Accessed April 30, 2024.

51 "Challenges," *NATO Defence Innovation Accelerator for the North Atlantic*, Accessed June 4, 2024.

Beyond explicit expenditures on R&D, militaries are able to take risks to be early adopters of cutting-edge technologies and help to bolster their development. For example, militaries represent a relatively large proportion of the microgrid market, with one US official asserting the US DoD represented 30% of the demand.[52]

Additionally, as a large customer and generally one of the larger public institutions in many nations, a military can use its buying power to help to drive increased supply of carbon free electricity, electric vehicles and charging equipment, advanced batteries, sustainable fuels and other clean energy capabilities which can serve to provide the stability to underpin future growth.

However, military initiatives to reduce emissions, increase efficiency, or leverage cleaner energy throughout its enterprise must focus on the ways that do so while also enhancing core mission capabilities to sustain investment by decision-makers.

Outline of this Report

This issue of the World Climate and Security Report explores each of the key sources of emissions highlighted in this introduction in the context of our fundamental question: can military innovation help address the climate challenge? The following three sections delve deeper into operations and operational systems, infrastructure and installations, and finally, supply chains and the defense industry.

The first section, "Leveraging Technological Innovation in a Changing Operational Environment", explores multiple new technologies that are likely to be integrated into military systems. These include, but are not exclusive to, low carbon technologies, and it makes the case that new technologies can integrate both a stronger fighting force and a lower environmental impact.

52 Patrick Tucker, "'We Need to Own the Heat The Way We Now Own Night,' Pentagon Climate Leader Says," *Defense One*, August 24, 2022.

In the second section of this report, "The Infrastructure Energy Transition as a Priority for MODs' Decarbonization Strategies", a combination of new technologies and innovative approaches to using existing technologies is described. Where the carbon emissions impact of operations tends to result from the burning of fossil fuels by military platforms, installations rely on commercial energy sources for much of their power and as a result, the examination of innovation extends to incorporate not only innovation for the military but also innovation in energy procurement.

Finally, the third section of this volume, "Military Supply Chains", explores the extended carbon footprint of militaries in an effort to understand what innovations might impact a more expansive definition of their carbon footprints. In addition to broadening the understanding of what might be incorporated into such an assessment, this section expands the innovation landscape to policy drivers that militaries might impose upon supply chains to address their emissions.

Across all of these papers there is a common theme. Military innovation can make a significant contribution to addressing the climate challenge, but militaries cannot solve the problem without stronger partnerships with other government agencies, policymakers, and private industry.

A U.S. Army paratrooper assigned to the 173rd Airborne Brigade uses a Dronebuster 3B to disrupt enemy drones as part of Exercise Shield 23, April 20, 2023 in Pula, Croatia.

Source: US Army photo / Sgt. Mariah Gonzalez

II. The Evolving Character of War: Leveraging Low-carbon Technologies in a Changing Operational Environment

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Introduction

The character of military conflict is changing. While the reasons why wars are fought have remained relatively unchanged over time, spanning economic and ideological disparities, resource scarcity, and the pursuit of influence, the characteristics of military conflict are rapidly evolving.[53] New and emerging technologies are opening avenues for militaries to become more accurate, connected, lethal, and sustainable.

Military operations[54] are increasingly reliant on information systems that can provide accurate and up-to-date information, on advanced weapons systems that can prove more targeted and lethal, on autonomous systems and artificial

53 'Global Trends 2040: The Future of the Battlefield', Office of the Director of National Intelligence, 2021, https://www.dni.gov/index.php/gt2040-home/gt2040-deeper-looks/future-of-the-battlefield.

54 Military operations include the use of small military weapons as well as carrier systems and transport vehicles, as well as 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.

intelligence (AI) that enable less human interaction in deadly environments, as well as on low-carbon technologies that can reduce the logistical burden of fuel dependence. At the same time, the operational environment is changing due to emerging geopolitical tensions in the Indo-Pacific and on the European continent. Climate change is impacting the demand for military operations, exacerbating resource scarcity, empowering non-state armed groups, and driving calls for militaries to spend more resources on humanitarian aid and disaster relief (HADR).

In this evolving strategic context, governments of the North Atlantic Treaty Organization (NATO) and the European Union (EU) are taking action to increase their competitive edge and operational effectiveness.[55] Prompted by the invasion of Ukraine in 2022, European governments have reinstated their commitment to strengthen their defense capabilities. Out of the 27 EU member states, 20 increased their defense expenditure in 2022.[56] The largest part of defense investment—understood as investments in research and development as well as the procurement of new equipment—has been allocated to the procurement of new equipment.[57] More broadly, NATO Secretary General Jens Stoltenberg expects 18 Allies to reach the 2% of GDP defense expenditure target in 2024, which represents a six-fold increase since 2014.[58] The EU released in March 2024 its first Defense Industrial Strategy with the goal of enhancing defense readiness in light of military threats on

55 Operational effectiveness is a 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.

56 'Record High European Defence Spending Boosted by Procurement of New Equipment', European Defence Agency, November 2023, https://eda.europa.eu/news-and-events/news/2023/11/30/record-high-european-defence-spending-boosted-by-procurement-of-new-equipment.

57 'Record High European Defence Spending Boosted by Procurement of New Equipment'.

58 NATO, 'Secretary General Welcomes Unprecedented Rise in NATO Defence Spending', NATO, 2024, https://www.nato.int/cps/en/natohq/news_222664.htm.

the European continent.[59] Moreover, the ascension of Finland and Sweden to NATO underscores the need for European and North American governments to coordinate their defense policies and ensure operational readiness.

There is much focus on the benefits of emerging technologies such as (semi-) autonomous systems and information technology to military readiness, but the opportunities brought by low-carbon technologies are often overlooked. Low-carbon technological innovation offers opportunities to reimagine the ways wars are fought. For instance, reducing the dependence on fossil fuels in military operations would have remarkable benefits for militaries' tooth-to-tail ratio—i.e., the resources needed to supply and support combat soldiers. Yet little research has been done to uncover the impact of what scholar Duncan Depledge has called "low-carbon warfare" on the future of military operations and how this interacts with other emerging technologies such as automation and AI.[60]

To fill this gap, this chapter takes the first steps toward an inclusive analysis of the future of warfare that integrates considerations of military decarbonization in the broader scope of technological, geopolitical, and security trends that affect military operations, including climate change. Compared to previous studies that focus on isolated trends, this chapter provides a more comprehensive view of the future of warfare. This can support the development of targeted approaches to the future of warfare and stimulate the development of relevant recommendations for NATO members to boost operational readiness in the coming years.

The research approach consists of three steps that are mirrored in the structure of this paper. After the rationale of the paper is outlined in section one, the second part consists of an analysis of key technologies affecting the future of warfare, including their applicability to military operations and the ways they

59 'European Defence Industrial Strategy', European Commission, accessed 13 March 2024, https://defence-industry-space.ec.europa.eu/eu-defence-industry/edis-our-common-defence-industrial-strategy_en.

60 Duncan Depledge, 'Low-Carbon Warfare: Climate Change, Net Zero and Military Operations', *International Affairs* 99, no. 2 (6 March 2023): 667–85, https://doi.org/10.1093/ia/iiad001.

could contribute to climate-proofing. Next, six vignettes are presented that illustrate how future global conflict dynamics could play out in relation to climatic changes and the potential role of innovative technologies in boosting operational effectiveness. Finally, the paper makes five high-level policy recommendations for NATO members to maximize the opportunities arising from technological innovation in a changing climate:

1. **NATO members should approach military innovation in an integrated way, ensuring equipment and personnel can handle extreme weather and environmental conditions to maintain operational readiness.** This includes integrating low-carbon technologies with other innovations to address climate-related challenges and enhance operational readiness in strategic regions like the Indo-Pacific and Arctic circle, coordinated closely with NATO partners for future interoperability.
2. **To maintain battlefield advantage, NATO members must grasp synergies between climate change-related technologies and evolving operational environments.** By outpacing opponents in adopting low-carbon and adaptation technologies, NATO members can navigate harsher environments effectively, using technologies like unmanned electric aerial vehicles for enhanced operational flexibility and stealth.
3. **Timing is critical for NATO and members' investments in climate change-related technological innovation, as climate impacts alter military capability needs across planning and training cycles.** With military platforms operating for decades and procurement systems slow to decarbonize, strategic allocation of funds from 2024 onward is essential, integrating energy considerations into new equipment procurement to meet 2050 decarbonization goals.
4. **Concrete milestones for military decarbonization are crucial to bolster societal support and resilience against adversarial influence.** Setting clear targets for operational energy and engaging in the energy transition can enhance public perception of militaries,

countering gray-zone tactics that exploit societal divisions regarding climate change responses.

5. **NATO members should foster public-private partnerships to leverage civilian technological advances for enhanced operational effectiveness and environmental sustainability.** By integrating civilian innovations through initiatives like NATO's Defense Innovation Accelerator (DIANA) project, NATO can harness advancements in low-carbon technologies alongside broader technological developments, benefiting from civilian research and development in energy transition efforts.

Rationale: Integrating strong and green

> *"But of course we cannot choose between either green or strong armed forces. We need strong and green at the same time."*
>
> *—NATO Secretary General Jens Stoltenberg at COP26 in Glasgow*[61]

The common discourse on the future of warfare is typically disjointed from debates on climate-proofing, which refers to military efforts toward climate change mitigation, adaptation, and resilience. Military and conflict studies most often focus on emerging threats from state and non-state actors, on the promises and perils of technologies like AI, as well as on the implications of

61 'Remarks by NATO Secretary General Jens Stoltenberg at the High-Level Roundtable "Climate, Peace and Stability: Weathering Risk Through COP and Beyond" in Glasgow, UK', NATO, November 2021, https://www.nato.int/cps/en/natohq/opinions_188262.htm.

these evolving trends for military readiness.[62] As part of a broader policy and scholarly effort to integrate climate change considerations in military studies, the impact of climate change adaptation and resilience on militaries has become more mainstream over recent years, while decarbonization is slowly catching up.[63] Climate change is increasingly seen as a concern for militaries as they manage dynamics such as the impact of rising sea levels on low-lying military installations, extreme weather conditions in fragile contexts, and the progressive melting of the Arctic.[64] Still, the opportunities and challenges associated with climate-proofing military operations remain dissociated from broader work on the future of warfare.

The same is true when looking at NATO and governmental pledges to boost operational readiness and, in parallel, commitments to decarbonize. Since 2022, there has been a notable push to increase defense spending, acquire new equipment, and invest in new weapons technologies among NATO and EU countries.[65] Most of these plans give low-carbon technologies a marginal role if any.[66] On a parallel trajectory, military decarbonization plans include ambitions to reduce the consumption of fossil fuels, and some, like the United Kingdom, also set timestamps for these targets in 2040 and 2050.[67] NATO has committed

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62 See for instance Rajeswari Pillai Rajagopalan and Sameer Patil, 'Future Warfare and Critical Technologies: Evolving Tactics and Strategies', 12 February 2024, https://policycommons.net/artifacts/11336642/future-warfare-and-critical-technologies/12225569/; Njall Trausti Fridbertsson, 'Technological Innovation for Future Warfare' (NATO Parliamentary Assembly Science and Technology Committee, 2022), https://www.nato-pa.int/document/2022-future-warfare-report-fridbertsson-025-stctts.

63 'Climate Change and EU Defence: Released New Report Analysing the Links between Climate, Energy and Defence', European Defence Agency, 8 June 2023, https://eda.europa.eu/news-and-events/news/2023/06/08/climate-change-and-eu-defence-released-new-report-analysing-the-links-between-climate-energy-and-defence#.

64 Depledge, 'Low-Carbon Warfare', 6 March 2023.

65 NATO, 'Secretary General Welcomes Unprecedented Rise in NATO Defence Spending', NATO, 2024, https://www.nato.int/cps/en/natohq/news_222664.htm.

66 'EDF Call For Proposals Descriptions', 15 March 2024, https://defence-industry-space.ec.europa.eu/document/download/77afc5d2-30b2-4f3f-917c-2c4368eb18e3_en?filename=EDF%202024%20Call%20Topic%20Descriptions.pdf.

67 'Ministry of Defence Climate Change and Sustainability Strategic Approach', GOV.UK, 30 March 2021, https://www.gov.uk/government/publications/ministry-of-defence-climate-change-and-sustainability-strategic-approach.

to achieving carbon neutrality by 2050.[68] Yet the way in which decarbonization timelines align with other military timelines is not always clear.

This separation stems from two misconceptions. The first misconception is that decarbonization would be detrimental to operational effectiveness, which is at odds with the key objective of militaries. That is, to boost operational effectiveness and gain leverage over the opponent. The second misconception is that low-carbon technologies should be implemented across military domains all at once. Given that not all low-carbon technologies are ready to be adopted by the military, in some quarters, there is the perception that it is less risky to choose not to adopt any and wait for improvements.

Yet excluding climate change and decarbonization from strategies to increase operational effectiveness is damaging military situational awareness and understanding of opponent capabilities. It is also closing the door to a wealth of opportunities arising from climate-proofing. The character of war is changing, and so are the prerequisites of military readiness and operational effectiveness. In order to reap the benefits arising from new technologies and avoid blind spots, militaries should analyze the future of warfare—and the inevitable changes in the operational environment—from an integrated, comprehensive lens.

This chapter follows the above-mentioned rationale. Operational effectiveness is seen through the lens of climate change, as the integration of climate intelligence in military decision-making is imperative to maintain effectiveness. At the same time, technologies strengthening military capabilities, such as artificial intelligence and automation or low-carbon technologies, are increasingly being developed and adopted. They interact with each other on the battlefield and can bring notable benefits. Balancing legacy capabilities that are heavily reliant on logistically challenging fossil fuels with, for instance, lighter footprint electrically driven swarm capabilities can simultaneously

68 Sabine Siebold, 'NATO Aims to Cut Emissions by 45% by 2030, Be Carbon Neutral by 2050', *Reuters*, 28 June 2022, sec. Europe, https://www.reuters.com/world/europe/nato-cut-emissions-by-45-by-2030-be-carbon-neutral-by-2050-stoltenberg-2022-06-28/.

increase operational effectiveness and accelerate decarbonization. The global shift to low-carbon technologies allows militaries to develop new capabilities that overcome existing challenges and offer opportunities to reimagine the future of warfare.

Technological innovation for military operations

The relationship between military and civilian industries when it comes to innovation and technological development has been long-standing and dynamic. This relationship is and has been, a two-way street characterized by both spin-offs and spin-ins. During the Cold War era, military spending propelled innovation predominantly within the defense sector. The relationship between the two industries was coined the "Military-Industrial Complex."[69] This relationship was characterized by spin-offs, which are military-originated technologies that find their way into civilian applications, such as the Global Positioning System (GPS).[70] However, with the decline in military expenditure post-Cold War, civilian research and development became the primary engine of innovation. This prompted a shift towards spin-in dynamics whereby civilian technologies are used for military purposes. For instance, AI technology that was not specifically created for military use, as well as the civilian communications systems Starlink have been used in military applications in the Russo-Ukrainian war.[71] Collaborative initiatives such as NATO's Defense Innovation Accelerator for the North Atlantic (DIANA) aim to

69 Charles J. Dunlap, 'The Military-Industrial Complex', Daedalus 140, no. 3 (2011): 135–47

70 Maaike Verbruggen, 'The Role of Civilian Innovation in the Development of Lethal Autonomous Weapon Systems', Global Policy 10, no. 3 (2019): 338–42, https://doi.org/10.1111/1758-5899.12663

71 George Grylls, 'Ukraine Is Outflanking Russia with Ammunition from Big Tech', 12 September 2023, sec. news, https://www.thetimes.co.uk/article/ukraine-is-outflanking-russia-with-ammunition-from-bigtech-lxp6sv3qz.

foster partnerships between military and civilian innovators.[72] Despite challenges in collaboration, including legal and ethical concerns, the symbiotic relationship between the defense and private sector continues to deepen, forming what is now termed the "Military-Commercial Complex." [73] Public-private collaboration for military innovation remains essential.

For new technologies to be implemented in military operations, they should ensure that operational effectiveness is either maintained or improved and be at a maximum level of technological readiness. The main indication of whether a technology can be adopted for either civilian or military purposes is its technological readiness level (TRL). This is a widely used measurement of technological maturity, among others, by NATO militaries. In the military domain, the TRL scale reflects increasing levels of fidelity, integration, and operating environment demonstration until the technology reaches its final form and proves successful through mission operations. Up to TRL 3, civilian and military research share fundamental scientific goals, offering potential dual-use applications. Beyond this, the requirements of high-performance equipment for military use often point to a split in technological development.

The sections below highlight the most relevant technological innovations that are increasingly adopted by militaries around the world and that have the potential to reshape the way in which wars are fought in the next 10-20 years. It also briefly explores how these technologies may interact with each other on the battlefield.

72 'NATO Approves 2023 Strategic Direction for New Innovation Accelerator', NATO, 10 December 2022, https://www.nato.int/cps/en/natohq/news_210393.htm.

73 Emily Gilbert, 'Military Geoeconomics: Money, Finance and War', in A Research Agenda for Military Geographies (Edward Elgar Publishing, 2019), 100–114, https://www.elgaronline.com/display/edcoll/9781786438867/9781786438867.00014.xml.

Low-carbon technologies

The emergence of low-carbon innovation brings notable opportunities for militaries to increase the environmental sustainability of their missions and gain operational advantages. After outlining the main sources of emissions in military operations, this subsection discusses key operational advantages brought by low-carbon technologies. It then provides concrete examples of low-carbon technologies that could be adopted by NATO air forces, navies and armies in both the short and longer term.

Operational emissions and energy consumption

Greenhouse gas (GHG) emissions and energy consumption in military operations have been notoriously difficult to assess, considering the lack of a shared methodology to measure emissions. In addition, militaries have been exempt from reporting their emissions and setting decarbonization targets under international climate agreements such as the 1997 Kyoto Protocol or the 2015 Paris Agreement.[74] The United States, Canada, and NATO have been making notable efforts to streamline and coordinate efforts to measure and reduce military emissions, but these efforts still rely on estimations.[75] Estimations of GHG emissions from the military sector hover around 1% of total annual global emissions when both Scope 1 and 2 are taken into account.[76] Some experts argue that factoring in all effects throughout the supply chain (i.e.,

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74 Pierre Laboué, 'Military Emissions: Measuring Is Knowing', in *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*, 2022, https://imccs.org/wp-content/uploads/2022/06/Decarbonized-Defense-World-Climate-and-Security-Report-2022-Vol.-I.pdf.

75 Laboué. 'Military Emissions: Measuring Is Knowing', 2022

76 Stuart Parkinson and Linsey Cottrel, 'Estimating the Military's Global Greenhouse Gas Emissions' (SGR and CEOBS, November 2022), 10, https://ceobs.org/wp-content/uploads/2022/11/SGRCEOBS-Estimating_Global_MIlitary_GHG_Emissions_Nov22_rev.pdf; Duncan Depledge, 'Low-Carbon Warfare: Climate Change, Net Zero and Military Operations', *International Affairs* 99, no. 2 (6 March 2023): 667, https://doi.org/10.1093/ia/iiad001; Mohammad Ali Rajaeifar et al., 'Decarbonize the Military — Mandate Emissions Reporting', *Nature* 611, no. 7934 (November 2022): 29, https://doi.org/10.1038/d41586-022-03444-7.

Scope 1, 2, and 3) could push this figure to 5-5.5%.[77] The impact of warfighting activities, referred to as Scope 3 Plus, is very difficult to measure but has far-reaching consequences for the environment.[78] They include emissions emerging from fires in buildings and infrastructure, large-scale forest fires, soil degradation, debris and estimated reconstruction needs.[79]

Operational energy forms a substantial segment of overall military emissions among NATO partners. In 2020, NATO started developing an Operational Energy Concept, which refers to operational energy as "the energy necessary for training, moving, and sustaining military forces and weapons platforms for military operations."[80] This includes the energy usage in all domains, among which are weapons, platforms, communications, operational base functions, and the setup of the operational infrastructure.[81]

In 2021, 63% of the United States Department of Defense's Scope 1 and 2 emissions were produced in military operations, and the remaining 37% in installations.[82] According to the European Defense Agency, 53% of EU military GHG emissions in 2017 were produced by mobile activities, including

77 Parkinson and Cottrel, 'Estimating the Military's Global Greenhouse Gas Emissions', 7–8.

78 Linsey Cottrel, 'A Framework for Military Greenhouse Gas Emissions Reporting' (CEOBS, June 2022), 9, https://ceobs.org/wp-content/uploads/2022/06/CEOBS_A_framework_for_military_GHG_emissions_reporting.pdf.

79 Conflict and Environment Observatory (CEOBS), 'A Framework for Military Greenhouse Gas Emissions Reporting', 22 June 2022, https://ceobs.org/report-a-framework-for-military-greenhouse-gas-emissions-reporting/.

80 'NATO Allied Command Transformation Joint Force Development Experimentation & Wargaming: Branch 2023 Fact Sheet—NATO Operational Energy Concept' (NATO, 2023), https://www.act.nato.int/wp-content/uploads/2023/05/2023_Fact_Sheet_EiE_STJU23_Energy.pdf.

81 'Defence Operational Energy Strategy' (UK Ministry of Defence, 2023), 10, https://assets.publishing.service.gov.uk/media/6570b223809bc300133081cc/Defence_Operational_Energy_Strategy_2023.pdf.

82 'Department of Defense Plan to Reduce Greenhouse Gas Emissions' (U.S. Department of Defense, April 2023), https://media.defense.gov/2023/Jun/16/2003243454/-1/-1/1/2023-DOD-PLAN-TO-REDUCE-GREENHOUSE-GAS-EMISSIONS.PDF.

air, sea and land vehicles, and 46% by military bases.[83] The intensity of military activities, industrial development, climate conditions, and military scale are key determinants of military emissions. For instance, Germany's lower mobile-to-stationary emissions ratio compared to those of the United States is due to its smaller air force and navy, fewer foreign operations, and a focus on land-based activities. On average, the EU aligns with Germany.[84]

Transportation dominates operational emissions in both the United States and EU countries. Air forces in particular are the largest emitters, with 78% of total US operational emissions and 69% of EU emissions in 2017, respectively (see Table 1).[85] Between 2017 and 2021, the US military reduced its total operational energy demand from 85.5 to 78.4 million barrels.[86]

Table 1 Structure of US and EU operational emissions

	US operational emissions		EU operational emissions	
	2021	2017	2017	
Air Force	76%	78%	69%	3.6 million tons of CO_2
Navy	17%	15%	21%	1.1 million tons of CO_2
Army	6%	8%	10%	0.7 million tons of CO_2

83 Stuart Parkinson and Linsey Cottrel, 'Under the Radar: The Carbon Footprint of Europe's Military Sectors' (SGR and CEOBS, February 2021), 43, https://ceobs.org/wp-content/uploads/2021/02/Under-the-radar_the-carbon-footprint-of-the-EUs-military-sectors.pdf.

84 Parkinson and Cottrel, 'Estimating the Military's Global Greenhouse Gas Emissions', 6–7.

85 Axel Michaelowa, Tobias Koch, and Daniel Charro, 'MILITARY AND CONFLICT-RELATED EMISSIONS: KYOTO TO GLASGOW AND BEYOND', June 2022, https://thefivepercentcampaign.files.wordpress.com/2022/06/military-emissions_final.pdf; 'Department of Defense Plan to Reduce Greenhouse Gas Emissions' (U.S. Department of Defense, April 2023), https://media.defense.gov/2023/Jun/16/2003243454/-1/-1/1/2023-DOD-PLAN-TO-REDUCE-GREENHOUSE-GAS-EMISSIONS.PDF.

86 'Annual Energy Performance, Resilience, and Readiness Report'. US Department of Defence, 2022, https://www.acq.osd.mil/eie/Downloads/IE/FY22%20AEPRR%20Report.pdf

Operational gains from reducing fossil fuel dependence

There are notable vulnerabilities associated with fossil fuel dependence on the battlefield.[87] The longer the supply chain, the more vulnerable the success of the operation. Energy sources and fuel convoys can be sabotaged, leading not only to logistical issues due to reduced fuel supply, but also to the allocation of significant resources like personnel and armored vehicles for protecting the convoy. This was a vulnerability of the campaigns in Iraq and Afghanistan and led to the death or injury of thousands of troops and civilian contractors over time. In 2009, more than 3000 American troops were hurt while protecting convoys, most of them being fuel convoys.[88]

Moreover, the unstable energy markets over the last 3 to 4 years indicate that dependence on oil products for operations makes militaries subject to significant price volatility. In 2023, the US military reduced energy consumption to 76.2 million barrels, down from 85.5 million barrels in 2017. Despite the decrease, operational energy expenses rose from $8.2 billion to $9.1 billion, showcasing the impact of market volatility on operational costs.[89]

Furthermore, the logistical chain can severely impact fuel consumption and the costs of operations. For instance, the US operation in Afghanistan in 2012 emitted 20 tons of CO_2 per day, driven by the challenging logistics chain from Pakistan, which consumed significant fuel and incurred additional costs. This

87 Ben Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe' (The International Institute for Strategic Studies, February 2022), https://www.iiss.org/globalassets/media-library---content--migration/files/research-papers/2022/green-defence---the-defence-and-military-implications-of-climate-change-for-europe.pdf;

88 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/.

89 'Annual Energy Performance, Resilience, and Readiness Report' (US Department of Defense, 8 June 2023), 5, https://www.acq.osd.mil/eie/Downloads/IE/FY22%20AEPRR%20Report.pdf.

underscores the importance of increased self-sufficiency, especially in contested environments lacking robust energy infrastructure in the logistics chain.[90]

In this context, reducing the consumption of fossil fuels and ultimately transitioning to low-carbon energy sources can bring four important benefits to militaries.

1. Gains in operational energy efficiency will likely reduce the amount of fuels that need to be transported and protected by troops, especially when it comes to fossil fuels. These troops and resources can be allocated to other responsibilities, thus bringing more efficiency.
2. Integrating a larger share of low-carbon energy sources can limit price volatility for fossil-fuel based energy. Third, increased self-sufficiency reduces the reliance on complex (local) supply chains and exposure to risk.
3. Electric platforms can increase the stealth of platforms, acceleration power and reduce the need for engineering support for mechanical parts.[91] They can also be (partially) remotely maneuvered when integrated with automation.
4. Electrification reduces the risks of leaks and spills when a vehicle or platform is attacked, thereby reducing environmental damage caused by warfighting activities.

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90 Axel Michaelowa et al., 'Military and Conflict-Related Emissions: Kuyoto to Glasfow and Beyond' (Freiburg: Perspectives Climate Group, June 2022), 1, https://www.perspectives.cc/public/fileadmin/user_upload/military-emissions_final.pdf; Anna Dowd, Dominik P. Jankowski, and Cynthia Cook, 'European Warfighting Resilience and NATO Race of Logistics: Ensuring That Europe Has the Fuel It Needs to Fight the Next War', CSIS, 28 June 2023, https://www.csis.org/analysis/european-warfighting-resilience-and-nato-race-logistics-ensuring-europe-has-fuel-it-needs.

91 'Defence Operational Energy Strategy' (UK Ministry of Defence, 2023)

Low-carbon innovation for the air force

A notable part of efforts to decarbonize aircraft focus on enhancing energy efficiency through advancements in engines, body design, lower-emission fuels, and propulsion technologies. This can reduce the vulnerability to volatile markets and supply chain disruptions and increase the efficiency of military troops by reducing the size of fuel convoys. The US Department of Defense is focused on decarbonizing large military aircraft by prioritizing energy efficiency. This strategic focus specifically targets airlift, aerial refueling, and bombers, and aims to achieve efficiency improvements in propulsion, aerodynamic drag, and scalable enhancements across high operations tempo force. Demonstrations are underway for prototyped technologies, including C-17 microvanes, C-130 finlets, KC-135 vertical windshield wipers, C-17 engine pylon fairings, and finely tuned flight control surfaces. Simultaneously, the B-52 Commercial Engine Replacement Program aims for a 20% efficiency boost with new commercial-based engines, enabling upgrades to mission systems and improving maintainability. In collaboration with private industry and investors, an ongoing multi-year project aims to develop a Blended Wing Body cargo jet, offering significantly increased range and payload, along with up to 60% efficiency improvements in wide-body aircraft and engine upgrades.[92]

Sustainable aviation fuels (SAF)—synthetic fuels produced from non-petroleum feedstocks[93]—are considered the most viable means to reduce aviation emissions in the short to medium term. SAF have the potential to reduce up to 80% of lifecycle emissions compared to conventional jet fuel. At the same time, SAF can be easily integrated into existing platforms, eliminating the necessity for alternative propulsion systems. France's 'Defense Energy Strategy 2020' aims for aviation carbon neutrality by 2050 and relies for this on biofuels in

92 'Department of Defense Plan to Reduce Greenhouse Gas Emissions', 10.

93 Matteo Prussi et al., 'CORSIA: The First Internationally Adopted Approach to Calculate Life-Cycle GHG Emissions for Aviation Fuels', *Renewable and Sustainable Energy Reviews* 150 (October 2021): 111398, https://doi.org/10.1016/j.rser.2021.111398.

the medium term.[94] Another example is the US Defense Department's commitment to the SAF Grand Challenge aims to boost US SAF production to 3 billion gallons yearly by 2030, targeting 100% aviation fuel reliance by 2050, reaching an estimated 35 billion gallons.[95] Sweden's successful tests with a 50/50 biofuel mix in JAS 39 Gripen aircraft engines showcase unchanged function and performance.[96] The UK Royal Air Force has embraced SAF at a 50% blend, with plans to transition to 100% SAF in 2022, conducting high-profile bio-jet-fuel tests on F-18 and Gripen fighters. While conventional biofuels produced from organic waste and biomass are facing issues with environmental sustainability and are associated with land-use issues, synthetic fuels are more promising. Two types of synthetic fuels, e-fuels and solar fuels, offer sustainable options and are unconstrained by feedstock limitations. However, they still face some challenges due to energy intensity, high production costs, and dependency on clean electricity expansion.[97]

In addition to short- and medium-term solutions for decarbonizing aircraft like increased energy efficiency and blending SAF, emerging technologies for alternative propulsion bring notable opportunities in the longer term. Agility Prime, a US Air Force-led program, focuses on advancing electrification in rotorcraft and small mobility aircraft. The initiative aims to evaluate hybrid or electric vertical take-off and landing (VTOL) technologies. This can mitigate fuel logistics risk while enhancing resupply and recovery capabilities in closer proximity to conflict front lines.[98] Elroy Air develops the Chaparral, a hybrid-electric autonomous VTOL aircraft for cargo deliveries, while LIFT Aircraft works on the Hexa, an all-electric amphibious version. Finally,

94 Ben Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe' (The International Institute for Strategic Studies, February 2022), 10, https://www.iiss.org/globalassets/media-library---content--migration/files/research-papers/2022/green-defence---the-defence-and-military-implications-of-climate-change-for-europe.pdf.

95 'Department of Defense Plan to Reduce Greenhouse Gas Emissions'.

96 Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe', 11.

97 Kõrts, 'Climate Change Mitigation in the Armed Forces—Greenhouse Gas Emission Reduction—Challenges and Opportunities for Green Defense'.

98 'Department of Defense Plan to Reduce Greenhouse Gas Emissions', April 2023, 10.

battery-powered small UAVs are already in military use globally, but scaling up these efforts to larger aircrafts, such as jets, bombers, or transport planes will not be possible in the near term.[99]

Low-carbon innovation for the navy

Nuclear-powered maritime vessels have been in use ever since the 1950s, when the first US nuclear-powered submarine USS Nautilus was put in use. As of 2023, more than 160 submarines and surface vessels are nuclear-powered worldwide.[100] Using small nuclear reactors on board minimizes refueling needs and allows ships to remain at sea for long periods of time. For submarines, it maximizes stealth and brings certainty that sensors and weapons systems can operate at full capacity.[101] This is the case when compared to diesel engines, for instance. For surface ships, nuclear power allows for high-speed endurance and responsiveness, allowing for tactical flexibility, mobility, and ability to respond to crises in short periods of time.[102] It removes the need to store large amounts of fuels on board, thus reducing weight, and the need for combustion air and exhaust, thus increasing storage capacity. Nuclear -powered submarines will remain central to military powers as the United States, France, Australia, China and India have plans to modernize existing fleets or build new ones.[103] The US government has commissioned the construction

99 Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe', 17–18.

100 'Nuclear-Powered Ships', World Nuclear Association, 2023, https://world-nuclear.org/information-library/non-power-nuclear-applications/transport/nuclear-powered-ships#nuclear-naval-fleets.

101 'The United States Naval Nuclear Propulsion Program 2020' (Department of Eenrgy and Department of the Navy, 2020), https://www.energy.gov/sites/default/files/2021-07/2020%20United%20States%20Naval%20Nuclear%20Propulsion%20Program%20v3.pdf.

102 'The United States Naval Nuclear Propulsion Program 2020'.

103 Greg Torode, 'Inside Asia's Arms Race: China near "breakthroughs" with Nuclear-Armed Submarines, Report Says', *Reuters*, 9 October 2023, https://www.reuters.com/world/asia-pacific/inside-asias-arms-race-china-near-breakthroughs-with-nuclear-armed-submarines-2023-10-09/; Richard Sterk, 'India Levels Up in Nuclear Submarines', Defense Security Monitor, 1 May 2023, https://dsm.forecastinternational.com/2023/05/01/india-levels-up-in-undersea-nuclear-submarines/.

of Columbia class ballistic missile submarines as of 2020 to replace part of the older fleet.[104] As part of the trilateral AUKUS partnership, the Australian government has announced in 2024 the purchase of at least eight nuclear powered submarines.[105]

Various types of biofuels including straight vegetable oil, biodiesel (1st and 2nd generations), biogas, biohydrogen, and lignocellulosic-based bio-oil have been tested in both military and commercial maritime contexts over time. For instance, a Fischer–Tropsch biofuel blend underwent testing on five US Navy vessels during the Rim of the Pacific Exercise as early as 2012. Another initiative in the Port of Rotterdam involved testing a 100% renewable marine biofuel and completing 2000 running hours on the Alexander von Humboldt dredger vessel. This resulted in a 80–90% reduction in CO_2 emissions. Still, large-scale biofuel use in maritime operations faces challenges, including volume requirements, handling uncertainties in fuel supply, and higher production costs compared to fossil fuels in the short to medium term.[106]

Moreover, integrated hybrid or fully electric propulsion technologies have been explored by, among others, the US, UK, and Canadian navies. Hybrid propulsion has notable benefits for military platforms, as it dramatically reduces noise and increases stealth, while also boosting operational flexibility by minimizing demands on the Combat Logistics Fleet for frequent refueling at sea.[107] The US Navy is implementing integrated propulsion across five

104 'The United States Naval Nuclear Propulsion Program 2020' (Department of Eenrgy and Department of the Navy, 2020), https://www.energy.gov/sites/default/files/2021-07/2020%20United%20States%20Naval%20Nuclear%20Propulsion%20Program%20v3.pdf.

105 https://world-nuclear-news.org/Articles/Contract-for-expansion-of-Rolls-Royce-submarine-si

106 Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe', February 2022, 14.

107 Global Combat Ship Ultra-Quiet Hybrid Electric ASW Frigate, GE VERNOVA, 17 January 2022, https://www.gevernova.com/power-conversion/case-study/global-combat-ship-ultra-quiet-hybrid-electric-asw-frigate

classes of combatant ships and eight classes of logistics ships.[108] The United Kingdom is implementing advanced hybrid propulsion technology in three fleet solid support ships using GE technology.[109] The Canadian government conducts various exploratory projects including feasibility assessments of hybrid and all-electric technologies for navy ships.[110]

Low-carbon innovation for land tactical vehicles

Electric motors present distinct advantages over internal combustion engines in land warfare due to their simplicity, reliability, stealth, and power-to-size ratio. Considering the notable advancements in the civilian sector, Hybrid Electric Drive (HED) and electric technologies are expected to effectively serve land applications, particularly in lighter vehicles. The hybridization of wheeled vehicles can enhance range, functionality, torque, and traction. Technologies such as UK's MAN SV Foxhound and Jackal vehicles, the US Light Tactical All-Terrain vehicle HED version, and France's planned HED Griffon multi-role armored vehicle, showcase significant benefits for combat service support-logistic vehicles, including unmanned variants.[111]

Further, anti-idle technologies reduce liquid fuel demand and enable a "silent watch" mode, enhancing mission-critical capabilities. A notable example is the US Department of Defense's hybrid-electric Bradley Infantry Fighting

108 'Department of the Navy Climate Action 2030' (Washington: Department of the Navy, May 2022), 19, https://www.navy.mil/Portals/1/Documents/Department%20of%20the%20Navy%20Climate%20Action%202030.pdf?ver=ScwuxX5mGr9jXT1ewRvlxg%3d%3d&timestamp=1653339650456.

109 Riviera News, 'Royal Navy Ships to Be Equipped with Hybrid-Electric Propulsion', Riviera, 22 January 2024, https://www.rivieramm.com/news-content-hub/news-content-hub/royal-navys-fleet-solid-support-fss-ships-to-sport-hybrid-electric-propulsion-technology-79309.

110 Shiloh Fetzek, 'Carbon Emissions, Net Zero and Future Forces—Comperative Analysis of Radical Emissions-Reductions PLans and Processes for Defence' (The International Institute for Strategic Studies, October 2023), 13, https://www.iiss.org/globalassets/media-library---content--migration/files/research-papers/2023/10/carbon-emissions-net-zero-and-future-forces/iiss_carbon-emissions-net-zero-and-future-forces.pdf.

111 Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe', 16.

Vehicle demonstrator, currently undergoing testing. Plans include acquiring HED demonstrators for the Joint Light Tactical Vehicle and High-Mobility Multipurpose Wheeled Vehicle, offering enhanced survivability, lethality, and silent mobility.[112] Moreover, the US Department of Defense is implementing a standardized lithium version of the vehicle standard 6T battery, providing increased capacity, rechargeability via solar power, and support for anti-idle, silent watch, and auxiliary mission systems. Standardizing the lithium 6T battery streamlines logistics, supports supply chain initiatives, and facilitates interoperability with allied partners.[113]

Efforts are being made to overcome some of the challenges associated with hybrid and electric vehicles, powered both by batteries and hydrogen fuel cells. Current battery limitations include weight, slow charging, and limited range. Removable, swappable batteries might mitigate charging issues, while ongoing advancements in lightweight and energy-dense materials promise improvements in weight. In 2021, the Netherlands initiated tests on an electric truck to assess operational feasibility. Both full-electric and HED options necessitate high-powered charging stations exceeding ten megawatts for mission sustainability. The protection of such stations becomes a crucial operational requirement, especially in contested environments.[114] Fuel-cell vehicles powered by hydrogen, exemplified by General Motors' ZH2 hydrogen fuel cell-powered electric pick-up truck, offer advantages like rapid refueling and low fuel consumption at idle. However, they pose additional complexity in terms of market readiness, higher costs and energy density.[115] As hydrogen tends to be less dense and therefore less efficient than oil products like gasoline, it requires more space on a vehicle to allow for a similar range.[116]

112 'Department of Defense Plan to Reduce Greenhouse Gas Emissions', April 2023, 11.

113 'Department of the Navy Climate Action 2030', 17.

114 Barry, 'Green Defence: The Defence and Military Implications of Climate Change for Europe', 16.

115 Barry, 16.

116 Dan Tang et al., 'State-of-the-Art Hydrogen Generation Techniques and Storage Methods: A Critical Review', *Journal of Energy Storage* 64 (1 August 2023): 107196, https://doi.org/10.1016/j.est.2023.107196.

Artificial intelligence and automation

The symbioses between emerging technologies are as important as the emergence of the technologies themselves. As such, the synergy between AI and Autonomous Systems acts as an enabler in decreasing the need for human interaction.[117] For instance, the adoption of robotic and autonomous systems would lower emissions by eliminating the need for human presence on platforms, thus allowing for a reduction in their size and weight. The potential to replace humans or human decision-making represents a major potential shift in warfighting for the future. Being referred to as the first 'AI war'[118], an 'AI war lab'[119] or even the 'most technologically advanced war in human history'[120], the Russian invasion of Ukraine presents a use case of what the battlefield of the (near) future might look like. This battlefield is increasingly automated and enhanced with the use of AI technologies. At the same time, it raises serious questions about the ethical and legal implications of using AI systems and human-machine cooperation in the military domain.[121] Relevant legal and ethical frameworks are lagging behind.

One specific application of this is swarm technology, which is particularly interesting when it comes to its interaction with low-carbon applications. Swarming refers to the use of a group of unmanned vehicles powered by

117 'The Future of Battlefield', Office of the Director of National Intelligence, March 2021, https://www.dni.gov/index.php/gt2040-home/gt2040-deeper-looks/future-of-the-battlefield.

118 Robin Fontes and Dr Jorrit Kamminga, 'Ukraine A Living Lab for AI Warfare', NDIA's Business & Technology Magazine, 24 March 2023, https://www.nationaldefensemagazine.org/articles/2023/3/24/ukraine-a-living-lab-for-ai-warfare.

119 Vera Bergengruen, 'How Tech Giants Turned Ukraine Into an AI War Lab', TIME, 8 February 2024, https://time.com/6691662/ai-ukraine-war-palantir/.

120 David Ignatius, 'Opinion | How the Algorithm Tipped the Balance in Ukraine', Washington Post, 19 December 2022, https://www.washingtonpost.com/opinions/2022/12/19/palantir-algorithm-data-ukraine-war/.

121 'Enhancing EU Military Capabilities beyond 2040: Main Findings from the 2023 Long Term Assessment of the Capability Development Plan'. European Defence Agency. (LU: Publications Office, 2023), https://data.europa.eu/doi/10.2836/360180.

algorithms used in cooperation to achieve the same goal.[122] While not limited to unmanned aerial vehicles (UAVs), the use of drone swarms both over land and sea is seen as a key element in changing the balance of military power.[123] When a swarm of drones can be fully steered by AI, thus taking out human interference, it increases the potential for remote warfare to grow in scale and effectiveness while driving down costs for the military.[124] By employing smaller unmanned vehicles and removing any crew, their weight will be significantly reduced compared to current applications. This allows for the use of low-carbon propulsion systems in unmanned aerial or land vehicles, for instance using solar panels or hydrogen fuel cells for UAVs.[125]

These technological developments are of growing importance to NATO militaries when it comes to remote warfare. AI and autonomous systems allow militaries to engage in warfighting at increasing distances without the need to deploy a large number of troops.[126] This is particularly relevant for environments deemed non-accessible or too hazardous for human troops; such as environments characterized by extreme cold or heat, but also areas posing a chemical, biological, nuclear or radiological contamination risk. For instance, in the case of inaccessibility due to extreme temperatures, AI automated drones can be used for surveillance and reconnaissance of the area to gather data to detect, survey, and monitor the operational environment.

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122 David Hambling, 'What Are Drone Swarms And Why Does Every Military Suddenly Want One?', Forbes, 1 March 2021, https://www.forbes.com/sites/davidhambling/2021/03/01/what-are-drone-swarms-and-why-does-everyone-suddenly-want-one/.

123 Elliot Ackerman and James Stavridis, 'Essay | Drone Swarms Are About to Change the Balance of Military Power', WSJ, 14 March 2024, https://www.wsj.com/tech/drone-swarms-are-about-to-change-the-balance-of-military-power-e091aa6f.

124 T.X. Hammes, 'The Rising Dominance of the Tactical Defense?', in *Beyond Ukraine*: *Debating the Future of War*, ed. Tim Sweijs and Jeffrey H. Michaels (London: Hurst & Company, 2024), 205.

125 Depledge, 'Low-Carbon Warfare', 6 March 2023.

126 Alasdair McKay, Abigail Watson, and Megan Karlshøj-Pedersen, 'Remote Warfare: Interdisciplinary Perspectives', *E-International Relations* (blog), 2021, https://www.e-ir.info/publication/remote-warfare-interdisciplinary-perspectives/.

Increased AI and automation in the military domain also reduces the need for human interaction, which can be advantageous considering the changing societal perceptions of the military.[127] Especially in the EU, people's willingness to fight for their country has been decreasing over the past decade.[128] This goes alongside a general decrease in the size of conventional military forces observed in the United States and amongst NATO allies.[129] Germany, France, Spain, Italy and the United Kingdom are experiencing difficulties in recruiting young personnel. [130] This has consequences for military readiness. Unlike in Russia, it would be much more difficult for a European military to mobilize 300,000 troops.[131] Young people in Europe are holding opposing values towards warfare in general,[132] toward military operations abroad in particular, but also the military lifestyle and corresponding salaries.[133]

These trends are, however, fluid in nature and strongly driven by world events. Northern and Eastern Europe have seen a resurgence in interest and willingness to join the military fueled by the war in Ukraine.[134] The war in Ukraine

127 Nina Wilén and Lisa Strömbom, 'A Versatile Organisation: Mapping the Military's Core Roles in a Changing Security Environment', *European Journal of International Security* 7, no. 1 (29 November 2021): 18–37, https://doi.org/10.1017/eis.2021.27.

128 World Values Survey wave 7, 2017-2022, https://www.worldvaluessurvey.org/WVSDocumentationWV7.jsp

129 Raphael S. Cohen et al., 'The Future of Warfare in 2030: Project Overview and Conclusions' (RAND Corporation, 11 May 2020), https://www.rand.org/pubs/research_reports/RR2849z1.html.

130 Giulia Carbonaro, 'Why Are European Armies Struggling to Recruit Soldiers?', Euronews, 16 February 2024, https://www.euronews.com/2024/02/16/why-are-european-armies-struggling-to-recruit-soldiers.

131 Elisabeth Braw, 'Europe's Readiness Problem', *Foreign Affairs*, 30 November 2017, https://www.foreignaffairs.com/articles/europe/2017-11-30/europes-readiness-problem.

132 Kiran A. Ahuja and Jason S. Miller, 'Government-Wide Military-Connected Strategic Plan for Fiscal Years (FYs) 2024-2028 | CHCOC', 27 February 2024, https://chcoc.gov/content/government-wide-military-connected-strategic-plan-fiscal-years-fys-2024-2028.

133 Giulia Carbonaro, 'Why Are European Armies Struggling to Recruit Soldiers?', euronews, 16 February 2024, https://www.euronews.com/2024/02/16/why-are-european-armies-struggling-to-recruit-soldiers.

134 Wolfang Wagner, 'A Greater Willingness to Fight for Your Homeland', Vrije Universiteit Amsterdam, accessed 29 March 2024, https://vu.nl/en/research/a-greater-willingness-to-fight-for-your-homeland.

and shortages in recruiting new personnel has given way to a renewed debate on conscription, for instance in Denmark[135], Germany[136], Sweden[137], and the United Kingdom[138].

Information technology

The use of unconventional military means such as information warfare, economic coercion or cyberattacks are typically described as examples of hybrid threats. While their use is not new and their importance vis-à-vis conventional military means undecided, the speed, depth and scope of such hybrid threats has grown in importance.

The future of war is characterized by rapidly evolving information technology that is changing the way people live, think, communicate, and ultimately fight wars.[139] This is causing the boundary between the physical and cognitive battlefield to fade.[140] As the world increasingly digitizes, information warfare including cyber operations are indispensable in the toolbox of hybrid warfare.[141] This is taking place both on and off the traditional battlefield, as

135 ŠEJLA AHMATOVIĆ, 'Denmark to Begin Conscripting Women for the Military in Rare Move', POLITICO, 13 March 2024, https://www.politico.eu/article/denmark-extend-military-service-women-conscription/.

136 Nick Alipour, 'Germany Mulls Reintroducing Conscription', Euractiv, 13 March 2024, https://www.euractiv.com/section/defence-and-security/news/germany-mulls-reintroducing-conscription/.

137 Gil Barndollar, 'Sweden's New Model Army', *Foreign Policy* (blog), 15 March 2024, https://foreignpolicy.com/2024/03/15/sweden-nato-military-conscription-model-defense/.

138 Edward Stringer, 'Conscription Is Not the Answer for Britain to Get Its Military in Order', The Financial Times, 2024, https://www.ft.com/content/02e870cb-ecc8-4344-ac24-1b7e810eaf78.

139 Laura Jasper et al., 'Start with the End: Effect Measurement of Behavioural Influencing in Military Operations', HCSS, 14 November 2023, https://hcss.nl/report/start-with-the-end-effect-measurement-of-behavioural-influencing-in-military-operations/.

140 Laura Jasper *et al.*,' Start with the End', 14 November 2023

141 Cyber warfare is typically divided into three types of operations: the gathering of intelligence data, hard cyber operations (e.g., using malware), and soft cyber operations aimed at influencing the adversary. See Ducheine, Pijpers, and Arnold, 88.

cyber warfare is increasingly used for non-conventional military means such as espionage, sabotage, political or economic disruption.[142] This results in the need for coordination between military domains, operations and capabilities. The synchronization between all these elements highlights that the changing character of war not only imposes changes in operational capabilities but also its capacity and planning structure.

The importance of information for warfighting is reaching new heights due to unprecedented technological advances. This is only going to increase in the future due to information technologies being enhanced with machine learning and AI. This trend is referred to by some as the 'new international arms race,'[143] particularly when it comes to the cyber domain. For instance, making use of deepfake technology not only has the ability to alter perceptions of an enemy combatant but also to dissuade and influence a civilian population. This bears the risk of eroding the trust of civilian populations in democratic institutions in general and the armed forces in particular, which can complicate recruitment. This is also exacerbated for instance by disinformation campaigns blaming states and militaries for climate disasters.[144] Applied to climate change, the use of information technologies and their ability to alter the perception of the operational environment when it comes to weather conditions pose equal threat and opportunity. The US Navy has integrated weather into their information warfare capabilities, specifically related to meteorology and oceanography.[145] As weather is an important factor in determining behavior in the battlespace, the US 16th Air Force, which is

142 Cohen et al., 'The Future of Warfare in 2030'.

143 Rod Thornton and Marina Miron, 'Towards the "Third Revolution in Military Affairs": The Russian Military's Use of AI-Enabled Cyber Warfare', *The RUSI Journal* 165, no. 3 (28 May 2020): 12–21, https://doi.org/10.1080/03071847.2020.1765514.

144 'Climate Security and Misinformation: A Baseline—The Council on Strategic Risks', 23 April 2024, https://councilonstrategicrisks.org/2024/04/23/climate-security-and-misinformation-a-baseline/.

145 Mark Pomerleau, 'How Weather Is Playing a Role in Information Warfare', C4ISRNet, 21 December 2021, https://www.c4isrnet.com/information-warfare/2021/12/21/how-weather-is-playing-a-role-in-information-warfare/.

the service's first information warfare command, and specifically its Weather Wing, is tasked with predicting and influencing adversary behavior.[146]

Space technology and satellites

New frontiers in military operations are opening up due to new threats and technologies, and one of them is space. While space has long been an important supporting feature of military operations when it comes to surveillance, communication, and navigation,[147] it is now increasingly emerging as a decisive operational environment in its own right. China, India, Russia, and the United States have all been testing anti-satellite weapons and have increased their spacecraft launches.[148] In future conflicts, the use of new satellite technology could turn out to be a decisive factor in identifying and eliminating targets, especially across long and vast distances over land and sea.[149]

The use of satellites for tracking and monitoring rapid changes in the operational environment and their related hazards is not new. However, the use of satellite technology to enhance military resilience to climatic impacts on the changing operational environment has not been sufficiently explored.[150] Satellite technology can aid militaries in identifying rapidly changing weather conditions, understanding their potential impact, and determining how to

146 '557th WW Realigns under New Information Warfare NAF', 557th Weather Wing, 4 November 2019, https://www.557weatherwing.af.mil/News/Article-Display/Article/2007798/557th-ww-realigns-under-new-information-warfare-naf/.

147 Raphael S. Cohen et al., 'The Future of Warfare in 2030: Project Overview and Conclusions' (RAND Corporation, 11 May 2020), https://www.rand.org/pubs/research_reports/RR2849z1.html.

148 'War in Space Is No Longer Science Fiction', *The Economist*, 31 January 2024, https://www.economist.com/international/2024/01/31/america-china-and-russia-are-locked-in-a-new-struggle-over-space.

149 'War in Space Is No Longer Science Fiction'. 31 January 2024

150 'The Climate-Space Nexus: New Approaches for Strengthening NATO's Resilience', NATO Review, 18 August 2022, https://www.nato.int/docu/review/articles/2022/08/18/the-climate-space-nexus-new-approaches-for-strengthening-natos-resilience/index.html.

effectively respond.[151] Satellite data can also contribute to the development of early warning tools to understand the risks early on.[152]

These developments result in large part from an increase in investment in space technologies by both private and government parties, highlighting their dual use potential. The use of Starlink satellites during the Russo-Ukrainian war demonstrates how commercial applications can be integrated into military systems very quickly and with minimal effort.[153] The use of small and mostly cheap satellites is gaining importance for kinetic operations particularly when it comes to evading detection by enemy forces.[154] Lastly, using smaller satellites that are increasingly cost-efficient[155], and can be used together with more sustainable fuels like iodine,[156] aid both cost reductions and sustainability efforts.

151 'The Climate-Space Nexus: New Approaches for Strengthening NATO's Resilience', NATO Review, 18 August 2022

152 'The Climate-Space Nexus: New Approaches for Strengthening NATO's Resilience', NATO Review, 18 August 2022

153 Cole August et al., 'Artificial Intelligence in Military Planning and Operations—Peace Research Institute Oslo (PRIO)', 2024, https://www.prio.org/publications/13815; Enhancing EU Military Capabilities beyond 2040: Main Findings from the 2023 Long Term Assessment of the Capability Development Plan. European Defence Agency. (LU: Publications Office, 2023), https://data.europa.eu/doi/10.2836/360180.

154 Nicholas Eftimiades, Small satellites: The implications for national security. Atlantic Council, 5 May 2022, https://www.atlanticcouncil.org/wp-content/uploads/2022/05/Small_satellites-Implications_for_national_security.pdf

155 Christian Davenport, 'The Revolution in Satellite Technology Means There Are Swarms of Spacecraft No Bigger than a Loaf of Bread in Orbit', *Washington Post*, 11 April 2021, https://www.washingtonpost.com/technology/2021/04/06/small-satellites-growth-space/.

156 'Xenon Loses Ground to More Cost-Efficient Satellite Fuel Competitor', CORDIS | European Commission, 28 October 2022, https://cordis.europa.eu/article/id/442399-xenon-loses-ground-to-more-cost-efficient-satellite-fuel-competitor.

Ensuring operational effectiveness in a new strategic environment: Six vignettes

The reasons why wars are fought have remained roughly the same over the last centuries, but the actors, technologies and their interactions on the battlefield have continuously evolved.[157] Predicting the importance and impact of innovative technologies remains very difficult. Technological development rarely progresses in a linear fashion and the interdependencies between emerging technologies are as important as the emergence of the technologies themselves. For instance, it remains unclear how the symbioses between AI and low-carbon technologies will evolve and what their interdependence means for information or cyber warfare. At the same time, while certain low-carbon technologies such as batteries for electric transportation continue to face implementation challenges, future advancements may solve issues such as weight and lead time in batteries, bringing significant operational advantages to militaries.

This section outlines some of the most prominent global security dynamics expected in the next 10 to 20 years, the impact of climate change and innovative technologies on these dynamics, and potential implications for NATO members. The vignettes cover a diverse set of developments that may impact North American and European countries in different ways, ranging from dynamics of deterrence to direct military implications and indirect security interests. While predicting the way in which warfare will develop has repeatedly proven challenging and often resulted in faulty assessments, there are several commonly accepted trends that are discussed below.[158] This is not a comprehensive list but serves as a starting point to analyze the future of military operations in an integrated way (see Table 2).

157 Cohen et al., 'The Future of Warfare in 2030'.

158 Cohen et al., 'The Future of Warfare in 2030'

Table 2 Emerging security dynamics in a changing climate and the role of innovative technologies

Emerging security dynamics	Climate change impacts on the operational environment	The role of innovative technologies
1. Inter-state conflict in the Indo-Pacific		
Over the last two decades the world has witnessed China's rise and increasingly assertive role in the Indo-Pacific region.[159] At the same time, the People's Liberation Army has been increasing its level of professionalization and the sophistication of its military capabilities.[160] China has been advancing its interests in the South and East China Seas, causing nervousness in neighboring countries. The chances of Indo-Pacific states being involved in a military operation are slowly growing. NATO and the EU are committed to a rules-based international order in the Indo-Pacific. They have been expanding security dialogues with Indo-Pacific countries and are committed to continuing engagement to address cross-regional tensions.[161]	• Ocean acidification and water temperature increase require more frequent maintenance regimes for maritime platforms. They also have implications for the detection, localization and identification of submerged objects.[162] • Weather patterns are unstable, and the Indo-Pacific is the most natural disaster-prone region in the world. It has a high concentration of mega-cities located in coastal areas and along river beds that are increasingly vulnerable to floods. It is also the 'factory of the world' which could result in large-scale supply-line disruptions.	• HED maritime vessels reduce the need for maintenance and increase stealth, adding notable operational advantages in response to climatic changes. The combined use of automatic systems aids in rapid threat detection and mediation in regard to changes in the operational environment by being able to increase the speed and volume of data that is otherwise manually processed. • Increasing the fuel efficiency of aircraft engines can mitigate the issues created by sudden re-routing, while using SAF can reduce the dependence on volatile oil markets.[163] • The use of satellites in monitoring and predicting weather patterns in the Indo-Pacific provides notable benefits to NATO and their partners.

159 Raphael S. Cohen, Eugeniu Han, and Ashley L. Rhoades, 'Geopolitical Trends and the Future of Warfare: The Changing Global Environment and Its Implications for the U.S. Air Force' (RAND Corporation, 11 May 2020), https://www.rand.org/pubs/research_reports/RR2849z2.html.

160 Cohen, Han, and Rhoades. 'Geopolitical Trends and the Future of Warfare'

161 'NATO 2022 Strategic Concept', 2022, https://www.nato.int/nato_static_fl2014/assets/pdf/2022/6/pdf/290622-strategic-concept.pdf; Josep Borrell, 'The EU and the Indo-Pacific: Partners for a More Stable and Prosperous World', 2024, https://www.eeas.europa.eu/eeas/eu-and-indo-pacific-partners-more-stable-and-prosperous-world_en.

162 National Intelligence Council, 'Climate Change and International Responses Increasing Challenges to US National Security Through 2040', 2021, https://www.dni.gov/files/ODNI/documents/assessments/NIE_Climate_Change_and_National_Security.pdf.

163 Forrest E. Morgan and Raphael S. Cohen, 'Military Trends and the Future of Warfare: The Changing Global Environment and Its Implications for the U.S. Air Force' (RAND Corporation, 11 May 2020), https://www.rand.org/pubs/research_reports/RR2849z3.html.

Emerging security dynamics	Climate change impacts on the operational environment	The role of innovative technologies
2. Strategic importance of the High North and opening up of the Arctic circle		
The Arctic region is becoming increasingly more important for NATO militaries due to global warming and rising geopolitical tensions. Seven out of the eight member states of the Arctic Council are NATO members, the eighth one being Russia. Melting ice caps are making the region and its natural resources more accessible and economically viable for various parties, for instance through the creation of an ice-free Northern Sea Route for China-Europe shipping. This also brings increased potential for military activity and spill-over of conflicts.	• The High North is characterized by extreme cold temperatures. These temperatures may cause traditional fuels to freeze, emphasizing the significance of capacity building for adequate energy logistics in armed forces' operations. • Due to climate change the Arctic circle has been experiencing permafrost degradation, changes in sea ice dynamics and rising sea levels at an increasing rate. These environmental changes have implications for operational capabilities and energy infrastructure. • Melting ice caps and increasing surface temperature lead to coastal erosion. It also leads to geopolitical shifts in military power as Russia will soon gain access to both oceans from the North throughout the year.	• Operational limitations in the Arctic region due to extreme temperatures or reduced communications capability can be managed with the use of autonomous systems and satellite technology. Unmanned Aerial or Maritime Vehicles that are able to withstand extreme environmental circumstances bring operational benefits as human troops would not be able to endure harsh conditions for long time intervals.[164] Smaller satellites in bigger numbers can help circumvent the operational limitation of reduced communications. • Innovations like mobile operational energy microgrids that can withstand temperatures as low as -51 degrees Celsius and battery recharging systems for cold weather operations are under development by the Arctic Grid Energy Solutions initiative.[165] The light universal charger enables soldiers to recharge batteries during missions by connecting to a snowmobile battery.[166]

164 Gosselin-Malo, Elisabeth. 'Norway Special Operators Field Pitches on Fresh, Arctic-Capable Gear'. Defense News, 9 February 2023. https://www.defensenews.com/global/europe/2023/02/09/norway-special-operators-field-pitches-on-fresh-arctic-capable-gear/.

165 'DoD Prototyping Commercial Cold Regions Microgrid Solution for Military Use', Defense Innovation Unit, 2022, https://www.diu.mil/latest/department-of-defense-to-prototype-commercial-cold-regions-microgrid.

166 Elisabeth Gosselin-Malo, 'Norway Special Operators Field Pitches on Fresh, Arctic-Capable Gear', Defense News, 9 February 2023, https://www.defensenews.com/global/europe/2023/02/09/norway-special-operators-field-pitches-on-fresh-arctic-capable-gear/.

Emerging security dynamics	Climate change impacts on the operational environment	The role of innovative technologies
3. Growing impact of natural hazards		
Climate-induced natural hazards and disasters complicate military operational readiness,[167] and are happening at an increasing rate in Europe, the United States and their surroundings.[168] The re-tasking of military personnel and equipment to assist with Humanitarian Aid and Disaster Relief (HADR) would strain resources otherwise deployed in military operations, or required for training purposes. Besides the impact of natural hazards on operational capability due to HADR, natural hazards and extreme weather conditions also have a direct impact on operational ability due the increased volatility and unpredictability of the environment.	• Climate change is exacerbating the frequency and impact of natural hazards. • Due to the link between natural hazards—in particular extreme weather—and infectious diseases, military forces may have to respond in the case of health emergencies as well as increase the protection of their forces' health when operating in disaster areas. • The occurrence of natural disasters such as floods or forest fires hinders operational planning and training cycles.	• Remotely controlled or fully autonomous UAVs support NATO operations in the area of intelligence, surveillance and reconnaissance capability in the event of HADR, and for broader monitoring of weather events. • The use of low-carbon technologies could also improve the social acceptance of local communities when NATO provides HADR to climate-related events.

167 Reding et al., 'Science & Technology Trends 2023-2043: Across the Physical, Biological, and Information Domains'.

168 'Military Providing Disaster Relief Assistance on Maui', www.army.mil, 16 August 2023, https://www.army.mil/article/269149/military_providing_disaster_relief_assistance_on_maui.

Emerging security dynamics	Climate change impacts on the operational environment	The role of innovative technologies
4. Intercommunal violence in the Middle East, Sahel and Sub-Saharan Africa		
Scarcity of water, food and land resources can be a driver of tensions in areas that suffer from instability, ethnic fragmentation and political and economic marginalization.[169] Lacking successful adaptation capabilities, groups may choose to migrate or engage in illegal activities as a means to secure resources. Whether these trends exacerbate instability and spark inter-communal violence is context dependent, with factors like identity and tribal affiliation, inter-group relations and the legitimacy of local authorities impacting the likelihood. NATO militaries lead operations in some areas that could suffer from inter-communal violence, meaning that NATO work may be affected by such developments.[170] While NATO has been active in operations related to counter-insurgency missions and efforts to fight terrorism before, the nature of these threats is evolving due to climate change.[171]	• In regions that are highly vulnerable to climate change, resource scarcity is exacerbated. It becomes more difficult for NATO members to operate using local resources. • Extreme weather conditions in climate vulnerable areas are also more common. For NATO operations, this translates into issues for equipment, platforms, and planning. For instance, dust storms reduce visibility and helicopters cannot take off when temperatures reach 50 degrees Celsius.	• Using more electric land vehicles, especially light and possibly unmanned tactical vehicles, can support NATO operations regarding regional stability and development efforts.[172] • The use of AI and automation technologies can increase the accuracy and speed of pattern recognition when it comes to intercommunal violence, contributing to more effective early warning systems but also understanding conflict dynamics.[173] • Taking steps to decarbonize could also improve the social acceptance of local communities.[174] The use of disinformation campaigns creating false narratives surrounding NATO presence cause a more fragile and hostile operational environment. • Adaptation requires a conflict-sensitive approach in order to be successful. Militaries can support comprehensive planning and decision making by providing the security lens to the design of adaptation programs.

169 Perceptions of climate change and violent extremism' , UNICRI, October 2022, https://unicri.it/Publication/Perception-of-Climate-Change-and-Violent-Extremism.

170 'NATO on the Map', NATO, accessed 28 March 2024, https://www.nato.int/nato-on-the-map/#lat=50.106295094276646&lon=1.686714377215477&zoom=0&layer-3&layer-1.

171 'NATO on the Map', NATO, accessed 28 March 2024, https://www.nato.int/nato-on-the-map/#lat=50.106295094276646&lon=1.686714377215477&zoom=0&layer-3&layer-1.

172 Stoicescu,Kalev, 'Stabilising the Sahel. The Role of International Military Operations', ICDS, 1 July 2020, https://icds.ee/en/stabilising-the-sahel-the-role-of-international-military-operations/.

173 Cohen et al., 'The Future of Warfare in 2030'.

174 Dale F. Reding et al., 'Science & Technology Trends 2023-2043: Across the Physical, Biological, and Information Domains' (Brussels: NATO Science & Technology Organization, March 2023), https://www.nato.int/nato_static_fl2014/assets/pdf/2023/3/pdf/stt23-vol1.pdf.

Emerging security dynamics	Climate change impacts on the operational environment	The role of innovative technologies
5. The empowerment of non-state armed groups (NSAGs)		
Resource scarcity and the absence of alternatives to resource-dependent livelihoods may lead individuals to join NSAGs.[175] These groups take advantage of existing grievances and societal divisions, offering alternative public services where governmental institutions are weak. In this way, they gain relevance at the expense of governmental authorities. This has been a particularly prominent trend in the Sahel (Boko Haram), East Africa (al-Shabab), and Iraq/Syria(ISIS/Daesh).[176] NSAGs are linked to the expansion of illicit activities like drugs, weapons and human trafficking, abductions or cattle rustling, in order to generate revenue. Young people with (perceived) limited future job opportunities are often targeted by NSAGs and recruited to engage in illicit activities. As part of NATO's commitment to project stability and fight terrorism, these dynamics will become increasingly relevant for Allies.[177]	• In regions that are highly vulnerable to climate change resource scarcity is exacerbated. It becomes more difficult for NATO members to operate while relying on local resources. • Extreme weather conditions in climate vulnerable areas are also more common. For NATO operations, this translates into issues for equipment, platforms and planning. For instance, dust storms reduce visibility and helicopters cannot take off when temperatures reach 50 degrees Celsius. • Offering aid in the aftermath of natural disasters is a key strategy of NSAGs to mobilize support. The climate-related increase in frequency and/or impact of natural hazards may lead to the increase in power of NSAGs.	• Using more electric land or air vehicles, especially light and possibly unmanned tactical vehicles, can support NATO operations in contested environments.[178] Such semi or fully automated vehicles increase stealth and offer the possibility to engage in operations from remote locations without deploying a large number of troops to hazardous areas. • Taking steps to decarbonize could also improve the social acceptance of local communities. The use of information technologies is central in driving grievances and societal divisions within local communities, negatively impacting NATO's image and complicating its operational environment. NATO militaries can counter these threats without the use of kinetic capabilities by decreasing their environmental footprint.

175 Tim Sweijs, Marleen de Haan, and Hugo van Manen, 'Unpacking the Climate Security Nexus', HCSS, March 2022, https://hcss.nl/wp-content/uploads/2022/03/Unpacking-the-Climate-Security-Nexus-HCSS-2022-1.pdf

176 'Perceptions of climate change and violent extremism', UNICRI, October 2022

177 'NATO 2022 Strategic Concept', 2022, https://www.nato.int/nato_static_fl2014/assets/pdf/2022/6/pdf/290622-strategic-concept.pdf

178 Neta C. Crawford, 'Pentagon Fuel Use, Climate Change, and the Costs of War' (Boston Univeristy, 13 November 2019), https://watson.brown.edu/costsofwar/files/cow/imce/papers/Pentagon%20Fuel%20Use%2C%20Climate%20Change%20and%20the%20Costs%20of%20War%20Revised%20November%202019%20Crawford.pdf.

Emerging security dynamics	Climate change impacts on the operational environment	The role of innovative technologies
6. Urban warfare in South Asian megacities		
South Asia has the largest concentration of megacities in the world, and the density of populations will continue growing up to 2030 in India and Pakistan.[179] The more these cities expand, the more difficult it is to maintain good governance, and there is a risk of NSAGs gaining importance. Such parallel governance structures will cause issues for public authorities and have the potential of destabilizing cities and countries. Unstable megacities can also exacerbate humanitarian crises in the case of, for instance, pandemics. While this is unlikely to cause NATO militaries to engage directly, the potential for regional or global spillover may be an indirect security interest of NATO.	• Coastal megacities in South Asia like Mumbai are located less than 1 meter above sea level and face a high risk of flooding. • Extreme heat and drought in dense urban areas like megacities can exacerbate health issues and lead to the rapid spread of viruses, with possible international consequences considering the increased need for HADR.	• Small (unmanned) electric vehicles can bring advantages in terms of maneuverability and self-sufficiency in environments that are difficult to access and monitor. • Due to the problem of crowded spaces and therefore decreased accuracy of air force capabilities, AI and autonomous systems provide the advantage of working with high-precision weaponry such as loitering munitions to reach otherwise inaccessible areas.

179 'Climate and Security in the Indo-Asia Pacific', International Military Council on Climate and Security, IMCCS Expert Group, 29 July 2020, https://imccs.org/climate-and-security-in-the-indo-asia-pacific/.

Conclusion and policy recommendations

The future of war will be shaped by technological developments and their interaction with the evolving strategic and operational environment, as well as by the way in which governments and militaries choose to respond to these trends. The increasing use of and interlinkages between AI and automation and information technology on the battlefield are bringing new dimensions to the ways in which wars are fought. Space technology has the potential to transform warfare and bring additional complexity to the operational environment. Low-carbon technologies can support militaries to reduce their dependence on fossil fuels, shorten supply chains and bring additional operational advantages over combustion engines, such as stealth, thrust, and a reduced need for technical maintenance. For instance, investing in HED for maritime vessels, especially when paired with automated vessels, or the use of SAF blending for aircraft, can boost operational effectiveness and mitigate vulnerabilities such as scarce local resources and complexity of supply chains.

To strengthen operational effectiveness, the role of these technologies should be assessed as a whole rather than as separate entities, and in relation to emerging conflict dynamics and climatic impacts on the operational environment. While new generations of AI, automation, information technology and satellites are quickly becoming common-place in military operations, it is less clear how low-carbon technologies will impact these new capabilities. This chapter took the first steps in making this analysis, and provided case-specific recommendations on how NATO militaries can boost effectiveness in a changing operational environment.

Below is a set of five high-level recommendations for NATO members to maximize the opportunities arising from technological innovation in a changing climate.

1. **Approach military innovation in an integrated way.**

   NATO equipment and military personnel should be able to withstand extreme weather and environmental conditions such as extreme temperatures. Failing to do so will affect operational readiness. Climate change is affecting the operational environment in NATO territories and in regions of strategic importance such as the Indo-Pacific, MENA region, Sahel, and the Arctic circle. Low-carbon technologies used in combination with other military innovations should not only address climate-related challenges but also boost operational readiness in light of emerging conflict dynamics. This should be done in close coordination with NATO allies to ensure the interoperability of future systems.

2. **Be a fast mover in understanding the synergies between climate change-related technologies and the evolving operational environment.**

   The use of climate change-related innovative technologies in the military domain is an imminent trend. As such, by moving faster than opponents in adopting low-carbon and adaptation technologies, NATO militaries can maintain an upper hand on the battlefield. Being a late adopter of climate related military innovation may create blind spots. Confronted with changing and harsher operational environments, such as the Arctic Circle with its limited range of communications technologies, it is imperative that NATO militaries invest in technologies with broader deployability. For instance, unmanned electric aerial vehicles can boost the effectiveness of NATO operations by increasing stealth and the possibilities to access contested areas prone to rapid changes in the atmosphere without human involvement. By moving swiftly to adopt these technologies, NATO can overcome challenges posed by traditional limitations and ensure strategic advantage across diverse operational scenarios in the near future.

3. **Consider the timing of investments in and adoption of climate change-related technological innovation.**

   There is an increasing need for adaptation strategies throughout the whole operational planning cycle, as climate-induced changes impact NATO military capability requirements for planning and training cycles. Military platforms are in operation for decades, and it takes long time intervals to manufacture and operationalize new equipment. Procurement systems are not changing fast enough to facilitate decarbonization. Allocating new funds for defense spending from 2024 onwards should be done strategically, focusing on integrating energy consumption considerations and low-carbon criteria into procurement processes for new military equipment. The time frame to act if militaries want to reach their 2050 goals is rapidly closing.

4. **Show concrete milestones for military decarbonization to strengthen social license to operate and reduce the risk of behavioral influencing by opponents.**

   Societal perceptions of the role of the military have been changing over the last decades. In some countries in the European Union, militaries are struggling to recruit young people and uphold military readiness. Engaging in the energy transition and setting more concrete targets for operational energy can improve the image of militaries in society. At the same time, gray-zone tactics of information warfare whereby opponents try to destabilize western societies by playing on existing societal divisions may be used to worsen public perceptions of the military, if seen as providing an insufficient response to climate change.[180]

180 Defence Operational Energy Strategy' (UK Ministry of Defence, 2023), https://assets.publishing.service.gov.uk/media/6570b223809bc300133081cc/Defence_Operational_Energy_Strategy_2023.pdf.

5. **Foster public-private partnerships to leverage civilian technological advances.**

   By fostering a collaborative ecosystem between government and civilian innovators, encouraging knowledge sharing and working towards a common incentive, public-private cooperation can enhance the adoption of low-carbon technologies alongside other technological developments in order to enhance both operational effectiveness and environment sustainability. This is especially the case considering that most research and development in the field of the energy transition is taking place in the civilian space. Initiatives such as NATO's Defense Innovation Accelerator for the North Atlantic (DIANA) project, are crucial in integrating civilian innovations into military practices.

In conclusion, while the focus often centers on emerging technologies like AI and automation, the transformative potential of low-carbon innovations on the battlefield remains underexplored. To address this gap, this chapter advocates for integrating low-carbon technologies into broader strategic planning around the future of warfare. By considering climate-related technological advancements core developments impacting the future of military operations, NATO members can strengthen their defense posture but also lead in shaping a sustainable future for military operations amidst changing global dynamics.

A rescue swimmer from Coast Guard Air Station Elizabeth City is lowered on to the back section of a nacelle during a search and rescue exercise off the Virginia coast as the marine protector-class patrol cutter USCGC Seahawk (WPB 87323) provides a safety zone, Oct. 17, 2023.

Source: USCG photo / Petty Officer 2nd Class Ryan Noel

III. The Infrastructure Energy Transition as a Priority for Military Decarbonization Strategies

By **Sami Ramdani** and **Julia Tasse**

Though decarbonization presents challenges for armed forces, it comes with multiple benefits, and is well worth the investment and effort. As stated in the latest EU joint communication on the climate and security nexus: "The energy intensive nature of Member States' armed forces, who are also the largest public owner of free land and infrastructures in the EU, offers opportunities to become more efficient and generate climate and biodiversity benefits at scale."[181]

Further, decarbonization presents real benefits for defense energy security and autonomy –especially important since the Russian invasion of Ukraine in 2022 and the resulting pressures on natural gas and oil supplies throughout Europe. In this respect, the REPowerEU Plan of May 2022, in response to the invasion, aims at reducing dependence on fossil fuels and provides an ambitious roadmap towards fast forwarding the transition away from fossil fuels for the benefit of renewables. The decoupling of EU member states from dependency on fossil fuels may accelerate the inclusion of the renewable energy sources (RES) component in defense strategies.

In this chapter we will see why the infrastructure energy transition should be a priority for military decarbonization strategies. In the first part we will discuss energy consumption tracking and management solutions. Then we

181 European Parliament and European Commission, A new outlook on the Climate and Security Nexus: addressing the impact of climate change and environmental degradation on peace, security and defence., June 28, 2023.

will consider the existing technological paths to decarbonize the infrastructure energy supply. The third part is dedicated to infrastructure challenges to the energy transition. In the last section we present our recommendations.

Improving energy management through energy consumption tracking

Energy management can act on both production and consumption.[182] In both cases, a first step in order to reduce one's energy needs is increased energy efficiency, through the use of new technologies as well as through the overall system management. That is why several militaries are currently working on developing and implementing digital tracking solutions such as smart meters for buildings' energy consumption. Smart meters increase the cost-effectiveness of energy consumption and ensure the efficiency of energy allocation across military functions.[183] These metering systems should allow militaries to better understand energy use. Breaking down the energy consumed by source and by use makes it possible to apply sector-specific targets that would not have a negative impact on operational capacities. This would help militaries contribute to the objectives of increasing the share of renewable energies in the energy mix of their respective states. These metering systems ought to be generalized to all militaries and can support the implementation of defense-specific Energy Management Systems (EnMSs) based on the ISO 50001 standard. To address the issue of energy management, militaries can collaborate with external players through Energy savings performance contracts (ESPC) and Utility energy service contracts (UESC). An ESPC is a contract with a private company to pursue installation of energy savings

182 Energy management is the set of actions and processes aimed at optimizing energy consumption in order to preserve the environment and to rationalize and reduce costs while limiting the impact on consumers.

183 Irina Patrahau, Laura Birkman, Michel Rademaker, Tom Middendorp, Ella MacLaughlin, Resilient and Robust: Climate-Proofing the Military for Increased Military Effectiveness, The Hague Centre for Strategic Studies, April 25, 2023.

measures, such as more efficient equipment and renewable energy, where the savings are used to pay for the measures. In many cases, a single contract can combine multiple energy savings measures and can last for up to 25 years. A UESC is a contract with a local utility to provide energy management services focused on energy efficiency or demand reduction. These agreements typically do not exceed 10 years.[184] Despite the benefits of such optimization, militaries must be aware of such energy management systems' exposure to cyberthreats as they become digitized (generalization of remote measurement, supervision and control capabilities). The growing dependence on the Internet and on navigation-time positioning systems such as GPS and the increase in data exchanges for such energy management systems make it more complex to defend the energy architecture in cyberspace.

Energy efficient approaches to military installations can also be pursued for deployed military camps. In 2018, the NATO Science for Peace and Security (SPS) Programme launched the "Camp Energy Efficiency" project which sought to develop interoperable monitoring kits for energy data collection with the aim to identify and address wasteful energy consumption in deployed military camps. Canada has been tasked as NATO country project director in partnership with Australia. Germany, Netherlands and the USA are the other country co-directors.[185] This project resulted in the publication of an Energy Management Handbook to help camp energy managers implement efficiency measures.[186] The Energy Management Handbook was led by the NATO Energy Security Centre of Excellence in collaboration with the NATO Military Engineering Centre of Excellence, the United Kingdom Defence Science and Technology Laboratory and Natural Resources Canada's CanmetENERGY.

184 United States Government Accountability Office, DOD RENEWABLE ENERGY PROJECTS Improved Guidance Needed for Analyzing and Documenting Costs and Benefits, September 2016.

185 Natural resources Canada, NATO Science for Peace and Security camp energy efficiency project, March 28, 2022.

186 Cezary Kozłowski, Massimo Dacchille, Jean-Michel Meyer, Laurent Bellot, Martin Kegel, Jennifer Doran, ENERGY MANAGEMENT HANDBOOK: ENERGY MANAGEMENT FOR MILITARY DEPLOYED FORCE INFRASTRUCTURE, NATO Energy Security Centre of Excellence, February 1, 2022.

The energy transition of the defense sector cannot be limited to infrastructure operated by militaries. This process must also involve industry. Some measures that governments could use to deepen the involvement of the industry in the improvement of defense sector energy efficiency include:

- Systematically measuring the energy consumption of military systems
- Including eco-design and energy efficiency requirements in all procurement procedures and in the requirements for future military capabilities
- Auditing militaries' industrial contractors, on how they take eco-design and energy efficiency into account in their work and products
- Analyzing the life cycle of systems and estimate their environmental impact at various phases

Decarbonized energy supply

The decarbonization of buildings "relies primarily on technologies already available on the market" according to the International Energy Agency.[187] The implementation of energy efficiency measures (e.g. improved insulation, better energy efficient equipment, behavior changes, smart control solutions), electrification (e.g. replacing oil, coal and gas boilers by other solutions such as high efficiency electric heat pumps) and local renewable power generations (e.g. solar and wind energy, supported by battery storage and smart grid system) could greatly reduce emissions.[188]

Most GHG standard[189] emissions from buildings are due to electricity purchased from external suppliers (scope 2 emissions).[190] Purchasing decarbonized

187 International Energy Agency , Net Zero by 2050, May 2021, p.141.

188 *Idem*, p.141-146.

189 Standard emissions are generated by civilian and administrative operations while non-standard emissions are defined as those from military operations, law enforcement and other operations.

190 Pierre Laboué, TECHNOLOGICAL INNOVATION: WHERE THE HARD PART BEGINS, in Decarbonized Defense: The Need for Clean Military Power in the Age of Climate Change, International Military Council on climate and security, June 06, 2022, p.20.

electricity from the grid would sharply reduce military emissions. Therefore, decarbonization of military infrastructures relies on the decarbonization of national electricity mixes. Militaries can incentivize their providers by using public tenders to purchase green electricity.

Militaries' dependency on external electricity suppliers limits their capacity to act on the decarbonization of their electricity supply. It also decreases the resilience of this electricity supply. Indeed, by using civil energy sources, armed forces are exposed to shortages and black outs affecting the civil sector, hindering their operational capacity. Installing renewable energy production capacity on military infrastructures, in combination with storage technologies and micro-grids can accelerate the decarbonization of these infrastructures while strengthening their energy resilience.

Energy security at the installation level has three components: reliability, resilience, and efficiency.[191] Energy reliability is the percentage of time the energy delivery systems can supply stable, installation well-mannered electricity to its customers. Energy resilience refers to the electrical supply's ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions to the external energy supply or installation power disruptions and failures. Energy efficiency is the ability of the installation to minimize the energy demand of its operations without sacrificing operational performance. The implementation of microgrids integrating decentralized renewable energy production and storage capacities is an excellent way to guarantee the three components of energy security. For maximum energy security gains, energy transition technologies (renewable energy production, microgrids and storage technologies) must be combined and if possible in a holistic approach to maximize synergies.

The following sections will explore armed forces solutions for reinforcing resilience and decarbonizing, from economic incentive schemes to technological solutions. After introducing Power Purchase Agreements, this study

191 Ronald E. Giachetti, Christopher J. Peterson, Douglas L. Van Bossuyt, Gary W. Parker, Systems Engineering Issues in Microgrids for Military Installations, INCOSE International Symposium. 30, September 30, 2020.

will examine on-site decarbonized energy production, and then assess complementary technologies—specifically, microgrids and storage technologies.

Power Purchase Agreements

Green Power Purchase Agreements (Green PPAs) are power purchase agreements from renewable energies which operate over the medium or long term (5 to up to 30 years).[192] In addition to guaranteeing the supply of renewable energy, these contracts protect from market price volatility. PPAs are called "on-site" when renewable energy production facilities are installed on a client's site. In this case, energy operators fund the design, installation, and operation of equipment. Clients, who are site owners or tenants, consume energy that is produced. PPAs are said to be "off-site" when energy production equipment is not installed on a client's sites.

During the last decade, innovation in renewable energy sources has reduced their cost, making them competitive against fossil fuels, including for some military purposes. In 2010, the global weighted average levelized cost of electricity (LCOE)[193] of onshore wind was 95% higher than the lowest fossil fuel-fired cost.[194] In 2022, the global weighted average LCOE of new onshore wind projects was 52% lower than the cheapest fossil fuel-fired solutions. The global weighted average LCOE of utility-scale solar photovoltaics (PV) was 710% more expensive than the cheapest fossil fuel-fired solution in 2010 but cost 29% less than the cheapest fossil fuel-fired solution in 2022. Defence actors have thus turned towards power purchase agreements to take advantage of such cost savings. Given these dynamics, militaries are rethinking the framework of their energy supply. For example, at the EU level, the Consultation

192 ENGIE, What are Power Purchase Agreements?, December 23, 2021.

193 The levelized cost of energy (LCOE) is a figure used to measure the lifetime cost of energy production by a given asset. It expresses the average total cost of building and operating the asset per unit of total electricity generated over an assumed lifetime.

194 International Renewable Energy Agency, Renewable power generation costs in 2022, August 2023.

Forum on Sustainable Energy in the Defence and Security Sector (CF SEDSS) plans to conduct a study on the subject in the coming years.

Decarbonized energy production capacities

Solar energy

Solar energy presents potential strategic advantages, as well as operational and cost advantages for militaries. Photovoltaic solar energy is one of the easiest renewable energy sources to produce, cheap to operate, and requires little maintenance. It can be deployed in many parts of the world, including cold climates, though dust accumulation on photovoltaic solar panels can affect their performance, limiting their use in the desert. However, innovations toward self-cleaning panels could help mitigate this risk for militaries.

Solar energy can also improve the resilience of military installations. A distributed array of solar panels might be more difficult to disable than a single centralized generator or a single electricity grid access point. Militaries have great potential for solar energy thanks to the many lands and buildings in their possession.

The strategic advantage of photovoltaic solar energy is that it is less vulnerable to supply chain disruption once the system is in place. [195] In this regard, as NATO countries represent a small share of the solar industry, they are dependent on external supplies, especially from China. But that vulnerability is low, particularly compared to existing fossil fuel supply dependencies. Consider, for example, a scenario in which China deliberately restricts solar panel exports as a result of flaring geopolitical tensions. There would not be any direct energy supply disruption. Contrast that with the cut-off of Russian gas to Europe. While the Russian gas disruption created significant and immediate issues because of the need to heat homes and run power plants, an interruption in

195 Marju Kõrts, Climate Change Mitigation in the Armed Forces– greenhouse gas emission reduction—challenges and opportunities for Green Defense, NATO Energy Security Centre of Excellence, April 03, 2024.

the supply of a manufactured goods like a solar panel is different. It would lead to a delay in the deployment of new solar panels, but would not affect the functioning of those already installed.[196] Thus, it would be in the militaries interest to keep abreast of production capacities in allied countries, so as to find a solution quickly in the event of a supply disruption.

In recent years, LCOE for solar PV has fallen partly because the amount of power each module can produce has steadily increased. Modules in 2009 were 290W, in early 2019 modules were 405W and more recently we have seen module power increase further to 600W.[197] The solar panel industry is exploring new materials, such as perovskite solar cells, demonstrating promising potential for higher efficiency and lower production costs. The US Department of Energy Solar Energy Technologies Office (SETO) supports research and development projects that increase the efficiency and lifetime of hybrid organic-inorganic perovskite solar cells, speeding the commercialization of perovskite solar technologies and decreasing manufacturing costs.[198] Militaries could consider engaging with these types of projects to demonstrate demand for such technologies.

Other renewable sources of energy

While solar PV is the most widespread renewable energy source on military sites, other renewable energy sources are also being developed, including electricity production through wind turbines, hydropower, biofuels, and hydrogen. In countries that own large defence estates, there are immediate opportunities to generate energy by implementing renewable energy farms.[199]

196 Ben McWilliams, Simone Tagliapietra, Cecilia Trasi, Smarter European Union industrial policy for solar panels, Bruegel, February 03, 2024.

197 Trinasolar, Game Changing Solar Energy Technology, April 20, 2022.

198 The U.S. Department of Energy Solar Energy Technologies Office, Perovskite Solar Cells, 2024.

199 Marju Kõrts, Climate Change Mitigation in the Armed Forces– greenhouse gas emission reduction—challenges and opportunities for Green Defense, NATO Energy Security Centre of Excellence, April 03, 2024.

A Liverpool Royal Navy base has become the first site in the United Kingdom and Europe to have a Hover wind-powered[200] microgrid installed to generate renewable energy. It is estimated the wind turbine technology, combined with other systems, will reduce the site's dependence on grid energy by 63%.[201]

Geothermal energy is of great interest to the US Department of Defense because it is a renewable energy that is not intermittent and there is no critical materials issue. In September 2023, the US Air Force, The US Army, and The Defense Innovation Unit (DIU) initiated exploratory geothermal projects at four installations in the United States, completing agreements with three companies: Eavor Inc., Teverra, and Zanskar Geothermal and Minerals, Inc.[202] In april 2024, the DIU announced that it is doubling to six the number of technology companies involved. The new companies joining the initiative are Fervo Energy, GreenFire Energy, and Sage Geosystems for new projects at Naval Air Station Fallon, Nevada; Naval Air Facility El Centro, California; and the Army's Fort Bliss in Texas.[203]The US Navy has long had a geothermal power plant at US Naval WEAPONS Station China Lake, in the Mojave Desert.

Globally, 2022 was a record year for renewable electricity capacity additions, with annual capacity additions amounting to about 340 GW.[204] Key policies announced in 2022, especially REPowerEU in the European Union, the Inflation Reduction Act (IRA) in the United States and China's 14th Five-Year Plan for Renewable Energy, will lend further support to accelerate renewable electricity deployment in the coming years. However, Solar PV is today the only renewable energy technology on track with the IEA Net Zero Emissions

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200 A hover turbine is a roof-mounted wind turbine that generates up to 100,000 kWh of electricity each year.

201 Neil Hodgson, Naval base cuts dependance on grid energy by 63% after installing hi-tech roof-top unit, TheBusinessDesk, March 31, 2023.

202 Defense innovation unit, U.S. Air Force, U.S. Army, the Defense Innovation Unit, and Industry Advance DoD Installation Energy Resilience with Geothermal Energy Solutions, September 29, 2023.

203 Patrick Tucker, Geothermal energy easing US military's logistics challenges, Defense one, April 16, 2024.

204 International Energy Agency, Tracking Renewables, 11 July 2023.

by 2050 (NZE) Scenario. Wind, hydro, geothermal, solar thermal and ocean energy use needs significant investments in order to expand faster to get on track.

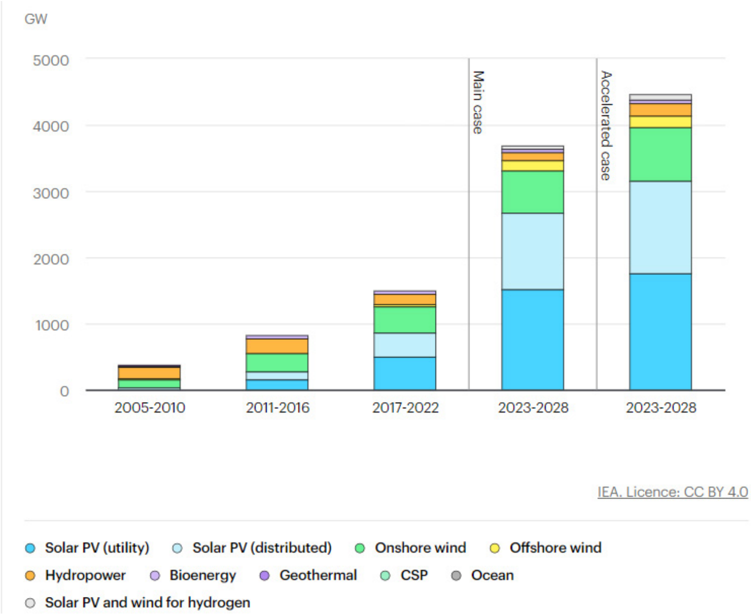


Figure 1: Renewable capacity growth by technology, main and accelerated cases, 2005–2028 [205]

In Europe, offshore wind has a huge potential but it currently remains largely untapped, with most countries having zero installations despite having extensive coastlines suitable for it.[206] Of the 238 GW of installed wind capacity, only 12% is offshore. Only the United Kingdom, Germany, the Netherlands, Denmark and Belgium are investing in its development to a sufficient extent.

205 International Energy Agency, Renewable capacity growth by technology, main and accelerated cases, 2005-2028, December 13, 2023.

206 Simone Tagliapietra, Ben McWilliams, Cecilia Trasi, European clean tech tracker, Bruegel, March 03, 2024.

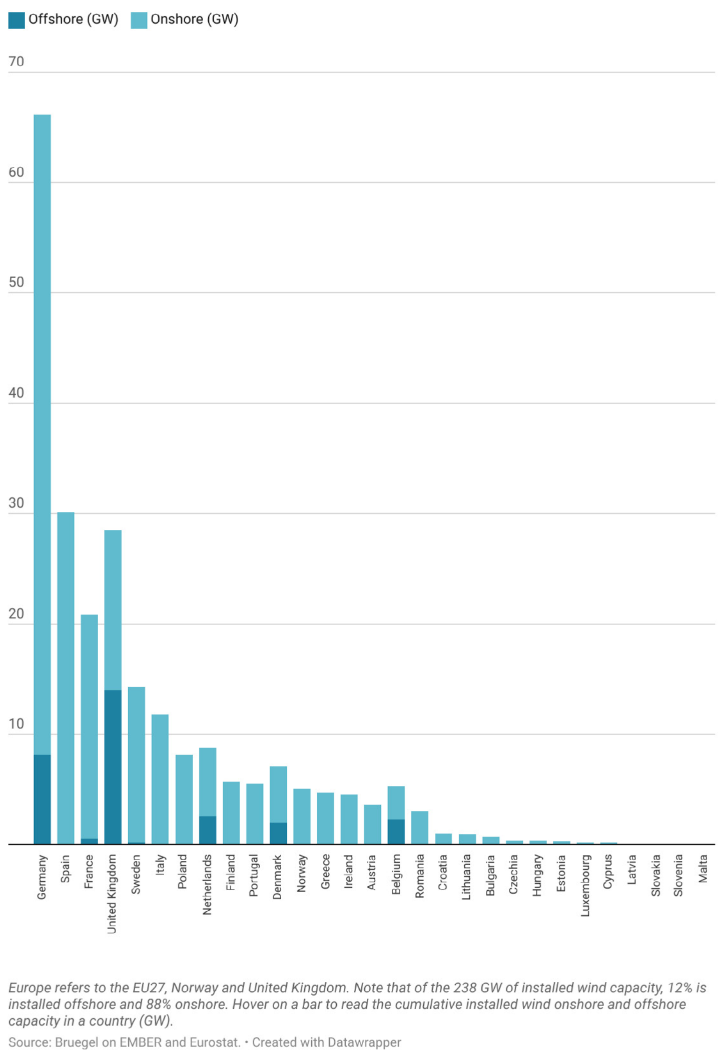
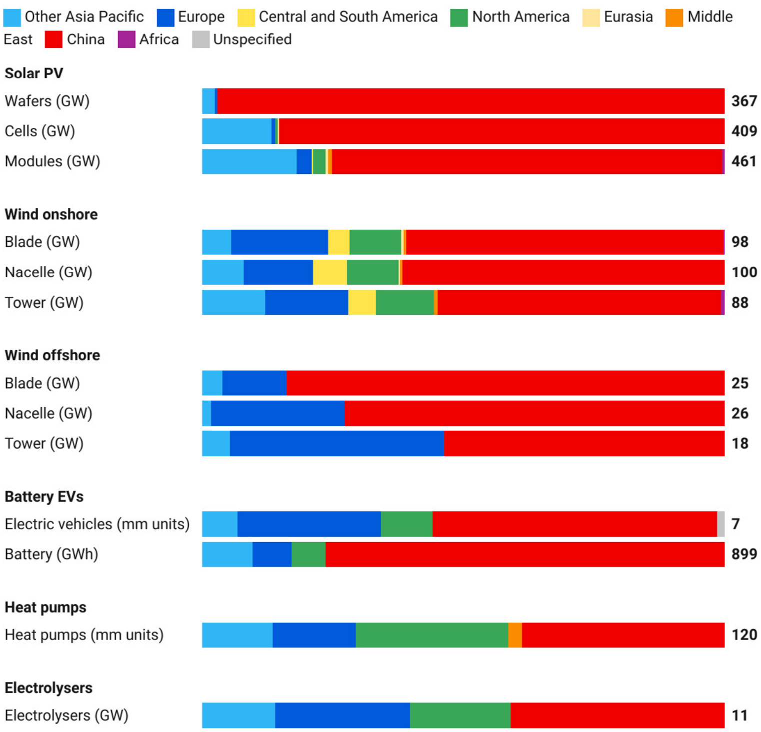


Figure 2: Installed offshore and onshore wind energy capacity in Europe (GW), 2022[207]

The strategic observation made for solar applies to other clean tech. NATO countries are dependent on external supplies, especially from China. This constitutes a vulnerability that should be noted. However, though an

207 *Ibid.*

interruption in the supply of manufactured goods would lead to a delay in the deployment of these technologies, it would not affect the functioning of those already installed.



The numbers at the end of the bars on the right indicate the total manufacturing capacity at the global level of each technology, expressed in the corresponding measurement unit.

Source: IEA, Energy Technology Perspectives, 2023. • Created with Datawrapper

Figure 3: Regional shares of manufacturing capacity of selected clean technologies, 2021 [208]

208 Giovanni Sgaravatti Simone Tagliapietra Cecilia Trasi, Cleantech manufacturing : where does Europe really stand ?, Bruegel, May 17, 2023.

Nuclear energy

A system running on renewable energy sources (RES) needs dispatchable generation capacities.[209] In order to avoid losing the resilience benefits obtained by the installation of renewable energy production capacities, it is preferable that the dispatchable energy source is also an on-site production capacity. The installation of small modular reactors (SMRs) as a decarbonized backup for solar and wind production is a potential clean energy solution to this challenge. Small modular reactors (SMRs) are defined as nuclear reactors generally 300MWe equivalent or less. The units are modular which makes it possible to optimize the share of renewable energies in the energy mix while keeping the possibility of increasing nuclear capacity later. This would enable military installations to disconnect themselves completely from the national grid and achieve climate goals. For safety reasons, it is preferable to have a buried installation, an option that is not possible with solar and wind production capacities. It is possible for SMRs to have their design optimized for non-electric applications.[210] This involves single or multi-purpose use—generating commodities like hydrogen, e-fuels or potable water, providing heat for industrial applications and district heating, together with or without electricity generation for the grid.

The US DoD intends to host a small nuclear reactor, in the 2-10 MWe range, at Eielson Air Force Base in Alaska, committing to buy the power, not the reactor itself. The reactor is expected to be operational by the end of 2027. According to DoD spokesman Lt. Col. Mike Andrews. "If the full demonstration proves to be a cost-effective energy resilience alternative, NRC-licensed [reactors] will provide an additional option for generating power provided to DoD through power purchase agreements."[211]

209 Technologies whose power output can be readily controlled—increased to maximum rated capacity or decreased to zero—in order to match supply with demand.

210 International Atomic Energy Agency, Advances in Small Modular Reactor Technology Developments, September 2022.

211 Rajesh Uppal, US Military plans Battlefield Small Nuclear Reactors (SMR) for military bases and deployed troops, IDST, December 20, 2022.

The US DoD is also exploring the potential uses of SMRs through Project PELE, which could serve as a model or uncover best practices for other allied militaries. The project is studying the potential for using mobile nuclear reactors to eliminate long fossil fuel supply lines and whether SMRs could power high-energy demand systems such as microwave directed energy weapons. The Project PELE, full-scale transportable prototype is slated to be ready for delivery this year. The microreactor prototype will then be tested at the Idaho National Laboratory for three years to check its operability.

SMRs are also emerging in the private sector. While commercial units exist, the industry has not yet scaled to optimize production costs given questions regarding long-term profitability and demand. The US military investment in such commercial efforts could help address these concerns, and potentially lay the groundwork for greater private sector, or civilian uptake of such technologies. This could promote the development of specific, selected technologies. Armed forces can thus be a market driver for the development of SMRs and for technologies standardization. In Europe, however, the military use of SMRs is less advanced. For example, at the EU level, the Consultation Forum on Sustainable Energy in the Defence and Security Sector (CF SEDSS) excludes the issue of nuclear energy from matters dealt with by its working groups.

Challenges to broader military SMR deployment include risks of proliferation, waste disposal, pollution, high water use, and high costs.

Microgrids

The response readiness of armed forces largely depends on a secure and resilient supply of electricity. The national grid is susceptible to large-scale disruption, whether from devastating natural weather events, military and cyberattacks from near-peer competitors, terrorists or international crime syndicates. The Russian invasion of Ukraine shows that in the event of conflict, electricity grids are a priority target. In this context, it is clear that it is necessary to strengthen the energy security of military infrastructures. Microgrids are key to enable autonomy from national grids in case of need, associated to independent energy production systems, thereby increasing infrastructure resilience.

In order to maximize the gains in resilience and synergies that can be generated by the different energy consuming sectors, it is important to have a holistic vision of the infrastructure energy transition. Microgrids are a technology that allows this holistic approach of the energy transition since the implementation of a microgrid involves thinking simultaneously the implementation of energy production capacities, energy storage capacities, energy data tracking solutions and solutions to protect the whole energy architecture from physical and cyberattacks.

In combination with renewable and nuclear energy production, microgrids offer important opportunities to decrease reliance on fossil fuels. Microgrids are local energy grids with the ability to operate autonomously. With microgrids, all power sources and loads in the network can be cut off or closed at any time. The infrastructure energy system can therefore immediately respond to power supply and load demand, increasing power consumption efficiency.[212]

Data gathering and defining critical infrastructure are crucial to designing a properly sized system—the identification of loads being particularly crucial. Microgrids allow installations to integrate more distributed renewable energy sources such as solar PV. It is worth noting that 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.[213] Microgrids that use fossil fuels often capture the waste heat from combustion and valorize it for building heating. This makes fossil fuel use far more efficient than what often

212 Marju Kõrts, Climate Change Mitigation in the Armed Forces– greenhouse gas emission reduction—challenges and opportunities for Green Defense, NATO Energy Security Centre of Excellence, April 03, 2024.

213 Irina Patrahau, Laura Birkman, Michel Rademaker, Tom Middendorp, Ella MacLaughlin, Resilient and Robust: Climate-Proofing the Military for Increased Military Effectiveness, The Hague Centre for Strategic Studies, April 25, 2023.

happens in large power plants where vast amounts of useful heat are wasted.[214] Microgrids present an opportunity to reduce energy costs through lowering demand or shifting demand to times when electricity prices are lower.

The armed forces have a leading role to play in the technological development of microgrids because they are an important potential consumer of this technology. Militaries combined have the scale to create a market demand signal strong enough to encourage private investment and drive down hardware costs. For example, increasing military-focused projects have led market analysts to forecast the military sector to be the fastest growing microgrid market in North America.[215] The US Army is leading the way in technical and economic testing and validation of microgrid technology as it looks for new ways to bolster energy security on military bases. In February 2022, it the US Army announced that it wished to build microgrids on each of its 130 bases worldwide by 2035. Concerning the homeland, in 2022, the US Navy and Marine Corps planned to build cybersecure microgrids at critical military facilities. The move came after the US Navy entered into a partnership with renewable energy company Ameresco in 2021, which involved the signing of a $173 million contract for the construction of a 3MW battery system, 19MW combined heat and power plant, and a microgrid control system. Ameresco said the microgrid would provide the Norfolk Naval Shipyard in Portsmouth, Virginia with "long-term energy security while reducing the electricity imported from the grid by 68 per cent."[216] As US bases begin to experiment with the technology, they face several major questions around microgrid design, evaluation, economics, and operation. Most microgrid research on resilience studies show how the microgrid responds to natural disasters. However, resilience with respect to attacks requires a different approach than resilience to natural disasters, underscoring the different functions of civilian and military microgrids. The civilian infrastructure is designed to work in unison and strengthen the electric grid while the military microgrids are for

214 Rocky Mountain Institute, ADVANCING MILITARY MICROGRIDS, September 2013.

215 Andrew Burger, Global microgrid market to grow 21%, exceed $35B by 2020, Microgrid Media, June 1, 2016.

216 Ben Cook, Why the US military is driving storage innovation, Tamarindo, September 29, 2023.

isolating the military from the civil grid and enable critical infrastructure to continue to function in order to carry out mission-essential tasks. Both developments are conducted in parallel, mutually enriching R&D, but it is worth noting that the military is one of the bigger markets for microgrids, therefore influencing their development. The differences in goals will cause these microgrids to be designed and constructed differently. Just because a civilian microgrid developer has built multiple for the civilian side does not indicate that they are a good match for the military side.[217]

Attacks can be either physical or cyber, such as attacks to disrupt the incoming installation power or against the microgrid itself. Consequently, methods to increase the resilience of microgrids must combine security analysis with the technical analysis of the microgrid. Researchers work on a method to model, analyze, and design military microgrids with the objective to improve their resilience in the face of disconnections from the larger electrical grid.[218] An article in *Military Review* describes the ideal military microgrid.[219] The conceptually improved microgrid would:

- Not require fuel resupply,
- Have a diverse selection of power generation assets,
- Have a high volume of energy storage,
- Provide or absorb high power levels on demand, and
- Feature resilient distribution systems, all while maintaining its mobility.

Many of these desired aspects are not technologically feasible today. However, there is much research and development into technologies for improving toward the ideal military microgrid. The required developments fall broadly into two

217 Wendell Bunch, A review of microgrids ability to enhance readiness for military and first responders, North Carolina State University, 2022.

218 Christopher J. Peterson, Douglas L. Van Bossuyt, Ronald E. Giachetti, Giovanna Oriti, Analyzing Mission Impact of Military Installations Microgrid for Resilience, Systems 2021, 9, 69. September 15, 2021.

219 Nicholas Barry, Surya Santoso, Modernizing Tactical Military Microgrids to Keep Pace with the Electrification of Warfare, Military Review, November 2020.

categories: energy generation and energy transport. A rapidly reconfigurable microgrid may be desirable for military applications to quickly bypass damaged components or subsystems so that power delivery can resume rapidly.

Moreover, microgrids can be used to link military bases to their urban environment with mutually beneficial implications. The microgrid of the US Marine Corps base at Miramar, for example, was used during the 2020 Californian heatwave to provide 6 MW of power to the San Diego grid to avoid rolling blackouts in residential areas.[220] On one side, the installation of a microgrid on a military infrastructure can reinforce the resilience of the surrounding urban area, since the microgrid could eventually benefit the community with the electricity produced within it. On the other side, in return for these benefits, local public authorities could contribute financially to the installation of microgrids on military infrastructure. Thereby, armed forces could produce new configurations of crucial energy resource flows.[221]

Storage capacities

Addressing the intermittency of renewable energies and dependency on external suppliers requires new storage capacity solutions. Two promising avenues are improved, large scale batteries and hydrogen production capacity.

Large-scale batteries can operate in synergy with smart meters by storing excess energy and allocating it once required. Using different chemicals and materials affects the properties of the battery—how much energy it can store and output, how much power it can provide, or the number of times it can be discharged and recharged.[222] Lithium-ion batteries are currently the most widespread technology. Many alternative solutions are, however, being developed. Researchers are investigating new battery technologies with the goal

220 Jonathan Rutherford, Simon Marvin. Urban smart microgrids: a political technology of emergency-normalcy,Urban Geography, 2023, 44 (8), pp.1794-1815. October 06, 2022.

221 *Ibid.*

222 Patrick Bernard, Three battery technologies that could power the future, SAFT, March 24, 2017.

of managing safety concerns, specifically fire risk, and the sustainability of the materials used in the production of lithium-ion batteries (cobalt, nickel and magnesium).[223] From the point of view of consumers, and particularly militaries, there is also the question of the potential security risks posed by China's monopoly on the lithium-ion battery value chain. This is a factor to be taken into account when choosing technologies.

One example of nascent battery innovation is the advent of "new flow" batteries, in which electrolyte flows through one or more electrochemical cells from one or more tanks.[224] The US Department of Energy has nursed the domestic flow battery industry along since the 1980s but a lack of adequate R&D funding in earlier years stalled notable progress towards commercialization. Recent technological improvements have widened the span of applications for flow batteries, however. For example, in November 2022, a new flow battery from Lockheed Martin, named GridStar Flow, was installed at Fort Carson in Colorado to be tested for a two-year period.[225] If the test is successful by the end of the two-years program, the new battery will be installed at every DoD facility throughout the US and overseas. GridStar Flow is a one-megawatt battery. It's estimated that the power delivered by the battery will be the equivalent of the electricity consumption of 400 Fort Carson homes for an average day. In addition to helping Fort Carson maintain operations during grid-wide power outages, the Army anticipates that the new flow battery will help prevent grid outages by easing demand during peak periods. In November 2023, an example of a new flow battery using vanadium[226] was presented at an energy technology conference of the European Defence Agency.[227] When compared to lithium-ion batteries this solution has a longer life cycle, is non-flammable and involves fewer supply

223 Jacob Biba, 7 New Battery Technologies to Watch, Built In, May 06, 2024.

224 International Flow Battery Forum, What is a flow battery?, accessed March 14, 2024.

225 Tim Newcomb,The Army Has a New Flow Battery. It Could Change Military Power, Popular mechanics, January 03, 2023.

226 Visblue, Advantages, accessed December 04, 2023.

227 European Defence Agency, Greening Defence with Innovation: 2nd Energy Technology Solutions Conference & Exhibition, November 24, 2023.

chain risks. Other solutions are promising but still under development such as solid-state batteries (estimated to be at TRL 4-6).[228]

Militaries should conduct a technological watch on batteries in order to select the most suitable technologies for military use. Lithium-ion batteries are well suited for intra-day storage, as their ability to store energy efficiently is capped at around eight hours. In a civil operating environment, this is possibly adequate, but not for an organization with 24/7 operational needs. If a natural disaster or a physical/cyber-attack were to take on-site energy production capacities offline, battery storage capability would diminish rapidly after only a few hours. A truly autonomous energy system should have power that could be provided in the case of a prolonged interruption of external supply but also on-site production.

Hydrogen could be a complementary storage solution for batteries. Once hydrogen is formed, it can store energy indefinitely. Therefore, if and when the sector matures, hydrogen could maximize the total amount of energy produced by renewables in a system. Though currently less efficient for short-duration storage than batteries, the flexibility that hydrogen could provide in a microgrid system makes it extremely valuable for fulfilling operational energy needs in the long term. Hydrogen is an energy vector suitable for many applications such as: air conditioning, electricity production, storage, and transport. Meeting these needs with hydrogen would mean being able to produce it in large quantities. However, in order to contribute to decarbonization while increasing military autonomy, hydrogen must be self-produced with RES and/or nuclear energy. This implies the need to massively increase decarbonized energy production capacities of militaries.

The European Union has studied the opportunities and challenges of hydrogen in a military context through a project named RESHUB, which stands for "Defence RESilience Hub Network in Europe." RESHUB was conceived and

228 TS2 Space, Solid state batteries TRL, February 02 ,2024.

led by the Slovenian[229] Ministry of Defence under the Consultation Forum on Sustainable Energy in the Defence and Security Sector (CF SEDSS).[230] The aim of RESHUB is to help build a renewable energy harvesting and hydrogen energy storage capability in military bases notably in order to facilitate cross-Europe transportation.[231] The military site's electricity and heat-consumption records for two consecutive years were analyzed and used to create a representative consumption profile that includes typical daily and seasonal consumption variations. On the Postojna site, the combined installed capacity of photovoltaic panels and wind turbines is 2.5 times the peak consumption of the barracks, the refueling station and the electrolyzer.[232] Most of the power is supplied by the solar-power plant (80%). Yet, about 12% of the total annual power consumption is still met by the utility grid. Indeed, the capacity of the batteries is not sufficient to compensate for the differences in on-site energy generation and consumption.

However, an oversized RES energy system is an opportunity to distribute decarbonized electricity and hydrogen to the civil sector. On the Postojna site, about 19% of the total electricity produced and 7% of the hydrogen produced are available to external consumers.

The study concluded that it is the sale of large quantities of electricity and hydrogen to external consumers that allows an energy system of this type to be economically viable. In addition to being a financial advantage for the military, the sale of decarbonized energy to external consumers contributes to reduce the country's carbon footprint. From the successful example of the Postojna site, the European Union has supported the development of a tool that can be used for a configuration analysis, a sustainability assessment and economic

229 Other participating countries in the project are Austria, Belgium, Germany and Hungary.

230 European Defence Agency, Defence RESilience Hub Network in Europe RESHUB, March 10, 2020.

231 Mitja Mori, Urban Žvar Baškovič, Rok Stropnik, Andrej Lotrič, Tomaž Katrašnik, Robert Šipec, Jakob Lipar, Žiga Lesar, Boštjan Drobnič, Green energy hubs for the military that can also support the civilian mobility sector with green hydrogen, International Journal of Hydrogen Energy, December 25, 2023.

232 *Ibid.*

evaluation of a military (or civilian) site becoming a RES energy hub. By configuring the energy system appropriately, a RES energy hub can operate self-sufficiently for several days or weeks depending on the size of the system. The example of the Postojna site shows that meeting technical requirements and carbon neutrality are more easily attainable objectives than economic viability because of the relatively high investment in hydrogen-energy systems.

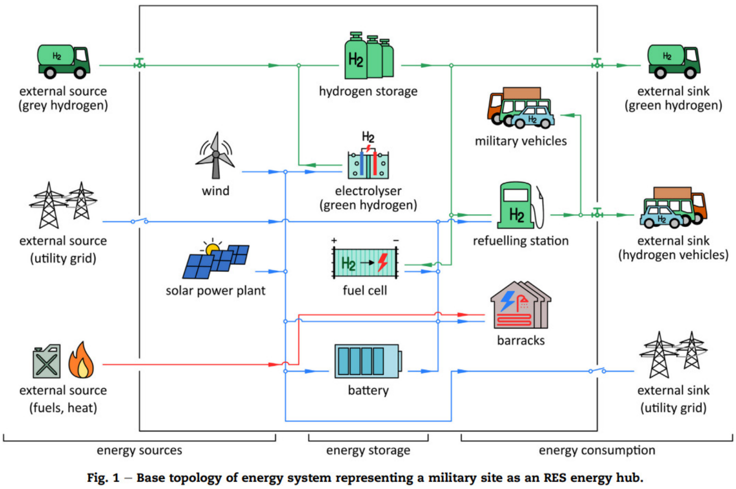


Figure 4: Base topology of energy system representing a military site as an RES energy hub [233]

Producing green hydrogen on military bases offers many opportunities for defense/civil sectors coupling as well. Hydrogen enables the conversion of electrical energy into heat (P2H), gas (P2G) or liquid fuels (P2L) and provides multiple consumption options such as fuel substitution, storage, transport and energy conversion. Thus, coupling the civil sector with hydrogen storage in the RES-based energy systems of military bases could help facilitate the decarbonization of the civil and defense sectors. One of the biggest challenges when using hydrogen for civil mobility is the limited availability of hydrogen-refueling stations. Military hydrogen-based energy hubs, intended to be up to a few hundred kilometers apart, could provide a network of refueling

233 *Ibid.*

stations for fuel-cell vehicles. Producing hydrogen from self-produced energy and storing it at the same location also addresses concerns about the cost and safety of transporting hydrogen from production sites to refueling stations in the context of the development of hydrogen-mobility infrastructure.

The deployment of green hydrogen production capacity for militaries will depend on the development of self-produced (i.e. produced on site) RES and nuclear energy. Given that hydrogen development will almost certainly be gradual, it will be important to prioritize the uses of limited hydrogen capacity in order to have the most effective decarbonization strategy possible. The military airbase in Leeuwarden, Netherlands, is a good example of such prioritization. The Dutch have installed a solar park in combination with electrolyzers to produce hydrogen for use in heavy duty transport, fleet, and ground equipment. The solar park is expected to be operational in 2024, 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.[234]

Heating

In Europe, the heating of military infrastructures consumes much more energy than their electricity supply.[235] Heating therefore is a priority sector for the decarbonization of military infrastructure. Not least as natural gas is the main source of energy for heating needs (around 50%) and is a source of geopolitical and economic instability in the context of the Russian invasion of Ukraine. The following chart from the European Defense Agency shows the evolution of heating sources for European defense in the 2016-2020 period.[236]

234 Irina Patrahau, Laura Birkman, Michel Rademaker, Tom Middendorp, Ella MacLaughlin, Resilient and Robust: Climate-Proofing the Military for Increased Military Effectiveness, The Hague Centre for Strategic Studies, April 25, 2023.

235 European Defence Agency, Defence Energy Data 2016 & 2017, June 2019.

236 European Defence Agency, Defence Energy Data 2016-2020, January 04, 2024.

Heating sources and current trends (all sources)

	2016	2020	Δ (2016-2020)	(%)
Natural gas (MWh)	4.632,49	2.357,92	-2.274,57	49
Fuel oil (Kt)	54,38	17,48	-36.90	68
District heating (imported) MWh	1.928	818	-1.110	58
Coal (Kt)	55.381,8	0	-55.381,8	100
Gasoil / marked diesel (Kt)	19.539.960	44.707.621	25.167	56
LPG (Litres)	1.335.564	1.072.431	-263.133	20
Wood pellets (Kt)	16,33	17,89	1,56	9
Wood chips (MWh)	70.439	45.769	-24.670	35
Manufactured ovoids ()[3] (Kt)	3	1,8	-1,2	41
Biogas (MWh)	2.400	2.300	-100	4
Kerosene (Litres)	10.832.308	8.980.384	-1.851.924	17
Wood briquettes (Kt)	0,9	1,65	0,75	45
Solar thermal (MWh)	170.3	726	555,70	76

Figure 5: EDA's Energy Defence Data Collection Analysis and Sharing—heating sources and current trends

Of the 13 listed heating sources, four are on the rise. Of those four sources, three are renewable sources (i.e., solar thermal, wood pellets, wood briquettes). However, the increase is relatively small. There is still plenty of room for progress in integrating low-carbon technology for heating purposes.

Heat pumps are a primary technology for decarbonizing heating. The IEA Energy Technology Perspectives Special Briefing[237] and the Bruegel think tank's European clean tech tracker[238] rate heat pumps as one of the five technologies considered critical to the energy transition, along with solar PV, wind, batteries and electrolyzers. Heat pumps extract heat from a source, such as the surrounding air, geothermal energy stored in the ground, nearby sources of water or waste heat from a factory. They then amplify and transfer the heat to where it is needed. Because most of the heat is transferred rather than generated, heat pumps are far more efficient than conventional heating technologies such as boilers or electric heaters and can be cheaper to run.[239] Current models

237 International Energy Agency, The State of Clean Technology Manufacturing, November 2023.

238 Simone Tagliapietra, Ben McWilliams, Cecilia Trasi, European clean tech tracker, Bruegel, March 03, 2024.

239 International Energy Agency, The Future of Heat Pumps—How a heat pump works, November 2022.

are three to five times more energy efficient than gas boilers. The IEA estimates heat pumps globally have the potential to reduce global CO_2 emissions by at least 500 million tons in 2030 (equal to the annual CO_2 emissions of all cars in Europe today).[240]

Currently, heat pumps meet only around 10% of the global heating need in buildings, but their use has grown significantly in recent years. To get on track with the IEA Net Zero Emissions by 2050 (NZE) Scenario, the global heat pump stock would need to almost triple by 2030, to cover at least 20% of global heating needs. Increased policy support and incentives for heat pumps in light of high natural gas prices and efforts to reduce greenhouse gas emissions were key drivers behind the growing deployment. Around 40% of all heat pumps are manufactured in China, making the country the largest producer and exporter of this technology, with most of its exports going to Europe. Installations of heat pumps remain concentrated in new buildings and existing single-family homes.[241] Thus, the installation of heat pumps during the renovation of public buildings, such as military infrastructure, could create the necessary demand to increase the percentage of global heating needs covered by heat pumps to get on track with the NZE Scenario. Even if heat pumps are a mature technology, further policy support and technical innovation are needed to reduce upfront purchase and installation costs, remove market barriers to complex renovations, and improve energy performance and durability.

Another solution is to connect military bases to district heating where possible. District heating involves generating heat in a centralized location and then distributing it to residences, businesses and industry in a local area.[242] District heating networks offer great potential for efficient, cost-effective and flexible large-scale use of low-carbon energy for heating.

240 International Energy Agency, Heat Pumps, accessed May 04, 2024.

241 Yannick Monschauer, Chiara Delmastro, Rafael Martinez-Gordon, Global heat pump sales continue double-digit growth, International Energy Agency, March 31, 2023.

242 International Energy Agency, District Heating—Energy System, accessed May 04, 2024.

Mobility

There is an increasing number of alternatives to fossil fuels for short and medium-range road transportation solutions. For light-duty vehicles, the main solution is electric battery vehicles. For heavy trucks, sustainable fuels and hydrogen can offer an alternative to diesel fuels in the short term, and emerging battery and fuel cell electric equipment could provide new alternatives in the medium term.[243]

The renewal of militaries' non-tactical vehicle fleets can be integrated into a holistic approach to decarbonizing military infrastructure.[244] Indeed, in some cases, hybrid or electric vehicles can be tied into microgrids to provide battery storage capacity.[245] While electric coupling is already the subject of current research, it can be taken further as today's electric vehicles often include heat pumps in addition to air conditioning. This could allow them to provide not only electricity, but also heating and cooling. Bidirectional coupling between EVs and an electricity grid is still at a very early stage and the subject of research.[246] However, this type of connection is likely to become the standard in the future. This concept is commonly referred to in the literature as Vehicle-to-Grid (V2G) or Car-as-Power-Plant (CaPP).

In the case of a Battery Electric Vehicle (BEV), in times of an energy surplus in the electricity sector, some of this energy would be stored in the car battery . Fuel Cell Electric Vehicles (FCEVs) offer the potential for coupling not only the energy and transport sectors via electricity, but also to integrate hydrogen. This turns the EV into a power plant and not just storage. The CaPP-concept can be extended if there is also a thermal connection between the car and the

243 Pierre Laboué, TECHNOLOGICAL INNOVATION: WHERE THE HARD PART BEGINS, in Decarbonized Defense: The Need for Clean Military Power in the Age of Climate Change, International Military Council on climate and security, June 06, 2022, p.20.

244 In this chapter dedicated to infrastructure we only consider the question of non-tactical vehicles and how they can be included in a holistic approach of an infrastructure energy system.

245 Ronald E. Giachetti, Christopher J. Peterson, Douglas L. Van Bossuyt, Gary W. Parker, Systems Engineering Issues in Microgrids for Military Installations, INCOSE International Symposium. 30, September 30, 2020.

246 Simon Massat, Georg Franke, Stephan Rinderknecht, Exploring the potential of a cross-sector integration of electric vehicles in residential buildings as a possible energy supply source, Journal of Building Engineering, Volume 77, October 15, 2023.

building. In this case, the car could provide heat in addition to electricity. This concept, currently referred to as Car-as-Combined-Heat-and-Power-Plant (CaCHP), has been the subject of very limited research so far. Furthermore, it considers only the heat produced by the Fuel Cell (FC) during electricity generation. However, this can be taken even a step further by considering not only the waste heat, but also the heat generation system of the car itself, such as the heat pump. This creates the opportunity to produce heat independently of the electricity generation and supply it to the building when the car is parked and connected. The car's air conditioning system could also be used. The additional use of the EV as a source of cooling, referred to as Car-as-Cooling-Heating-Power-Plant- (CaCHPP-), would be a fourth way for EVs to supply energy to buildings, extending the previous concepts to a new and holistic integration of vehicles in the energy demand of buildings. These solutions would be all the more economically attractive when energy is produced on site.

Thus, in the context of the renewal of non-tactical vehicle fleets, it would be interesting for militaries to conduct a technological watch in this sector in order to integrate non-tactical vehicles into a holistic approach to the infrastructure energy system and thus maximize gains in resilience while decarbonizing. This once again demonstrates the multiple innovations and co-benefits that can be created in the process of decarbonizing armed forces.

The holistic approach

What we understand from the above review of infrastructure energy transition technologies is that, for maximum effectiveness, these technologies need to be combined. Thus, a holistic vision for military infrastructure energy systems is needed for the transition. Two European projects illustrate this approach. One concerns domestic military infrastructure, but is still in its early stages due to lack of funding: the ENSSURE project (ENergy Self-Sufficient REsilient military base). The other concerns deployed military camps, and is already launched. This is the INDY project (Energy Independent and Efficient Deployable Military Camps).

The ENSSURE project was conceptualized under the Consultation Forum on Sustainable Energy in the Defence and Security Sector (CF SEDSS), initiated by France and with the support of Belgium, Bulgaria and Norway.[247] The European Defence Agency (EDA) provided technical support to the project. ENSSURE explores the feasibility of energy self-sufficiency for infrastructure needs, including electrical islanding capacity, in small to medium-sized permanent military bases, through the combined use of RES, energy management and energy efficiency tools and methods. Buildings' energy efficient renovation and energy management would be combined with a smart grid relying on renewable production and storage. The objectives are:

- Total fossil fuel independency for buildings' energy needs;
- Near-zero greenhouse gas emissions (GHG) related to infrastructure;
- Resilience of critical military activities through autonomous off-grid capability.

Notably, the expected impact of the project is replicability throughout other military infrastructures in different geographic regions.

The INDY project is funded by the European Defence Fund (EDF). Its consortium is composed of twenty partners, two affiliated entities and nine sub-contractors from thirteen European Union and associated countries. INDY's expected outcome is a strategic roadmap to develop and implement solutions for energy independent and efficient deployable military camps. The roadmap will propose:

- a new approach to energy production, conversion, storage, transport, distribution and final usage;
- top-of-the-edge planning and simulation tools to develop new technologies, energy products and management systems for deployable military camps, using experience from the civilian sector and applications.

247 European Defence Agency, New Energy Consultation Forum project to promote low carbon military camps, February 17, 2022.

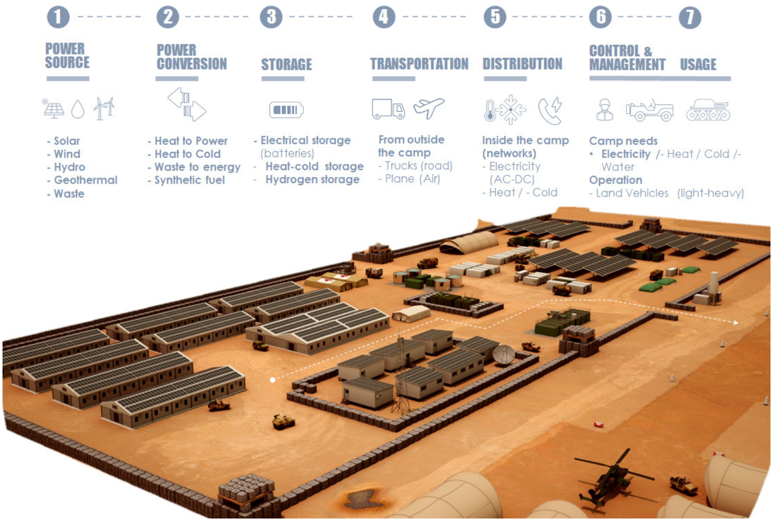


Figure 6: INDY Energy Cycle for Deployable Military Camps[248]

The infographic below presents the project's quantified targets:

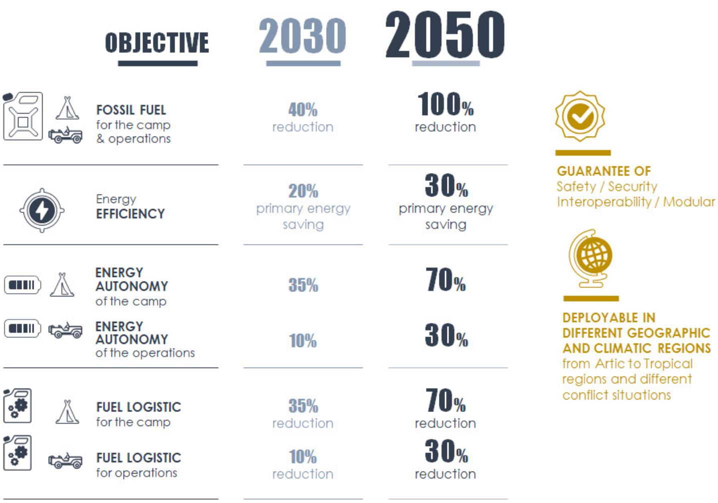


Figure 7: INDY's quantified targets[249]

248 INDY, https://www.indycamp.eu/, accessed April 22, 2024.

249 https://www.indycamp.eu/

The implementation roadmap that INDY will propose is a first step that could be used to set-up, in a second stage, a full-scale operational demonstration of a deployable camp fulfilling interoperability between inter-allied armies and NATO, with a modular and easily deployable energy system and adaptable energy mix.[250] The participation of partners from thirteen EU and associated countries and the support of their ministries of defense will allow the creation of a European market for sustainable energy systems in defense applications.

An opportunity for the military to lead

To decarbonize military buildings and infrastructure, several options, from efficiency to low-carbon energy sources, are available. Their adequacy in a military context is heterogeneous, and this chapter mapped out the most relevant pathways for their deployment. From that perspective, Off-site Power Purchase Agreements (PPAs) represent a low-hanging fruit to decarbonize the external electricity supply, whereas renewable energy on-site production processes must be accelerated. In the heating sector, there is important room for progress in the penetration of RES. This should be a priority, as the sector is responsible for the largest share of energy consumption by infrastructure on national territories. There are various energy storage technologies, including several types of batteries and hydrogen. Militaries need to think strategically at each site to determine what type of storage would be optimal in terms of fulfilling the role and activities of the infrastructure in question. While in the field of energy production the civil sector is leading technological progress, militaries have an important role to play in the field of storage. This is best demonstrated by flow batteries. The RESHUB project also demonstrates the huge potential of collaboration between the civilian and defense sectors. The example of the military airbase in Leeuwarden shows that the energy storage system of infrastructure can also contribute to the decarbonization of mobility. Such approach to the energy system encourages synergies between the different activities of armed forces. RES, storage technologies and micro-grid

250 Anonymous conversation with project official, April 05, 2024.

technologies are mature enough to be considered sufficiently reliable for use in the defense sector. Renewable energy installations are capital intensive, so more investments are needed. However, operating expenditures are expected to decrease, which leads to economic benefits in the long-term.

Challenges to the energy transition of infrastructure

The technologies needed to achieve carbon neutrality in the building sector are mature. This could be achieved in two decades in Europe and North America. The main obstacles are the lack of financial resources and the lack of qualified personnel. These elements are highly dependent on political will.

Lack of financial resources

While technologies for achieving carbon neutrality in buildings are mature, the financial means devoted to militaries for their energy transition are not sufficient.[251] In many cases, the budgets allocated to renovating buildings and installing energy production facilities should be increased. In the European Union, innovative projects in the infrastructure field, such as the ENSSURE project, are not adequately funded despite EDA providing technical support to the project, including to raise EU funding. In March 2019, EDA launched 'IdentiFunding', an online tool that allows defense stakeholders to identify existing EU funding schemes available for their defense-related projects. IdentiFunding covers more than 20 funding opportunities currently open for defense-related projects.[252] This tool could therefore help to identify funding sources for projects on the energy transition of military infrastructures. But, while IdentiFunding is an important achievement, it is not sufficient, because for the time being, structural bottlenecks seem to hinder European armed forces access to funding

251 Estelle Hoorickx, Les armées face aux changements climatiques : état des lieux et défis à relever pour la Défense belge, Sécurité & Stratégie 153, June 2023.

252 European Defence Agency, Identifunding Factsheet, October 01, 2021.

for decarbonization of military infrastructures. Indeed, according to various sources,[253] European militaries often encounter difficulties obtaining funding from the European funds they have applied for in order to implement projects related to the energy transition of infrastructures.

Lack of qualified personnel

In Europe, numerous ministries of defense suffer from shortcomings of qualified personnel. This can be a hindrance to basic activities such as monitoring and analyzing energy consumption and production data. On the one hand, qualified personnel are lacking overall, and on the other hand, personnel rotation contributes to the lack of qualified personnel in the "right place." It is thus necessary to increase training in order to ensure that energy management methodologies spread and converge. To address the European lack of qualified personal, the EDA has organized since 2017 the Defence Energy Managers Course (DEMC), aimed at increasing energy efficiency and reducing energy consumption in the military domain through the application of defense-specific Energy Management Systems (EnMSs) based on the ISO 50001 standard.[254] The EDA DEMC is the first of its kind to be run at the multi-national level and to deliver both theoretical and practical EnMS training to energy managers from European navies, armies and air forces. Nonetheless, having a certain number of qualified personnel is not merely enough. The ministries of defense also need a specific organization at the right level to allow the implementation of a military energy strategy, which is not yet the case in all defense ministries.

Lack of data on GHG emissions

Understanding means of action, and catalysts, for a more sustainable and safer energy consumption amongst armed forces' infrastructures relies on mapping out both their vulnerabilities and their carbon footprint. Such a diagnostic does not materialize easily, considering the difficulty of mapping

253 Anonymized interview, January 31, 2024.

254 European Defence Agency, First EDA Defence Energy Managers Course successfully concluded, April 19, 2018.

complex systems and the culture of confidentiality associated with defense issues. The element lagging behind when it comes to building safer and more sustainable energy systems for the armed forces remains the assessment of the greenhouse gases (GHG) emissions associated with that infrastructure. The latter are indeed much more important than often said. Indeed, within the carbon footprint of the US Department of Defense, building and facilities represent a minority, but as operational GHG emissions decrease, this minority is increasingly important (see graph below). When examining military GHG emissions, differentiating infrastructure and facilities from vehicles and equipment, training-related emissions from operations-related emissions, home-based from abroad emissions, as well as direct from indirect (up the value chain) emissions, is both necessary and challenging.

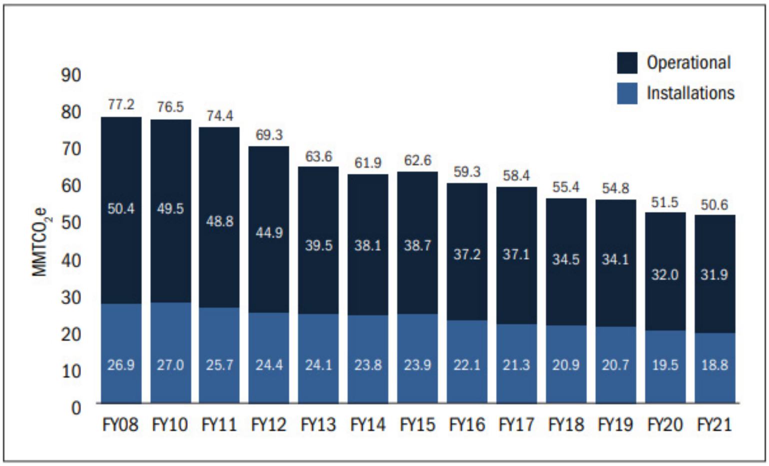


Figure 8: DoD's Scope 1 and 2 GHG emissions over time (the 2008 baseline plus the 2010–2021 reported values)

Source: Department of Energy, Office of the Under Secretary of Defense for Acquisition and Sustainment, Department of Defense Plan to Reduce Greenhouse Gas Emissions, April 2023

For a GHG reporting framework to be efficient, relevance, consistency and accuracy are paramount. Systematicity[255] as well as standardization are key for such reports to be useful for alliances.

Emissions reporting is a common exercise for the private sector. Numerous emissions assessment methodologies have been developed in the civil sector and, based on those, few have been suggested in order to better understand and characterize military GHG emissions in a standardized manner.

First and foremost, a shared methodology should have common scopes and norms, in order to facilitate the establishment of a standardized comparison method. Reporting criteria could reflect existing tools such as ISO series[256] and National Inventory Report protocol. A second pillar is based on the definition of the scope (in time, geography and value chain), and the capacity to generate and compute the associated data. In that perspective, limitations and uncertainties should be as clear as the accuracy and relevance of the data.[257] As such, it is important to underline that emissions reporting is far easier for homebased infrastructures and facilities than for operations abroad. Another layer of difficulty lies in the complexity of military supply chains.[258]

As a result, the accuracy of a carbon footprint-monitoring methodology for defense infrastructure relies on the cooperation of the private sector. Data will be issued both by military infrastructure managers themselves and by suppliers—the latter either unraveling its own data associated with specific products or services, or communicating a general figure.

Implementing such methodologies amongst NATO member states will also imply mutual reliability of data (apart from interoperability and

255 As a disciplined process of being systematic and enable comparison

256 As defined by the International Organization for Standardization (ISO), ISO series are standards which offer a common ground for accounting greenhouse gases. Among ISO series, one can find the ISO 14067:2018 https://www.iso.org/standard/71206.html

257 Conflict and Environment Observatory, A framework for military greenhouse gas emissions reporting, June 2022.

258 See chapter of Clingendael

standardization), thus depending upon technical tools, human resources, and external and independent audits. Informing decision-making and investment allocation relies upon dependable data. If transparency is the last obstacle to a coherent and comprehensive emissions- tracking system, then fostering closer cooperation amongst members of the alliance on climate issues, as has been done for a few years now, is paramount. As underlined, emissions linked to infrastructure are easier to monitor and account for than operational emissions. As such, monitoring installation's emissions is a reasonable first step for a broadly-shared standardized method among NATO allies.

Recommendations

Facilitate the renewable energy supply and production of militaries

The fastest way to decarbonize the electricity supply of militaries is to sign contracts with external suppliers guaranteeing the renewable origin of electricity. This would also foster the development of renewable energy sources (RES), through the long-term visibility and buying power associated with military stakeholders. Increasing self-production of decarbonized energies is the other way of decarbonizing the electricity supply while allowing the improvement of self-sufficiency and resilience of military infrastructures. However, there are obstacles hindering the development of decarbonized energy production from militaries.

First, there can be technical limits to the installation of decarbonized energy production means on military infrastructures. Indeed, those decarbonized energy production means could interfere with military activities if not implemented with care. Therefore, each military site should be audited to determine how it could most efficiently contribute to decarbonized energy generation within the bounds of its role in fulfilling its military mission.

The objective of decarbonized energy self-production is onsite consumption. However, in some specific situations, the produced energy can be neither used nor stored. In each country, mechanisms enabling militaries to sell the over-production of energy should be implemented. This possibility of selling the production excess would also be a financial incentive for militaries to increase their decarbonized energy production. The production of decarbonized energy on military sites would then not be regarded as a cost but as an opportunity to generate profit.

Set quantified targets for infrastructure decarbonization

Militaries must work towards drawing up and developing quantified indicators adapted to the defense sector. Clear energy consumption baselines need to be established so that more tangible targets to reduce fossil fuel usage can be set. It's essential to quantify and monitor CO_2 emissions and/or energy consumption for a more tailored approach to decarbonization. The civil administrative activities of the militaries should have energy objectives in line with the general objectives from their public State administration.

Militaries could alsoadopt specific objectives that would not undermine operational capacities, such as a certain percentage of low-emission vehicles in the administrative fleet by 2030, or a certain percentage of self-generated decarbonized energy in electricity consumption. The UK MoD Climate Change & Sustainability Directorate has adopted a sectoral approach to achieve a NetZero objective by 2050. In this context the Royal Air Force aims to have the first NetZero airbase (RAF Leeming, under Project Vital) by 2025, a NetZero estate by 2030, and a Carbon Net Balanced Service by 2040.[259]

259 Jon Lake, NET ZERO BY 2040: RAF CHIEF'S AMBITIOUS PLAN TO GO GREEN EXAMINED, key.aero, March 24, 2023.

Finance the military energy transition

Establish sustainable procurement

Numerous countries announced significant increases in their defense budgets following the Russian invasion of Ukraine in 2022. In order to avoid carbon lock-in, each country should set budget increases allocated to low-carbon technologies and buildings' renovation. Moreover, sustainability principles should be integrated in all defense procurement processes and across supply chains. The defense industry must be incentivized to allocate funding and human capital to develop low-carbon military technologies and engage in climate action. The decarbonization process of the defense sector needs to consider the energy mix used in the supply chain. Taking this into account for energy consumption would allow militaries to adapt their requirements for manufacturers.

Assist European ministries of defense in accessing EU funding

In section III.1, it was noted that IdentiFunding had not yet enabled ministries of defense to obtain European funding, notably for their projects related to the energy transition of infrastructures. In this context, dedicated working bodies should be established in order to support ministries of defense in the preparation of applications for infrastructures' energy transition funding. Having access to high-level expertise on this type of procedure would increase the chances of obtaining funding. The starting point of this new working body could be to collect and analyze the experiences of the various projects that have tried to obtain European funding, to no avail, in order to better understand the obstacles.

Strengthen training and awareness courses

Technological solutions are not enough. A climate-literate workforce is also essential for transforming how militaries understand and respond to the opportunities and challenges arising from decarbonization. Defense actors need to be appropriately trained in the necessary planning, engineering, design, procurement, construction, operating, maintenance and other technical skills required to maximize the use of decarbonized energy at military sites. Training at a multi-national level is also necessary in order to ensure that energy management methodologies spread and converge. In Europe, this need is covered by the EDA Defence Energy Managers Course (DEMC). Participating States must make the most of this kind of program by sending personnel representing the different military domains (air, land, sea). It is then up to militaries to ensure the widest possible dissemination and implementation of the knowledge acquired by the people they have sent to DEMCs for training. In Europe, there are uncertainties about the future funding of the EDA DEMC.[260] It is crucial to ensure it given the high quality of the program, and its importance from a security and energy perspective. In addition to training programs, communication campaigns within the armed forces would contribute to the spread of knowledge on decarbonization.

Conclusion

To support their energy transition processes and evaluate its evolution, militaries have to implement a standardized energy consumption tracking methodology. To increase the share of decarbonized energies in their energy mix, it is also important to focus, initially, on the energy supply for infrastructure. This energy supply can be decarbonized using existing technologies, whereas decarbonizing military vehicles still requires significant technological progress.

260 Anonymized interview, January 24, 2024.

Moreover, decarbonizing infrastructure energy supplies through the development of decarbonized energy production is a necessary prerequisite for decarbonizing mobility. Firstly, it is fundamental to build up significant decarbonized energy production capacity, so that the production of hydrogen or e-fuel can then be envisaged. In this respect, Leeuwarden air base is a good illustration of how the energy transition of the armed forces should be carried out chronologically, so as to reinforce self-sufficiency and resilience. It should be noted that hydrogen could be beneficial for certain specific applications (drones, electricity storage, autonomous generation of electricity), but its use for major military platforms remains excluded for the moment.

On mobility, the civil sector leads in technological development, while on the infrastructure side, the armed forces have a leading role to play in the technological development of microgrids and small modular reactions (SMRs)—namely because militaries could be an important consumer of these technologies. Building resilient energy systems on military infrastructure (combining decarbonized energy production and storage capacities with microgrids) could have beneficial implications for the civil environment as well. Reducing the external supply of electricity by on-site production from decarbonized energy brings an obvious gain in resilience. Decarbonizing the heating of military infrastructure would allow significant gains in resilience since natural gas, an easily weaponizable energy, is the main source of energy for heating needs (around 50%) of European armed forces.

Reducing the consumption of fossil fuels and increasing the production of decarbonized energies can be a real economic and security opportunity for the armed forces. Indeed, the cost of fossil fuels will increase in the coming years, while becoming an energy producer will allow militaries to sell part of it.

The security and financial benefits of decarbonization to militaries are significant and clear, and should therefore be a mission priority. It is now up to governments to lend the political will, and the financial and human resources necessary, to fulfill that mission.

Naval Facilities Engineering Systems Command-Southwest runs a micro-grid power plant in support of a request by San Diego Gas and Electric (SDG&E) responding to a statewide flex alert, a step before the issuance of an Emergency Load Reduction Program, August 17, 2022.

Source: NAVFAC Southwest photo / Mario Icari.

IV. Sustainable Security: Reducing Emissions in Military Supply Chains

Authors: **Emil Havstrup**, **Lennaert Jonkers**, **Louise van Schaik**

Introduction

When the relationship between climate change and defense is discussed, the emphasis is often on the impacts of extreme weather events and climate-induced conflicts. A secondary concern that is only beginning to emerge in the literature is how militaries contribute to climate change as they emit large amounts of carbon, for instance, when operating heavy machinery such as tanks or fighters. Yet what is only beginning to be understood are the potential emissions linked to the supply chains that support militaries through equipment purchases, fuel use, air travel, etc. Supply chains incorporate partners beyond the military themselves, often with very energy-intensive industries. By addressing decarbonization within the defense-industrial sector, value chain considerations emerge as pivotal elements in strategizing and implementing effective decarbonization efforts. This includes the development and procurement of key technologies and provides an opportunity to meet the challenge of getting to net-zero emissions for all sectors by 2050. [261]

Following the invasion of Ukraine, European countries have poured billions of Euros into their national defense budgets with the goal of maintaining larger standing armies and procuring new equipment. A central element in this policy change has been the desire to scale up defense industry production capabilities, notably in Europe. The increased demand for new technology

261 The European Union alongside other institutions and national governments have established targets for net-zero carbon emissions by 2050. This has been done to ensure that global heating does exceed 1.5 degrees Celsius of average warming in line with the Paris Climate Accords.

and materials will mean that millions of tons of greenhouse gas emissions (GHG) will be emitted into the atmosphere, raising a predicament of how countries will achieve their domestic net-zero goals. Military procurement will have a marked effect. Increased production of equipment such as fighter jets and ammunition will mean higher demand for goods such as cement, steel, and jet fuel, which are all highly carbon-intensive to produce, as well as emissions linked to their use.

The new investment into military resources also presents opportunities to reduce this dependency on fossil fuels. By reevaluating procurement processes and increasing investment in promising emerging technologies, there are ample opportunities to introduce measures that will contribute to the decarbonization of carbon-intensive industries and, eventually, the military itself. They are also likely to reduce the costs of fossil energy purchases from sources outside Europe and provide operational advantages, such as the ability to operate in a more autonomous and quiet manner.

This chapter will explore viable opportunities and actions for policymakers to address supply chain emissions and support climate mitigation efforts. This chapter will first present preexisting research and data on emissions from militaries and their suppliers. We will review what information is available and highlight any potential data gaps. Following this, we will investigate promising innovations and business ecosystem dynamics to integrate more sustainable technologies into defense products and practices. After this, we explore current pressures and incentives to promote change within militaries and their suppliers, as well as where potential roadblocks emerge. The focus is to identify and leverage opportunities for reducing carbon emissions at every step of the value chain.

What are the sources of emissions and approaches to measuring them?

Most companies use the Greenhouse Gas Protocol to report emissions, in line with the Kyoto Protocol.[262] This initiative divides emissions into three categories: scope 1, 2, and 3. Scope 1 emissions encompass the direct emissions of a company or organization, for example, from their own factories or testing of the products that they use. Scope 2 are the indirect emissions from the energy purchased by a company or organization. These emissions occur offsite where the energy was produced but are reported by the consuming company. Scope 3 is a voluntary category under the Protocol that represents the emissions occurring from the value chain of the company or organization, both upstream and downstream. This includes waste, business travel, investments, extraction of materials, and transportation of purchased fuels.[263] The scopes were originally intended to be applied to civilian economic activities and face applicability challenges when used to classify militaries.

For a military organization, the supply chain can be understood to equal scope 2 and 3, and several studies estimate that these often constitute the majority of military-related emissions. Scope 3 typically accounts for the majority of reported emissions for organizations, as it includes reporting on a wider set of activities than that conducted within an organization. Energy utilities supply electricity and fuel for installations and vehicles, waste companies manage the garbage generated through military operations, and the defense industry produces many of the carbon-intensive goods such as aircraft and naval vessels used for operations. Supply chain (i.e., scope 2 and 3) emissions often constitute the majority, if not the vast majority, of emissions when reported on

262 Greenhouse Gas Protocol, World Business Council for Sustainable Development, and World Resources Institute, GHG Protocol Standards and Guidance Update Process, Accessed June 24, 2024.

263 Greenhouse Gas Protocol, World Business Council for Sustainable Development and World Resources Institute, A corporate Accounting and Reporting Standard, 2004.

by militaries, as seen in the Norwegian case below.[264] [265] This means that the greatest potential for emissions savings is in this category, making it vital to address if net zero is to be achieved, especially in light of increasing demand for heavy carbon-intensive armaments.[266]

We have rephrased the varying scopes to be more applicable to militaries. These are outlined below in Figure 1:

Upstream emissions		Institution specific	Downstream emissions
Scope 3 Indirect emissions **Purchased equipment** This could be ammunition, vehicles, aircraft, etc. **Extraction of materials** The extraction of the materials used in construction of purchased goods **Purchased services** This can take the shape of outsourced labor **Transportation and distribution** **Fuel and energy production** The cost of producing fuel consumed **Business travel and employee commuting** **Leased assets** Assets leased from outside the armed forces such as vehicles	**Scope 2** Indirect emissions related to energy and heating. Produced offsite but reported by military. **Purchased electricity** Electricity purchased from the grid **Purchased heating and cooling** Includes products such as natural gas	**Scope 1** Direct emissions of the military in its activities and upkeep. **Fuel usage by tanks, aircraft, naval vessels, etc.** **Energy usage by the military in general**	**Scope 3** Indirect emissions **Waste** Includes both general waste from staff, but also end of lifecycle for equipment **Leased assets** Emissions from equipment leased to other organizations **Investments** **Research and Development**

Figure 1: This figure depicts the classification of scope 1, 2, and 3 emissions as outlined in the GHG protocol. It has been adapted to better illustrate what emissions are linked to armed forces. It does not include warfighting activities (scope 3+).[267]

264 Joshua Snodin, Beatriz Vasconcelos, Gabrielle Desarnaud, Arnaud Buzenet, Adele Balog, Quentin Montaclair and Clotilde Rey, From stroll to sprint. A race against time for corporate decarbonisation, CDP and Capgemini Invent, 2023, 42.

265 Carbon Trust, An introductory guide to Scope 3 emissions, 2023 .

266 Micheal Nienaber and Kamil Kowalcze, "Germany to Place Leopard Tank Order Worth Up to $3.2 Billion", *Bloomberg*, May 12, 2023.

267 Rostyslav Bun, Gregg Marland, Tomohiro Oda, Linda See, Enrique Puliafito, Zbigniew Nahorski, Mathias Jonas, Vasyl Kovalyshyn, Iolanda Ialongo, Orysia Yashchun, and Zoriana Romanchuk, "Tracking unaccounted greenhouse gas emissions due to the war in Ukraine since 2022", Science of the Total Environment 914, no. 169879 (January 2024).

Figure 1 also highlights downstream and upstream scopes. These should be understood as emissions that occur outside the organization either before or after they perform their role in the value chain. The supply chain of a company producing equipment for the military would look different from this. For example, the European Association for Aerospace, Security and Defence Industries (ASD) differentiates between upstream, those emissions further up in its own supply chain, and downstream, which includes the emissions linked to their products used by end users such as the military.[268] This chapter mainly focuses on the upstream aspect of military scope 3, meaning the emissions of the industries that supply militaries with products and services.

Obligations to report on military scope 3 emissions vary from one jurisdiction to another and, at times, do not apply to militaries due to the potential sensitivity of this information.[269] [270] Different militaries have diverging definitions for what encompasses scope 3, what they consider relevant emissions, and what they are obligated to report by law.

Weak reporting requirements also risk producing incorrect or imprecise analyses as researchers are forced to apply emissions averages from parties they have data from to provide a comprehensive picture of the supply chain as a whole. Organizations such as the Conflict and Environment Observatory (CEOBS) and Scientists for Global Responsibility (SGR) have extrapolated data from militaries that do report emissions and then applied the same per-head emissions to other militaries to achieve rough estimates. This has resulted in estimates of military emissions representing between 1% and 5.5% of global

268 The Association for Aerospace Security and Defence Industries in Europe, "Understanding greenhouse gas emissions from defence", Accessed June 24, 2024.

269 Doug Weir, Benjamin Neimark and Oliver Belcher, "How the world's militaries hide their huge carbon emissions", *The Conversation*, November 9, 2021.

270 The Military Emissions Gap," Tracking the long war that militaries are waging on the climate", Accessed June 24, 2024.

emissions. [271] [272] The issue with this is that there can be significant discrepancies between various nations, such as energy mixes with varying carbon intensity and the rate of deployment of forces. These estimates are also made without access to data from many countries on Scope 3 emissions, further complicating the analysis.

Many of these inconsistencies are related to the military exemptions for global emissions reporting to the UNFCCC. Though NATO militaries have begun to report on emissions, they often omit Scope 3 or provide data that is aggregated to such a degree that it becomes difficult to use in an analysis. In certain jurisdictions, scope 3 emissions reporting is mandatory, but only for certain categories or topics. In the United Kingdom (UK), for example, large businesses are required to report the emissions from their business travel.[273] From the reporting of private businesses we can surmise that scope 3 reporting will both provide a detailed overview of the non-combat activities of militaries and highlight the wider civilian economic effort supporting military activities. Businesses use this to identify particularly carbon-intensive practices in their supply chain to help inform and guide their decarbonization efforts. This UK legislation also suggests that reliable data will depend on the regulation in place. Though more standardization is being introduced by the EU's Corporate Sustainability Reporting Directive (CSRD), it still falls behind in enforcement and does not reveal the military side of the scope 3 equation, thus denying researchers a comprehensive overview of the data.

For policy interventions to be effective, accurate data will be needed to properly inform policy makers. Accurate data will also help to enforce accountability on parties and pressure them to adapt and innovate to limit their own GHG emissions.

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271 Stuart Parkinson and Linsey Cottrell, "Estimating the Military's Global Greenhouse Gas Emissions", Scientists for Global Responsibility and Conflict and Environment Observatory, 2022.

272 Adam Healy and Miguel Lopez, "Defence Zero. Volume 1: Military Emissions and Potential Solutions", Roland Berger LTD, 2023.

273 His Majesties Treasury, "2023-24_Sustainability_Reporting Guidance: 2023-24", July, 2023, page 12.

Examples of how supply chains are covered in national reporting

National militaries are often exempted from emissions reduction targets and international reporting schemes.[274] Below we delve into concrete examples of North American and European NATO member countries to illustrate difficulties in emissions reporting and varying approaches to enforcing reductions.

Canada's Federal Government has set itself the goal of reducing absolute scope 1 and 2 emissions by 25% by 2025 and 90% by 2050.[275] Canada's National Safety and Security fleet (NSS) is comprised of aircraft, naval vessels, and land vehicles and is not required to meet these targets.[276] As of fiscal year 2022—2023, Canada has reduced emissions by 39.8% from 2005 levels, but this statistic omits its National Safety and Security fleet (NSS).[277] In addition, it should be noted that Canada does not consider scope 3 emissions in its governmental emissions reduction targets. This approach may mean that a significant amount of emissions linked to government operations are not accounted for and fall outside of emissions-reduction measures. This highlights the challenges of assessing the size of a military's carbon footprint.

The Norwegian Ministry of Defense, in comparison, has an expanded definition of scope 3 emissions that includes fuel production and several other forms of upstream and downstream emissions.[278] However, despite the expanded definitions, reporting of scope 3 emissions is not required for their

274 United Nations Framework Convention on Climate Change, "The Paris Agreement", Article 6, 2015.

275 Harry Bowcott, Giacomo Gatto, Alastair Hamilton and Erik Sullivan, "Decarbonizing defense carbon emissions", July 1, 2021

276 Government of Canada, "Government of Canada's Greenhouse Gas Emissions Inventory", Last updated December 6, 2023.

277 Treasury Board of Canada Secretariat, "The Greening Government Strategy", Last updated May 29, 2024

278 Simen Kirkhorn, Kristian Blindheim Lausund, Tove Engen Karsrud, Petter Prydz, "Forsvarssektorens miljø og klimaregnskap for 2022", Forsvarets forskningsinstitutt, 2023, page 50.

yearly emissions reporting.[279] A further complicating factor in analyzing this data is that certain energy sources are not included in respective scopes but reported separately. Norway's Ministry of Defense (MOD) is more proactive in reporting on their scope 3 metrics than many other NATO member countries, but it still demonstrates that even under more exhaustive reporting, there may be data gaps.

National militaries often have definitions of scope 3 that differ from one another and make comparability difficult even when there is extensive reporting. The United Kingdom's Ministry of Defense, for example, does not include a supply chain component in its scope 3. While it does account for metrics such as waste, duty travel, employee commuting, and service family accommodation, there are no references to the emissions tied to military products.[280] In the absence of reporting on the UK defense-industrial sector, organizations such as Scientists for Global Responsibility have attempted to provide estimates for this aspect of the supply chain by cataloging the emissions of different UK-based weapons producers.[281]

Finally, the United States, in its reporting and reform efforts, has a mixed track record for meeting climate targets and for reporting.[282] The US Department of Defense (DOD) does report on emissions linked to its military operations. And while data for scope 1 and 2 emissions are readily available,[283] the US DOD has not reported on scope 3 emissions since 2016, when such requirements were suspended.[284] [285] However, the DOD began tracking scope 3

279 Idem, 41.

280 UK Ministry of Defence, "Annual Report and Accounts 2022–23", July 20, 2023, 204.

281 Stuart Parkinson,"The Environmental Impacts of the UK Military Sector", Scientists for Global Responsibility and Declassified UK, 2020.

282 Jen Judson, "US Army's shortfalls and successes in reaching its climate goals", Defense News, October 9, 2023.

283 United States Department of Energy, "Comprehensive Annual Energy Data and Sustainability Performance", July 1, 2023.

284 US Department of Defense, "Report on Greenhouse Gas Emission Levels", March 23, 2022, 3.

285 US Department of Defense, "Department of Defense Plan to Reduce Greenhouse Gas Emissions", April 2023, 16.

emissions again in 2022, as a result of Executive Order 14057 and is required to set reduction targets that include scope 3 emissions.[286] This again highlights the gaps in policymaking on this topic and demonstrates that backtracking on reporting does happen in certain jurisdictions and cannot be taken as a given.

For national militaries, major sources of scope 3 emissions emerge in the purchasing of energy, goods, and services. The Norwegian military, for example, identifies air travel and purchased goods and services as their two largest sources of emissions. They, in fact, play an outsized role when considering the total scope 3 emissions of the military. As demonstrated below in Figure 2, purchased goods and services hold the vast majority of Norwegian scope 3 military-related emissions, while domestic flights for the armed forces represent the next highest amount. This means that the highest potential for decreasing scope 3 emissions for this country will come from the decarbonization of the products and goods purchased by the military. Studies conducted by the Conflict and Environment Observatory (CEOBS) and Scientists for Global Responsibility (SGR) suggest this pattern will be similar for other European countries, but it will depend on the composition of the forces in question and the scope of their operations. It is important to note that this not only accounts for goods such as weapons or vehicles purchased from defense contractors but also encompasses a wider array of companies supporting the operations and maintenance of the military.

286 Executive Office of the President of the United States, "Implementing Instructions for Executive Order14057. Catalyzing Clean Energy industries and Jobs Through Federal Sustainability", August 2022, 7.

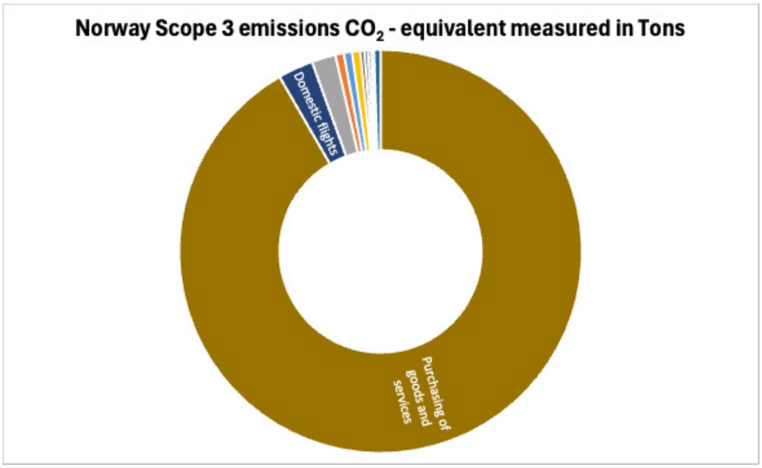

Figure 2: the share of emissions that various categories account for in the Norwegian reporting on scope 3 emissions. Values are in CO_2—equivalent and measured in tons.

Examples of how the Defense Industry reports on the emissions of its Supply Chain

The military defense industry is subject to different regulations and standards of emissions reporting. Often, these companies are bound by reporting regulations such as the Corporate Sustainability Reporting Directive (CSRD) in the European Union that enters into force from 2024 onwards for companies with more than 500 employees. In addition, companies often voluntarily commit themselves to ambitious sustainability goals and promote transparency as an element of their business strategies.

Therefore, reporting on GHG emissions can differ among companies. Some defense-industry companies, such as Leonardo, do not publish scope 3 emissions data; they only provide data for scope 1 and 2 and have no reduction targets that include scope 3.[287] Thales, on the other hand, has set reduction targets to achieve net-zero by 2040, but only includes scope 3 business travel

287 Leonardo, "Bilancio Integrato 2022", December 31, 2022, page 49.

emissions in these calculations.[288] Boeing has a similar approach to including scope 3 emissions from business travel,[289] and also reports on scope 3 downstream emissions.[290] Both Boeing and Thales demonstrate in their reporting of scope 3 how a significant portion are downstream rather than upstream emissions. Thales reports these scope 3 emissions as "other emissions." In total, these equaled 9,312 ktCO_2 in 2021. Figure 3 below helps to demonstrate this imbalance:

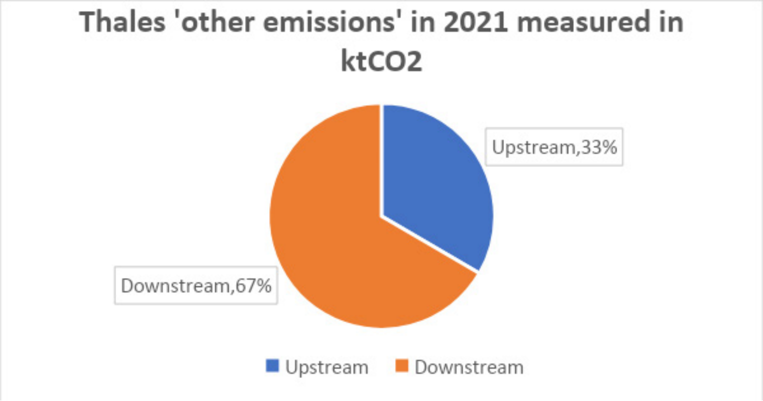

Figure 3: percentage of scope-3 emissions from Thales in 2021 that occurred either upstream or downstream.

Thales serves as a good example of where the majority of scope 3 emissions in the defense-industrial sector are located. Other companies also report that a majority of their scope 3 emissions, and a significant part of their total reported emissions, occur further down the value chain, often from the use of their products. This is in line with the reporting from the European Association for Aerospace, Security, and Defence (ASD) that posits that the majority of the emissions from their consortium members come from scope 3 and specifically from downstream emissions.[291] American industry giant Lockheed Martin

288 Thales, "Annual_Environment_Report_2021", September 29, 2022, page 8.

289 Boeing, "2023 Sustainability Report", 2024, Page 74—96.

290 Idem, 74.

291 The Association for Aerospace Security and Defence Industries in Europe, "Understanding greenhouse gas emissions from defence", Accessed June 24, 2024.

also highlights the significance of their downstream scope 3 emissions in their reporting.[292] This helps to demonstrate the high emissions linked to the use of these companies' products and suggests that there is a great opportunity for emissions savings from innovating on products purchased by militaries.

We see that defense companies also report significant emissions from their scope 3 emissions, specifically those occurring downstream. This encompasses the use of their military equipment by the military themselves and falls under scope 1 reporting from militaries.

This would suggest that defense companies do not necessarily constitute the majority of scope 3 emissions for militaries, but it is the wider civilian resources drawn upon to support the military, such as the production of fossil fuels or civilian use of aircraft, that make up a majority of these emissions. This demonstrates that there is a dual approach to emissions reduction. One approach is targeted at green R&D aimed at reducing the operational emissions of militaries as registered under downstream scope 3 emissions from defense contractors. The second approach is the wider decarbonization of the civilian economy, as the military draws substantially on these goods and services.

Compared to other industrial sectors, the defense industry is arguably not more relaxed in its reporting of emissions. Often, they provide reporting in line with a long-term growth strategy to either prepare for new regulations or market themselves better.[293] Many companies have joined global reporting and net-zero goal-tracking initiatives such as the Transitions Pathway Initiative. Here, they highlight the initiatives that they have launched or are a part of and also report on their progress toward reaching these emissions goals.[294] Saab, in particular,

292 Lockheed Martin, "2022 Sustainability Performance Report", 2023, Page 44.

293 Leonie Nimmo, Hana Manjusak, "Environmental CSR reporting by the arms industry", *CEOBS*, December 2021.

294 Global Climate Action, "GCAP UNFCCC—Index", accessed June 24, 2024.

seems to be very engaged with these issues,[295] and is among many of the companies that have pledged themselves to be net-zero by 2050 along with BAE.[296]

However, gaps and differences in reporting standards remain across the industry, the severity of which often depends on the regulations in place. This inhibits transparency as data cannot be guaranteed to be correct. It also means that companies will have different reporting standards that do not align. The Science Based Targets Initiative (SBTi) has been created in response to this gap and seeks to provide guidance and validation services to companies to ensure compliance with net-zero goals. Though even this initiative faces struggles in ensuring transparency due to recent controversies regarding the use of carbon credits.[297]

In addition, traditional sustainability reporting methodologies often fall short in terms of providing a holistic overview, as they rely on absolute or relative metrics that are not necessarily applicable to the organizations using them. While reporting frameworks come accompanied by emissions reduction targets, they often fail to highlight the local or specific context that organizations such as militaries operate within. For example, a reduction target of 50% and reporting in line with this fails to illustrate the context in which these emissions take place. It does not account for the specific impact that an organization has or what its share of the global carbon budget is. A target of 50% percent may seem ambitious, but if the emissions that are still emitted under this program account for a disproportionate amount of the global carbon budget, then this may still be unsustainable and prevent authentic and ambitious mitigation efforts. Alternative methodologies such as Context Based Sustainability (CBS) have emerged in an effort to address these concerns by tailoring emissions reduction efforts to organizations by providing them with science-based metrics that are specific to them and their local environment. It moves beyond the current norm of absolute or relative targets by

295 Global Climate Action, "GCAP UNFCCC—Actor profile: SAAB AB", accessed June 24, 2024.

296 Global Climate Action, "GCAP UNFCCC—Actor profile: BAE Systems", accessed June 24, 2024.

297 Virginia Furness, "Exclusive: Corporate climate watchdog document deems carbon offsets largely ineffective", *Reuters*, May 9, 2024.

highlighting the local context of an organization and specifying their impact on the environment.[298] [299] Though while CBS addresses the gaps currently existing in reporting, it is also a much more intensive reporting process that requires the dedication of significant resources to complete. This creates a high barrier to entry for both private and public entities. Mandated reporting, including CBS, could help address this concern, but the emphasis should be on ensuring that organizations are given incentives to provide authentic sustainability indicators that remove these data gaps.

These examples demonstrate the significant hurdles to ensuring that reporting and decarbonization plans are trusted to affect sustainable change.

Interconnectivity in the field and questions of who owns what emissions

As mentioned previously, organizations such as SGR and CEOBS seeking to quantify military emissions have faced challenges in accessing data and have thus been forced to make a series of assumptions in their calculations that risk producing incorrect results. There are also risks with both under- and overestimating emissions. If emissions are not properly labeled and accounted for, there is a high risk that they may be accounted for twice in many of these analyses. Scope 3 emissions of defense companies might be added onto scope 1 reporting from militaries, thus double-counting these emissions. Downstream emissions of arms suppliers risk being counted twice in these analyses as they encompass the scope 1 and 2 emissions from national militaries. It also means that current estimations of the total emissions that can be attributed to militaries are very rough estimates. The holes in the data are so extensive that the reliability of these numbers cannot be assured.

298 Center for Sustainable Organizations, "Context-based sustainability (CBS) ", accessed June 24, 2024.

299 Mark W. McElroy and Jo M.L. van Engelen, *Corporate sustainability management : the art and science of managing non-financial performance* (London: Routledge, 2011).

Supply chain cataloging is also difficult because many components are constructed by several companies, for example, the Leopard 2 tank and its variants.[300] The designs for the product are owned by Krauss-Maffei Wegmann, while part of the armament including the main cannon are built by Rheinmetall. This collaboration also includes companies whose primary function is to produce civilian goods.

If reporting from scope 3 emissions is optional and clearly defined, it risks creating gaps in accounting. It is apparent that the significant data gaps have raised uncertainty regarding the validity of the analysis attempting to quantify scope 3 emissions. This dynamic allows companies to avoid the responsibility for decarbonizing, as they can argue that certain emissions are outside of their scope. Defense industry companies, as highlighted by reporting from the European Association for Aerospace, Security and Defence Industries (ASD), and industry partners have significant scope 3 emissions. Despite not being directly responsible, they arguably have a shared responsibility to reduce their carbon footprint as producers of carbon-intensive equipment.

Where is the greatest potential for innovation?

For efforts aimed at tackling military scope 3 emissions, it is important to pinpoint emission hotspots within the value chain. The reporting frameworks mentioned previously can help identify these emission hotspots. They can be matched with innovations that allow for the adaptation of existing technologies and the development of novel solutions. It is key that these novel innovations and technologies are platform agnostic, allowing for broad integration options. Within the context of strategic priorities, it will be crucial that innovations contribute to related objectives, such as diversification and decentralization of energy sources, localized energy production, modularity and scalability, and the reduction of environmental impact. While these types

300 Rheinmetall, "Main battle tank Leopard", accessed June 25, 2024.

of innovations support decarbonization within Scope 1 and 2 primarily, Scope 3 holds the most significant potential for decarbonization and should thus be a primary focus. This requires a collaborative, ecosystem-oriented approach to emission reduction for militaries. To address Scope 3 in particular, innovations play a pivotal role, such as new materials, novel production methods, and product life cycle considerations.

The following are examples of promising technologies for decarbonization efforts:

Energy Harvesting Technologies: Various energy harvesting technologies, including tidal turbines, oscillating water columns, portable wind turbines, inflatable wind turbines, flexible solar cells, and solar concentrators, offer efficient solutions for powering remote military operations where traditional power sources are scarce. While energy harvesting technologies are directly supporting the decarbonization efforts for Scope 1 and 2, they also contribute to increasing Scope 3 emissions due to their (highly variable) manufacturing processes, materials, and efficiencies. For instance, the production of solar panels involves the extraction and purification of silicon, which is energy-intensive, whereas kinetic energy harvesters might use less energy-intensive materials and processes. To this end, it is important to look more broadly at technologies across all emission scopes to pinpoint the areas for much-needed innovations within a product-specific value chain.

Energy storage systems: To support a more resilient and green supply chain, there must be a core emphasis on expanding the storage capabilities for renewable energy within Europe and North America. By storing excess renewable energy when it is produced and plentiful, it can be tapped into when needed to support industries in their operations and manufacturing.[301] These storage options have thus far been reliant on conventional battery technologies. However, the energy storage needs of the coming decades will likely

301 Alberto Bettoli, Martin Linder, Tomas Nauclér, Jesse Noffsinger, Suvojoy Sengupta, Humayun Tai and Godart van Gendt, "Net-zero power: Long-duration energy storage for a renewable grid", Mckinsey, November 22, 2021.

require novel innovations such as flywheels[302] and energy vaults[303] that can store energy for long periods without high losses in the interim period. These energy storage systems include Uninterruptible Power Supply (UPS) systems, which provide backup power during outages or faults. Additionally, resource scarcity considerations are a driver for innovations, making the exploration of new technologies increasingly viable as supply-chain risks increase .

Hybrid Power Systems (HPS): Hybrid Power Systems (HPS) can help reduce supply chain emissions linked to procuring and transporting fuels such as diesel and kerosene. These integrate renewable energy sources, traditional fuels, and energy storage and transform defense operations by providing resilient and reliable energy in remote or hostile environments. These systems are designed to reduce the military's dependence on fossil fuels and cut greenhouse gas emissions in various areas, such as within the supply chain, aligning with broader sustainability goals. Crucially, HPS enhances operational security by minimizing reliance on long and vulnerable fuel supply chains often targeted in conflict zones[304]. They ensure the uninterrupted functioning of essential technologies such as radar and communication systems, thereby maintaining a strategic advantage. This shift towards self-sustaining energy solutions marks a significant advancement in military logistics and strategy, enhancing overall mission effectiveness and safety. By integrating renewable energy sources, HPS significantly reduce reliance on fossil fuels, thereby decreasing greenhouse gas emissions. For industries that are part of a military value chain, this means a direct reduction in Scope 3 emissions.

Intelligent Power Management Systems (IPMS): For defense, Intelligent Power Management Systems (IPMS) employ Artificial Intelligence (AI) and Internet of Things (IoT) to optimize power allocation, such as prioritizing critical systems in military vehicles, dynamically managing energy in mobile power stations, enhancing efficiency in defense facilities, regulating power

302 Mohammad Imani-Nejad, "High-performance flywheels for energy storage", MIT Energy Initiative, accessed June 25, 2024.

303 Energy Vault, "Break through with G-VAULT", accessed June 25, 2024.

304 ScienceDirect, "Hybrid Power—an overview", accessed June 25, 2024.

in data centers and industrial automation, balancing supply and demand in smart grids, and controlling consumption in smart buildings, including HVAC systems. This optimization reduces operational costs, enhances reliability, and provides high-energy electrical power for essential military capabilities in contested and remote environments.

Cross-cutting technologies for supply chain optimization: The use of artificial intelligence (AI), machine learning (ML), and possibly quantum computing offer the potential to support more efficient supply chains by optimizing the use of energy and promoting greater efficiency during manufacturing. By analyzing historical and real-time data, AI and ML can accurately forecast energy consumption patterns, ensuring a stable supply during peak times and enhancing resilience. These technologies also improve the system's ability to switch intelligently between different renewable energy sources based on predicted yields from weather conditions, reducing reliance on any single source. Moreover, AI and ML contribute to grid stability by quickly detecting and addressing anomalies, thereby enabling prompt mitigation strategies to prevent or minimize outages. Overall, AI and ML play a crucial role in developing a more robust, resilient, and reliable energy infrastructure.

Quantum computing: While currently, most quantum computing technologies are still in the R&D or prototype phase, it is expected that with advancements in quantum, this technology will become increasingly more relevant for military applications over the coming five years. Significant advancements are expected in the field by 2027, in part due to provisions in the 2024 National Defense Authorization Act (NDAA).[305] Quantum computing could solve complex optimization problems for energy grids, leading to more efficient resource use, improved resilience, and better integration of renewable sources. In material research, quantum computing could expedite the development of new, more efficient energy storage, transmission technologies, and renewable energy sources. It can potentially improve climate modeling and prediction, aiding in preparation for energy system disruptions due to climate change.

305 Kelley M. Sayler, "Defense Primer: Quantum Technology", US Congressional Research Service, last updated October 25, 2023.

Quantum computing could also revolutionize cybersecurity through quantum cryptography, offering theoretically unbreakable encryption to safeguard energy systems from cyber-attacks. Additionally, it could optimize supply chains, thus enhancing the efficiency and resilience of energy resource management.

Strategic Partnerships and Ecosystem Collaboration

When considering different pathways for defense sector decarbonization, it is helpful to consider an ecosystem perspective. Fostering partnerships and collaboration with industry partners, technology startups, and research institutions to leverage expertise, share resources, and accelerate innovation in decarbonization technologies is essential. Collaborative research projects, joint ventures, and technology transfer agreements can facilitate the development and adoption of cutting-edge solutions.

Startups embody the cutting edge of technological innovation, often pioneering solutions that address specific decarbonization challenges. Their agility, risk tolerance, and focus on innovation position them as invaluable partners in the defense decarbonization journey. Startups can introduce breakthrough technologies that target high-emission areas within the value chain to realize emissions reductions within Scope 3. The key to leveraging startups lies in creating ecosystems that support their growth and integration into the defense value chain, including mechanisms for funding, mentorship, and regulatory compliance assistance. However, startups face hurdles in navigating the complex and risk-averse landscape of defense contracting and the monopoly primes have on defense procurement, underscoring the need for tailored support and engagement strategies.

Primes, with their extensive resources, technical expertise, and deep ties to defense establishments, are essential players in scaling and integrating decarbonization technologies. They serve as the integrators of innovations developed by smaller firms, including startups, into comprehensive systems that meet the stringent requirements of defense applications. Primes are also key in reducing

Scope 3 emissions for defense decarbonization efforts within the value chain. They can, for example, invest in internal R&D to advance decarbonization technologies, leveraging their understanding of defense needs and operational contexts. An example of this is Ratheon Technologies advancing hybrid-electric propulsion through the Scalable Turboelectric Powertrain Technology (STEP-Tech) demonstrator. As a modular and scalable demonstrator platform, STEP-Tech is intended for rapid prototyping of distributed propulsion concepts applicable to a wide range of next-generation applications, including advanced air mobility vehicles, high-speed eVTOL, and blended wing body aircraft.[306] Primes have the potential to upscale technological solutions such as the provision of renewable energy for bases through offshore wind farms.[307] Their role involves not just technology integration but also the management of complex projects and the assurance of compliance with defense standards. The challenge for primes is to maintain their innovative edge and collaborate effectively with smaller innovators while navigating the strategic and financial implications of transitioning to greener technologies.

Ministries and Departments of Defense: The defense establishments themselves, as the end users of decarbonization technologies, have a critical role in defining the strategic direction and operational requirements for innovation. They can do this by incentivizing primes and their suppliers to pursue more ambitious decarbonization measures. Their commitment to sustainability goals, articulated through strategic planning and policy frameworks, sets the agenda for technological development and procurement priorities. Defense establishments must foster an internal culture that values innovation and sustainability, enabling new technologies and practices to be adopted. Additionally, they need to invest in testing and evaluating infrastructure to ensure that new technologies can be effectively integrated into existing systems without compromising operational readiness or security. The challenge for defense establishments is balancing immediate operational requirements with

306 RTX, "RTX STEP-Tech demonstrator completes first engine run and electrical system integration test", June 20, 2023.

307 European Defence Agency, "Symbiosis: Offshore Renewable Energy for Defence", accessed June 25, 2024.

long-term sustainability objectives, which require foresight, flexibility, and a willingness to invest in transformative technologies.

Research Institutes: The successful development, testing, and implementation of decarbonization technologies in the defense sector depends on a robust ecosystem that supports foundational research and facilitates the commercialization of innovations. Collaborative research initiatives between government, academia, and industry can lay the groundwork for breakthrough technologies. These partnerships, supported by targeted funding and policy incentives, can accelerate the transition from research to commercial viability. Furthermore, mechanisms for technology demonstration and pilot projects within defense contexts can provide critical validation and feedback, paving the way for wider adoption.

Procurement: A Catalyst for Innovation

Procurement departments within defense organizations play a pivotal role in driving decarbonization technologies from concept to deployment. By prioritizing suppliers and partners committed to sustainable practices, defense entities can significantly influence the reduction of carbon footprints across their value chains. This entails a shift towards sourcing materials and technologies that are less carbon-intensive and more efficient in their use and longevity, thereby minimizing waste and energy consumption. By embedding sustainability criteria into procurement processes, these departments can leverage their purchasing power to stimulate market demand for innovative decarbonization solutions. Moreover, procurement can act as a bridge, facilitating collaborations between defense entities and innovative suppliers, including startups and prime contractors. The challenge lies in balancing the urgency of environmental objectives with the rigorous demands for reliability and security inherent in defense procurement.

Investment in R&D and expanded vehicles for fund allocation

Allocation of resources to research and development (R&D) programs focused on developing and testing innovative technologies is essential for decarbonization efforts within defense. This funding can support internal R&D initiatives within defense organizations and external partnerships with academic institutions, research labs, and private sector companies. R&D within the defense sector must prioritize sustainability as a core criterion. Innovations in materials science, energy storage, and propulsion technologies offer potential pathways to significant reductions in carbon emissions. Technology scouting and assessments to evaluate the potential of these technologies are essential when making capital allocation decisions. These mechanisms for evaluating new technologies' potential applicability, feasibility, and effectiveness through technology scouting programs, innovation challenges, and pilot projects are important and must align with existing procurement practices to ease adoption. It is also crucial to conduct demonstration projects and field trials to showcase the capabilities and benefits of decarbonization technologies in real-world settings. These projects can help build confidence among stakeholders, identify technical challenges, and inform decision-making regarding the adoption and scaling of innovative solutions.

In conclusion, decarbonizing the defense sector requires a coordinated effort that leverages the strengths and perspectives of procurement departments, startups, prime contractors, and defense establishments. By fostering an ecosystem that supports innovation, collaboration, and sustainable procurement, the defense sector can reduce its environmental impact and enhance operational effectiveness and resilience. It is important to work collaboratively with regulatory agencies and standards organizations to establish frameworks, guidelines, and certification requirements for decarbonization technologies in defense applications. Clear regulatory standards, such as the Corporate Sustainable Reporting Directive (CSRD) and the Science Based Targets Initiative (SBTi), can help mitigate risks, ensure interoperability, and facilitate the adoption of new technologies across defense platforms and systems. The path to decarbonization is complex and challenging, yet with a strategic and collaborative approach, it is within reach.

Pressures and incentives for innovation by the European Union, NATO and the United States

To reduce emissions of the military supply-chain, the European Union, NATO and the United States have launched the following major initiatives, though more innovation is needed.

EU initiatives

A key policy of the EU to incentivize sustainable lending to the private sector is its **taxonomy** that classified investments as green or grey and is linked to policies and lower interest rate regimes of governments, finance institutions, banks, and public and private investment funds that aim to promote sustainability.

For the moment, it is not greenhouse gas emissions but the social criteria of the taxonomy that provides the biggest barrier to access investment for the defense industry. This makes it difficult for the industry to access funding as the taxonomy classifies companies whose share of military sales exceeds 5% as unsustainable. This has had a knock-on effect where lenders and financial institutions are hesitant to work with defense contractors,[308] especially when they produce weapons that are banned under certain human rights conventions. This limits the defense industry's access to financing and loans, inhibiting their future development.

308 Sylvia Pfeifer, "Rise of ESG adds to pressure on European defence companies", Financial Times, 2021.

The European Investment Bank (EIB) has recently been invited by the European Council to relax its **lending policies** for defense-industry companies,[309] on the recommendation of the EU Commission.[310] This is a reaction to a wide array of defense ministers from across Europe advocating for greater access to finance and the industry's own requests. There is a perception that greater lending will help to support the growth of the industry, but it will likely mean rising emissions as these companies respond by expanding operations and ramping up production. This offers opportunities for conditioning loans with a commitment to net-zero targets and standards. This would help to promote not only the EU's wider net-zero targets but also its strategic autonomy by lessening demand from the military for imported fossil fuels[311].

The **Corporate Sustainable Reporting Directive** outlines that large companies are required to provide data on scope 3 emissions starting from fiscal year 2024. Specifically, these companies must have an average of more than 500 employees over the course of the year, be a publicly listed company, and be designated by national governance as having significant public relevance.[312] Companies will have to report in a consistent manner that aligns with those of the European Financial Reporting Advisory Group (EFRAG), making comparison between different entities easier. It replaced the Non-Financial Reporting Directive (NFRD), which required large companies to report on emissions metrics but lacked transparency. It ensures that reporting does not vary among member states by delivering a unified approach to cataloging emissions.[313] The reporting of Scope 3 emissions is only required where relevant but also focuses on the categories of significant emissions and what the emissions are in relevant categories. This creates the problem that all scope 3

309 European Council, "European Council meeting (21 and 22 March 2024)—Conclusions", March 22, 2024.

310 Josep Borrell, "Time to strengthen European defence industry", EEAS, March 11, 2023.

311 Giulia Cretti, Akash Ramnath and Louise van Schaik, "Transitioning towards energy security beyond EU borders", Clingendael Institute, October 26, 2022.

312 European Parliament and Council of the European Union, "Directive—2022/2464", December 14, 2022.

313 European Commission, "Commission staff working document, executive summary of the impact assessment", April 21, 2021.

emissions may not be accounted for, which will make it difficult to assess the full picture of what the scope of emissions looks like. The European Union is also seeking to rectify this by codifying how environmental claims should be substantiated in business-to-consumer products. This could also apply to defense companies if expanded upon.[314] Unsubstantiated claims in reporting, in general, are an overarching problem across countries.

The **Green Deal Industrial Plan (GDIP)** is an element of the EU's wider Green Deal package for lowering emissions and promoting greater biodiversity. It is specifically focused on reform of European industries to limit their effect on the environment and contribute to a more sustainable agenda.[315] A specific policy intervention is the **Net-Zero Industry Act**, which is aimed at supporting the establishment of new tech innovations that have low-to-negative carbon emissions. Their policy is focused on technologies that can be rapidly scaled up.[316] This is a potential opportunity for the defense industry to decrease its own emissions by receiving support to upgrade its operations. Additionally, other industries that defense contractors rely on can create products that are less carbon-intensive (e.g., steel producers). Some of these are already subjected to carbon pricing under the EU Emissions Trading Scheme. There is also high potential for spillover from other civilian-led initiatives. A greening grid should progressively help to eliminate some of the scope 3 emissions that militaries have, particularly linked to initiatives such as REPowerEU[317] and REFuelEU.[318] EU green industrial plans have the opportunity to provide green spillover effects that can help to lower scope 3 emissions of militaries in the long term.

314 European Commission, "Directive of the European Parliament and of the Council on substantiation and communication of explicit environmental claims (Green Claims Directive)", March 22, 2023.

315 European Commission, "The Green Deal Industrial Plan", accessed June 25, 2024.

316 European Commission, "Net-Zero Industry Act", accessed June 25, 2024.

317 European Commission, "REPowerEU", accessed June 25, 2024.

318 Jaan Soone, "ReFuelEU Aviation initiative", European Parliament, November 2023.

The **European Defence Agency (EDA)** serves as the hub for defense cooperation and coordination within the European Union. It seeks to promote joint procurement and investment from EU member states. It also advocates for further integration on matters related to defense. The EDA has significant potential to create an impact in this area by promoting research initiatives on net-zero technologies.[319] It also helps to coordinate efforts between member states, meaning that it can assist with joint procurement, giving militaries more leverage as consumers to demand sustainable products.[320] It also acts as an engagement platform between the defense industry and militaries, meaning that they can help to foster dialogue between militaries and the industry on the topic of green technologies.[321] The flagship project aimed at addressing decarbonization within the militaries of the European Union is the **Consultation Forum for Sustainable Energy in the Defence and Security Sector** (CF SEDSS).[322] It is tasked with producing research and policy options to promote a more ambitious energy transition within Europe's armed forces.

The **European Defence Fund (EDF)** also has significant funds available to support the development of energy-independent and efficient systems. There is a specific interest in introducing better energy storage devices and reducing dependencies on fossil fuels.[323] This aligns well with the **EU's Strategic Compass for Defence and Security,**[324] which emphasizes strategic autonomy as a core goal of the Union. The EDF helps to highlight how defense industries can play a key role in accomplishing this objective by investing in emerging technologies that further European strategic autonomy. One of the obligations of the Strategic Compass is for EU member states to produce

319 European Defence Agency, "Research & Technology", accessed June 25, 2024.

320 European Defence Agency, "Enablers", accessed June 25, 2024.

321 European Defence Agency, "Industry Engagement", accessed June 25, 2024.

322 European Defence Agency, "Consultation Forum Sustainable Energy", accessed June 25, 2024.

323 European Commission, "Annex 3 to the Commission Implementing Decision", March 15, 2024, 111-118.

324 Council of the European Union, "A Strategic Compass for Security and Defence", March 21, 2022.

national climate-security strategies that include information on their efforts to reduce defense emissions.

The **EU Defense Industrial Strategy (EUDIS)** seeks to revamp the EU's approach to the defense industrial sector by ensuring that production is increased to meet the current needs reflecting the existing security reality. It is aimed at supporting the industrial base by encouraging access to financing and investment to allow armed forces to continue to operate. Green procurement is mentioned but without much detail. Within Europe, defense companies are not able to achieve the same scale as their American counterparts, in part due to the construction of the single market. National entities still prefer their domestic alternatives and are hesitant to provide funding for contractors from another EU member state. This limits contractors' access to funding, thus inhibiting the potential to upscale the production of defense material and R&D efforts.

Though the strategy is not mainly aimed at addressing emissions linked to the production and use of military equipment, its proposed policies do offer avenues for policy interventions that can assist in this matter. Specifically, the **European Defence Industrial Programme (EDIP)** is a regulation announced as an element of the EUDIS that will secure the budgetary and legal framework for the overall strategy.[325]

The proposal to support the production of emerging technologies has great potential. This instrument is directed to fund EDF projects where an area of focus is on energy. Collaboration in this regard could help promote the transition towards green alternatives if it is also included in the research mandate of the EDF. However, such initiatives must also be aligned with the procurement policies of national militaries if they are to see rapid adaptation and use. Additionally, the MFF budget through the EDIP can be used to upscale production capabilities and reformed to include measures that take

325 European Commission, "Proposal for a regulation of the European Parliament and od the Council establishing the European Defence Industry Programme and a framework of measures to ensure the timely availability and supply of defence products ('EDIP')", March 5, 2024.

into account emerging green industrial technologies to reduce the impact of producing heavy equipment.

NATO

The **Defence Innovation Accelerator for the North Atlantic (DIANA),** [326] is a NATO initiative aimed at supporting the development of dual-use technologies within the alliance. It is mainly oriented toward supporting early-stage start-ups with the tools and support needed to develop new emerging technologies. DIANA offers financing for projects, as well as access to end-users for the envisioned product. DIANA seeks to encourage further dialogue and collaboration between tech developers and military end-users. The program mainly supports start-ups with technologies related to energy resilience, sensing and surveillance, and secure information sharing.[327] In particular, the energy resilience perspective has the potential to support net-zero goals. Many of the companies that are currently part of the Program are rethinking how to supply military forces with energy in isolated regions[328] [329] by establishing new smart grids[330] and developing alternative fuel cells.[331]

DIANA demonstrates a shift from the military being a driver of innovation to an adopter of emerging technologies. In prior decades the military was an early innovator of major technologies that were later adopted for civilian use. We may be witnessing the reverse where the military invests in and adopts civilian technologies that are relevant for them.

The **NATO Innovation Fund (NIF)** is a newly established investment fund with input from 24 NATO member states that seeks to pool investment to

326 NATO, "Defence Innovation Accelerator for the North Atlantic (DIANA)", accessed June 25, 2024.

327 Ibid

328 AquaGen, "Bring Power to the People with AquaGen", accessed June 25, 2024.

329 Kitepower, "Plug & Play, Mobile Wind Energy", accessed June 25, 2024.

330 Zelestium, "Zelestium, Clean energy to drive change", accessed June 25, 2024.

331 GaltTex, "World's First Truly Microtubular Solid Oxide Fuel Cells", accessed June 25, 2024.

support promising companies that have net-positive societal governance benefits.[332] NIF differs from the DIANA initiative by not being a policy tool of NATO but rather a financial instrument (fund) that seeks to invest in companies relevant to NATO's technological capability needs with a high profitability potential and net benefits for societal resilience.

NIF is created to help make up for the fragmented purchasing power of NATO member states, especially in Europe. Various national governments each purchase military goods separately and each have their own specifications for equipment they purchase. This makes it difficult to share equipment between NATO members and coordinate action. It also limits the return on investment from companies who develop these tools. Ultimately, this inhibits innovation. NIF contributes by directing funding to upscale technologies (Series-B) and also invests in other deep tech funds to provide indirect investments.

The NATO Sub-Fund 1 has emphasized environmental considerations among its suppliers, vendors, and partners, including tracking the percentage of portfolio companies and fund managers that mandate such policies. The Sub-Fund also focuses on upscaling low-carbon and green energy technologies, R&D into emerging technologies aimed at emissions reductions, and investments into climate change adaptation technologies.

While these initiatives reflect the NIF's commitment to environmental sustainability in its investment strategies, no reference benchmark has been designated for the purpose of attaining the environmental characteristics promoted by the Sub-Fund.

Additionally, it is clear that several initiatives from both the European Union and NATO have overlapping aspects. The EDF and EDIP have overlapping mandates to DIANA and NIF. There is a clear risk of siloing efforts between organizations, if intentions and goals are not properly communicated.

332 NATO Innovation Fund, "NATO Innovation Fund", accessed June 25, 2024.

Inflation Reduction Act (IRA) and Other US Initiatives

The **United States Inflation Reduction Act (IRA)** dedicates extensive resources to addressing a series of societal challenges, including climate change. It aims to accelerate the US economy's transition away from fossil fuels by emphasizing the development of alternative energy production methods and energy storage devices.[333] It also includes stipulations for industries to decrease their carbon footprint and support emerging industries throughout the United States.[334] [335] Significant parts of the bill have been earmarked for further research into green technologies. The IRA has also established a Greenhouse Gas Reduction Fund.[336] Further, there are significant tax incentives linked to the IRA and its promotion of greener industries.[337] The potential for the IRA to have an effect on the emissions of military supply chains emerges in research and spillover from the civilian-led green transition.

The research potential is linked to the resources dedicated to energy, for example. Similarly to the European Union, the United States could dedicate these funds to smart grid alternatives, new battery development, or localized energy production. Spillover effects relate to the general effect that the IRA will have on the United States at large. As the grid begins to decarbonize, the scope 3 emissions for the military should decrease, and products purchased will have a lower carbon footprint.

In addition to the IRA, the US has proposed a policy currently being considered at the White house level, that would require contractors that provide

333 Jonathan L. Ramseur, "Inflation Reduction Act of 2022 (IRA): Provisions Related to Climate Change", Congressional Research Service, last updated October 26, 2023, 22.

334 Ibid

335 Miguel Yanez-Barnuevo, "New Climate Law Jumpstarts Clean Energy Financing", Environmental and Energy Study Institute, September 12, 2022.

336 US EPA, "About the Greenhouse Gas Reduction Fund", last updated April 22, 2024.

337 Robin Bravender, "Podesta, IRS get to work on climate law's tax incentives", POLITICO Pro, May 10, 2022.

goods and services to the DoD to disclose their emissions.[338] This would help address many of the data gaps identified earlier and promote transparency in the contracts signed with the DoD. It is important that policy include a reference to its accounting methodology so that data is accessible and comparable to other industry partners.

How can defense unlock innovation potential?

To address the supply chain emissions of militaries, it is clear that a coordinated response that considers both the need for improved and modernized military capabilities and the limitations and potential for change from the contractors supplying militaries is needed. Such a response must account for the existing data gaps, take advantage of pre-existing policies from national and intergovernmental authorities and funds, and account for existing business dynamics and procurement policies that drive new innovation. **Specifically, what is needed is a targeted strategy aimed at upstream scope 3 emissions.**

For example, from a technology perspective, it is interesting to look where NATO allies are looking to acquire and develop capabilities to mass-produce all-domain attritable autonomous systems (ADA2),[339] these are unmanned platforms tolerable to a higher degree of risk and focus on area denial for opposing forces. They can be easily and cheaply replaced versus expansive military platforms that are time-consuming and much more expensive to replace. This is a direction that is going to be dominant in military doctrine, focusing on fewer technology platforms and more replaceable units. While the strategic imperative is without question from a defense perspective, the environmental consequences of these types of systems cannot be underestimated. In terms

338 US Department of Defense, General Services Administration and National Aeronautics and Space Administration, "Federal Acquisition Regulation: Disclosure of Greenhouse Gas Emissions and Climate-Related Financial Risk", Federal Register, November 14, 2022.

339 Defense Innovation Unit, "The Replicator Initiative", accessed June 25, 2024.

of environmental impact and emissions, these types of systems are adding substantially to emissions from military activities. There is an opportunity to reduce emissions by promoting R&D for novel materials that decrease the environmental footprint of these systems.

This is only one example among many highlighting the cascading effects that military operations and consumption have on the global climate and environment. Innovations will have to address several aspects of the value chain, each of which, in turn, represents a different source of emissions. This will mean incorporating green energy supply into the production of the base goods used to produce military equipment. The wider civilian sector decarbonization will reduce the scope 3 emissions of the military. However, significant R&D will have to be done to make the equipment and services used by militaries more compatible with an emerging sustainable world. This means investing in equipment that can increase longevity and that is less energy-intensive. It also means improving reporting transparency to identify further intervention points in the value chain.

Militaries have a significant influence in promoting greener and more sustainable practices throughout their supply chain due to their role as significant consumers of carbon-intensive goods. Decarbonization and reform of the status quo will be critical if public and private institutions in North America and Europe are to meet their net-zero goals. To this end, we have established a series of recommendations for how defense-industry companies, militaries, and policymakers can spur a more ambitious response to these emerging challenges:

Increase focus on the utilization of novel materials in the design and production of all-domain attritable autonomous systems.

By adding environmental considerations to the development and production processes, the emphasis of funding and resources could be allocated to the creation and utilization of novel materials such as Biodegradable Composites, Novel Battery technologies (such as Graphene-Based Batteries), and Bio-based Polymers.

Support upscaled alternative fuels production, and the gradual introduction of efuel/ sustainable aviation fuel—fossil fuel mixes for military vehicles and the wider supply chain.

By establishing more production centers for alternative fuels, militaries can address what is otherwise the most difficult aspect of the decarbonization process: mobility. This could make these alternative fuels a commercially viable alternative to traditional fossil fuels.

Have ESG reporting initiatives such as the CSRD clarify what is meant by relevance when considering scope 3 emissions reporting.

Some emissions risk slipping through the cracks of reporting and falling outside of emissions reduction targets. By improving access to information, data gaps will become rarer, making it easier to understand and assign responsibility for emissions. A renewed push from regulatory bodies to promote transparency should consider what incentives companies have not to promote certain emissions.

Linking emissions reduction targets to the carbon footprint of products.

Linking emissions targets to the carbon footprint of products would likely incentivize companies to invest more in making more efficient or 'green' products. This could help limit the emissions of products throughout their life cycles. In the example of Airbus, the company's products, in one year, have lifecycle emissions that will be greater than those of an industrialized country, yet there are no binding requirements on companies to curb the emissions of these products.[340]

340 Leonie Nimmo and Hana Manjusak, "Environmental CSR reporting by the arms industry", CEOBS, December 2021.

Mandate or incentivize net-zero goals for militaries, including goals for scope 3 emissions.

Without pressure from regulatory forces, militaries are unlikely to feel inclined to promote the green transition. If they are included in national reduction goals, it would incentivize the national government to invest more resources in their green transition.

Reconsider EU taxonomy and lending practices to account for defense-industry companies that conform to ambitious targets.

The European Union may find benefits to rewarding companies with ambitious net-zero targets. One potential consideration is to allow for companies that demonstrate a clear commitment to achieving net-zero through realistic targets to access more credit. This could be done by reforming green taxonomy to allow for the financing of defense contractors to incentivize wider investment into the industry.

A C-130J Hercules assigned to the 146th Airlift Wing, carrying the Modular Airborne FireFighting System, drops fire retardant chemicals onto a ridge line above Santa Barbara, Calif., on Dec. 13, 2017.

Source: USAF Photo / J.M. Eddins Jr.

V. Conclusion

At the outset of this report, we posed a question—can militaries innovate their way out of their climate challenges? Based on the assessments contained herein, the simple answer is no, not alone. The more nuanced answer reveals the need for a comprehensive strategy that includes research and development, but also incorporates a wider range of policy and procurement approaches. In other words, this is not a challenge that can be solved by a single tool such as military R&D, but rather a broader set of partnerships, policies and investments that fill a sustainability toolbox.

One constraint on military research as a solitary solution is the extended timeframe it takes to develop new military vehicles and equipment, and the length of time they are then in operation. Even if new zero-alternatives were available today, the decades-long lifecycles of preexisting systems and equipment mean it will require substantial time before they would be in operation.

Another constraint on the applicability of military research budgets to this problem is the narrowing focus of military research on mission-specific applications, driven both by limited funding available for research and the fact that commercial and civilian research efforts are much larger in scope and include programs that can be leveraged and integrated with military operations once complete.

Resilience to climate impacts aligns well with this mission-specific approach. Research into how best to weather storms and environmental changes is aligned with military mission requirements. For example, militaries have focused efforts on energy resilience, and are working on ways to leverage microgrids to manage installation energy consumption for mission assurance, even when the power supply is interrupted.

Yet despite these obstacles, there remains great potential for action and benefits from addressing the environmental costs of militaries. Increased efficiency in the energy use of platforms, even when incremental, has benefits both for operational capability and reduction of carbon footprint. Hybrid vehicles are a logical innovation that require little to no change in supporting logistics systems, and reduces the logistics burden. Artificial intelligence will increase efficiency, reduce costly accommodations for military personnel in vehicles, and potentially propel new avenues for research. It will be most effective to pursue decarbonization technologies that synergize with other advances that are occurring simultaneously.

Research programs provide clear pathways to novel technologies that will improve energy efficiency and the performance of systems in use, alongside the development of new technologies. However, the best opportunities to reduce the military's carbon footprint will be found in innovative procurement and policy approaches. While military research does not represent as large a portion of the global research enterprise as it once did, military procurement budgets remain extremely influential, often representing the single largest customer in their respective nations. As a result, acquisition choices can catalyze and steer markets toward particular policy outcomes even while prioritizing military missions.

Given that the largest direct source of emissions of militaries globally tends to be fuel use, in particular for aviation, the development of technologies to produce sustainable aviation fuel at scale and at a lower cost is perhaps the single most important technological advance needed to address military emissions. While the innovations will generally come from civilian research, the military plays an important role by sending markets a clear signal that there is sufficient long term demand for these products.

Procurement of carbon free electricity for fixed installations will also have a significant impact on military footprints. This may occur through targeted power purchase agreements or through the broader greening of the electric grid. Notably, the technologies that will enable this electricity shift already exist commercially.

In Europe, electricity bought commercially has a much lower carbon level than in the United States, but the trend is clearly moving toward a lower emissions level for both. Given the lower carbon footprint of European electricity, gas used to heat buildings tends to be the largest source of emissions for European bases, whereas electricity is still a larger source in the United States. To reduce emissions from gas, militaries would need to invest in upgrades focused on reducing heat system emissions, to include electrification of building heating systems (as was directed by the US Defense Department for all new facilities in 2023).

This report also explored the emissions of military supply chains, which some studies have concluded are even greater than the emissions of militaries themselves. There are still significant data gaps in reporting, but similarly to other sectors there are trends that would suggest a green transition is well underway. What is clear is that the majority of carbon emission reductions will come from innovations throughout the wider supply chain for equipment and goods consumed by militaries, while militaries themselves have a big role to play in this transition. Military leaders can incentivize this transition, and incentivize lower defense industry emissions, through procurement preferences for, and investments into, lower embedded carbon levels in the products they buy.

In conclusion, while the breadth of specific recommendations are incorporated into the individual chapters, they can be encapsulated in one central tenet—*acquisition and procurement innovation*. To address the climate challenge, militaries will need to think fundamentally differently about what they buy. This encompasses procurement policy, process and requirements, and will be more broadly impactful on the climate challenge than technology innovation within military research programs. While military mission is appropriately prioritized in defense budgets, it will be important to focus on ways to purchase energy and systems that meet *both* mission and sustainability requirements. Military acquisition leaders should send this market signal to civilian and commercial energy researchers and catalyze clean energy research by committing to purchase the products that are developed.

By broadening our concept of innovation to encompass a different way of managing military and defense organizations, military innovation can help reduce the large impact on the climate challenge.

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