Carbon Emissions, Net Zero and Future Forces – Comparative Analysis of Radical Emissions-reductions Plans and Processes for Defence

Shiloh Fetzek

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Contents

Cover

An RAF Typhoon *fighter jet refuelling in-flight over the North Sea, from a* Voyager *aircraft flying on a 43% blend of sustainable fuel, 17 April 2023*

Executive Summary

The energy transition is reshaping the modern battlefield and geostrategic competition, and it is increasingly clear that energy independence and diversification of supply will confer strategic advantage. Defence innovation is moving in this direction, spurred by a growing number of countries – primarily Western states and their allies – committing to reducing defence greenhouse-gas emissions to net zero by mid-century. Achieving this target will be a significant technical, cultural and political challenge. This paper compares how countries plan to address the complexities of the defence energy transition.

Militaries facing the decarbonisation challenge are adopting a common approach – implementing available technologies and practices for emissions reductions while building the technical and institutional capacity to rapidly accelerate innovation and implementation in the medium term. High-emitting platforms have long development and procurement timelines and are in service for decades, meaning that major technological advancements must be achieved soon for militaries to reduce their emissions to a level that they could offset to reach net zero by mid-century. Realising such advancements will require changes to business-as-usual procurement and new ways of working with civilian partners – including government departments (such as energy, trade and transportation), commercial aviation and shipping, and newcomers working on breakthrough technologies – to accelerate energy technology development and uptake.

The United Kingdom is at the forefront of efforts to advance this agenda, through a range of innovative policy and partnership arrangements. France is also a significant contributor, while the United States has made net-zero commitments under the current administration that add momentum to its considerable defence-innovation capacities. Countries including Australia, Canada, the Netherlands and New Zealand are leveraging domestic innovation and strengthening partnerships for technology-sharing, while NATO and the European Union are catalysing these processes by combining allies' efforts to overcome technological and institutional hurdles, in part to preserve interoperability. Other countries, including China, India and Japan, are developing and trialling lower-emissions technologies but have not committed to phasing out conventionally powered forces.

There are many open questions around the implementation and implications of the defence energy transition. For the highest-emitting sectors that are most difficult to mitigate, namely air and maritime fuels, the pace of the transition will be determined by how possible it is to develop lower-emissions fuels and how quickly they can be scaled. In taking on the decarbonisation agenda, defence will be competing with other users of critical minerals and materials like steel, aluminium and copper that will be in high demand as energy systems transition. Achieving defence net zero will require maintaining the political will to invest in research and development for breakthrough technologies, much of which will most likely emerge in the considerably larger civilian commercial sector, and be adopted or adapted to the defence sector's energy needs.

Defence will need to navigate interlinked technical and political challenges related to the pace of change in a significantly evolving strategic environment; timing the energy transition to optimise military effectiveness; managing the broader strategic implications of rapidly evolving weapons technologies, operating concepts and force structures; successfully negotiating resource allocation; and addressing the nature of security and defence priorities in a climate-changed future.

1. Defence Modernisation for a Decarbonised Future

Governments are under pressure to transition away from fossil fuels in the next two decades and achieve net-zero carbon dioxide equivalent (CO_2e) emissions by mid-century.[1] For the time being, reporting military emissions remains voluntary under the United Nations Framework Convention on Climate Change (UNFCCC). However, in recognition that achieving net zero will not be possible without making the defence energy transition – and in anticipation of the military exception potentially ending – a growing number of countries are bringing their defence sectors under national mitigation commitments. At present, military emissions account for anywhere from 1–5.5% of global emissions, although data remains opaque.[2] This proportion may increase as other sectors reduce emissions of both carbon dioxide and other greenhouse gases, which could increase pressure for defence to meet net-zero CO_2e.

The challenge for military planners and decision-makers is to make progress on net zero and seize the opportunities it presents without compromising capabilities. Getting militaries to emissions levels consistent with net zero is a major technical challenge, as air and naval platforms account for around 90% of operational emissions and over half of total defence emissions.[3] While armed forces can make some efficiency savings through engine or body design, lower-emissions fuels and propulsion technologies are required to bend the emissions curve. These technologies are still under development, and their cost and delivery timelines remain uncertain. Military platforms are in service for decades, particularly naval platforms, meaning that lower-emissions technologies are needed in the near term to achieve net-zero targets by 2050. States are making commitments to defence net-zero CO_2e before the technologies are mature, and there are inherent uncertainties around the delivery of these significant change programmes.

There is a range of thinking and practice informing the navigation of this agenda's potential or perceived trade-offs and drawbacks. Defence energy independence offers opportunities to escape some of the inherent challenges of fossil-fuel logistics for military operations, reducing dependence on energy suppliers with unstable or fluctuating political situations and supply lines exposed to disruption. The promise of escaping fossil-fuel dependency might open military actors to other supply vulnerabilities, including critical minerals. There is also a balance to strike in timing the transition to push the boundaries of what is possible in decarbonising major platforms, while avoiding becoming overly reliant on unproven technologies, and also avoiding exposure from continuing dependence on diesel, kerosene and gas in a global energy system trading progressively less in fossil fuels. All defence decarbonisation strategies emphasise that they will use available energy sources to assure the mission; mitigation is secondary to energy resilience and independence.

Defence faces an additional set of challenges related to the changing ways of conducting warfare and an evolving strategic environment. The digital revolution is setting the stage for more hybrid warfare and the increasing prominence of robotic and autonomous systems, accompanied by a corresponding set of technological challenges and developments. Militaries envision a future with expeditionary forces freed from fossil-fuel supply chains, with states increasingly deploying uninhabited systems and drawing on a wide range of new energy sources. Many countries committing to defence net zero are also increasingly focused on operating in contested logistics environments, such as the Asia-Pacific, and seek to develop the technologies needed in those scenarios, including lighter, more agile, dispersed and less-detectable capabilities with greater mobility and reach. It will take time to develop and transition to these technologies, and capabilities transformations will have their own strategic implications.[4] The technical shifts of defence decarbonisation could also reinforce strategic relationships, as allies train and exercise using new equipment and operating concepts, potentially along more polarised spheres of influence. In a fractured geostrategic landscape with increased grey-zone conflict and threats from non-state actors, next-generation capabilities could reshape the security environment. These are among the complexities defence is navigating in making this transition.

This paper compares radical decarbonisation plans from countries that have committed to achieving net zero across the defence enterprise or have set steep emissions-reduction goals for parts of their military as a contribution to national net-zero goals. It compares thinking from different national actors on how to solve the technical challenges of meeting net zero while operating in a changed global strategic environment shaped by climate impacts and their direct and indirect impacts on military operations.

The main objective of this study is to draw out useful elements of best practice. It compares countries' approaches, the contours of their policies, how they are prioritising and sequencing the types of investments they are making, and the institutional infrastructure created for delivering this agenda. The aim is to summarise the approaches rather than provide an exhaustive list of the investments being made or actions taken to date. For further discussion of lower-emissions technologies, see the IISS Research Paper 'Green Defence: The Defence and Military Implications of Climate Change for Europe'.[5] This paper concludes by defining the current state of play on this agenda and identifying some priority areas for further research.

2. Similar Contours Across Decarbonisation Plans

As countries are starting to engage with the challenge of decarbonising their militaries and achieving defence energy independence, similarities in approach are emerging. Global leaders on this issue are setting out ambitious policies – supporting implementation by resourcing new institutional infrastructure and engaging in outreach to allies and peers – while recognising that although many of the changes required to decarbonise defence will be technological, success will be underpinned by institutional advances in knowledge, culture and behaviour.

Phase One: Efficiencies and Available Technologies

Most countries are adopting a phased approach, implementing more straightforward measures for reducing emissions first, while establishing programmes to develop new technologies and capabilities that aim to enable steep reductions after 2030. Early efforts often focus on reducing emissions through energy efficiency, both in equipment design and in the built environment. Buildings can be retrofitted, redesigned or used more efficiently, while design and materials for operating platforms can focus on increasing efficiency – making vehicles more hydrodynamic or aerodynamic – or changes to equipment software or behaviour that reduce fuel consumption. New technologies enable training in simulated environments – offering the possibility of cutting platform emissions – and may provide new ways to collaborate remotely with allies.[6] Adopting these training methods could help efforts to build an all-domain force able to conduct combined-arms warfare with less distinguishing between the services (or between allied forces).

Militaries are pressing ahead with the electrification of their non-tactical vehicle fleet. (The electrification of tactical vehicles faces deeper challenges related to energy storage in batteries and electricity generation and charging in the field, which is under development but will take longer to deliver.) They are procuring greener energy, taking advantage of higher levels of renewable energy available on the grid and using microgrids and other distributed systems to bring energy generation 'inside the fence' at installations, which can offer greater resilience to outages and reduce dependency on local power grids. Military estates are potential sites for building offsets to address 'residual' greenhouse-gas emissions arising from defence energy use that may prove difficult to eliminate entirely. Such offset measures include carbon sequestration and siting renewable generation, including wind, solar and wave, on the estate to contribute green energy to electricity grids. These carbon sinks are also multi-beneficial for biodiversity through ecosystem restoration, adaptation and other sustainability goals.

Such changes are being made in the near-term as they are relatively affordable and relatively easy to achieve. In part, this is due to the existence of civilian technologies that can be used or adapted in military contexts, ongoing national climate-resilience and energy-transition programmes that benefit military installations, and the greening of other industries on which defence relies, such as construction and steelmaking. Other technologies, such as additive manufacturing, or circular economy practices can shorten supply chains and use resources more efficiently, including in theatre. By reducing energy costs and increasing resilience, improving efficiency may also have a clear financial benefit; this aspect may also assist with uptake.

Fuels: The Core Technical Challenge

Beyond the near term, militaries (like the rest of government and society) are counting on technological breakthroughs and innovation to achieve very rapid reductions in emissions in the 2030s and thereafter. For many militaries, the bulk of emissions comes from aviation fuel, with fuel and propulsion for long-lasting naval platforms also a major issue.[7] For larger militaries with expeditionary capabilities, the emissions balance is around one-quarter infrastructure, three-quarters mobility. (For the US, the balance is around one-third infrastructure and two-thirds mobility, reflecting a larger global installations footprint.[8]) Achieving net-zero transport and mobility will require significant investment in research and development (R&D), with uncertainties over when low-carbon alternatives may become available and their cost.

Alternative liquid fuel technologies are energy-intensive in terms of production and consumption, so militaries are exploring ways to catalyse innovation with the civilian sector. A leading example is the UK Ministry of Defence and Royal Air Force (RAF) working closely with industry through the Defence Suppliers Forum Climate Change and Sustainability Aviation Group to jointly develop and implement the UK's Defence Aviation Net Zero Strategy, balance ambition with realism about the technical hurdles, and address these hurdles through an accompanying Defence Aviation Net Zero Charter, which commits industry and academic partners to sharing best practices and reducing barriers.[9]

As well as benefitting from potential advances in civilian technology, military needs may drive R&D that develops technologies of use in the civilian market. However, some on the civilian side may be overly optimistic about what defence research institutions and industry will be able to produce. More likely, close cooperation between defence and other government departments, such as those responsible for energy and transport, may yield results; a portable nuclear reactor that is currently being prototyped is one example of the United States' productive inter-agency approach to technology development.[10]

Adaptation: Industry Relationships

Across countries and alliances, the defence energy transition is creating new forms of collaboration between the military and industry because some of the technologies defence seeks to adopt are at a more advanced stage of development in the civilian market and green-technology innovation ecosystem. For example, the US Army has approached the commercial sector to scope how the military can use and charge electric vehicles (EVs) in remote locations, as it is considerably further ahead in addressing the challenges and opportunities of EVs and EV infrastructure.[11] This process marks a significant change from traditional procurement models. Such engagement can be mutually beneficial for industry and the military if it helps catalyse the development and roll-out of more robust technologies for the energy transition by engaging industry to meet technically challenging defence requirements. (In the EV case, these challenges are rapid charging, transportable power and flexible infrastructure.)

Although the energy transition brings major energy users on the defence and civilian sides closer together, technologies developed for the civilian market may not meet the demands of military missions. As France's Defence Energy Strategy notes, civilian technology may not be suitable for defence needs if, for example, it cannot provide the high-power generation and storage requirements for directed-energy weapons, or adequate energy density for weapons such as missiles or torpedoes.[12] It would also be unsuitable if it created liabilities in a military context, such as through the use of lithium-ion batteries (which can catch fire or explode in ballistic environments) in hybrid or fully electric tactical vehicles. However, incorporating civilian technology developments may help to avoid the vulnerabilities associated with having to maintain unique technologies for the military and prevent a scenario where defence energy infrastructure is left behind by the faster-transitioning civilian space; therefore, militaries (including France's) are aiming to minimise the gap between civilian and military technologies.[13]

Balancing the Revolution

Defence leaders and planners are balancing current and future capability needs, anticipating emerging technologies and breakthroughs (and developing planning to incorporate them), and designing platforms for spiralling in new technology through mid-life upgrades. It is a complex exercise in managing uncertain technological advancement on a grand scale. Decisions about how to balance phasing in new acquisitions and shift away from sustaining fossil-fuelled systems have inherent tensions. For example, while more efficient technologies may come on the market, their high cost may mean governments can afford fewer platforms. This context may result in governments deciding on more modest mid-life upgrades for current platforms, which may help to power newer energy-intensive technologies on board, if not deliver significant overall efficiency savings. Planners will likely need to make many of these decisions while still working to develop more efficient technologies for next-generation platforms.

While there are many broad similarities between different militaries' approaches to the net-zero agenda, each state's strategy is unique and shaped by the size and scope of its military and missions, its role in alliance commitments, installation footprint, international obligations or orientation, defence-industrial base, domestic commitment to decarbonising, domestic sectoral breakdown of the decarbonisation burden, amount of political capital devoted to climate issues in general, pressure on defence, national (or multinational in the case of the EU) climate policy, and other factors. Momentum on this issue is also a product of political and climate leadership – the UK is pursuing a post-Brexit vision of 'Global Britain', the Biden administration in the US is making as much 'irreversible' progress as possible on climate while the political context is favourable, and France is continuing to lead on climate post-Paris Agreement. These major arms exporters also recognise the domestic industrial opportunities this agenda may unlock. So do countries with a tradition of exporting green-technology innovation, like the Netherlands. Economic and geo-economic positioning, domestic and alliance politics, and security demands in a changing geostrategic and physical climate will continue to shape the course of this overhaul of defence energy systems and capabilities in the next two decades.

3. National Approaches Shaped by Defence Prioritisation and Climate Momentum

The analysis below covers defence net-zero and climate-change strategies, other policies and plans, engagement with industry, institutional infrastructure for delivery, international engagement and network-building, and other notable aspects of national approaches in this area. It is not exhaustive in listing areas of investment but points to some projects that may be indicative of the types of investments being made. It does not necessarily evaluate the likelihood of success of these strategies, in part because sustaining the effort depends on variables that are unknowable over the coming decades, such as maintaining political will and dedicating funding, or competing military demands. However, the analysis does point towards some strong points or respective merits, as well as potential challenges ahead. The range of countries reviewed ensures a mix of those with larger and smaller militaries; they are organised alphabetically by region.

France

- National target: Net-zero CO_2e 2050 (EU target)
- Defence target: 50% reduction CO_2e by 2030, supporting government net-zero CO_2e targets
- Key defence-specific policies: Climate and Defence Strategy (2022), Defence Energy Strategy (2020), Defence Innovation Guidance Document (2020–2022)[14]

France's commitment to defence decarbonisation sits alongside its international leadership on climate change, particularly since enabling the Paris Agreement at the 2015 UN Climate Change Conference (COP21). Just prior to that meeting, the French ministry of defence (hereafter, MoD) organised a conference for defence leaders to bolster the security argument and bring urgency to the climate negotiations. The French have since been advancing the policy and implementation discussion domestically and internationally in a variety of forums. France has also integrated the security dimensions of climate change into its defence thinking, not least because of its involvement in areas where the nexus is evident, such as operations *Serval* and *Barkhane* to counter violent extremist organisations in the Sahel. Through these operations, France has developed a practical understanding of how climate acts as a driver of instability. Moreover, its experience of conducting military operations in extreme heat and aridity has exposed the challenges extreme climates pose for defence equipment and personnel, and highlighted the advantages of greater self-sufficiency in the operations of forward-operating bases and other assets.

On policy, France's 2022 Climate and Defence Strategy and 2020 Defence Energy Strategy stress the need for a rapid energy transition and a transformed approach to energy, with the aim of making the transition a point of operational advantage. These strategies move towards treating energy as a capability. Energy was newly integrated as a cross-cutting theme in the 2020 Defence Innovation Guidance Document and has continued to be treated in this way.[15]

To decarbonise major emissions sources, France has adopted an 'eco-design approach' for weapons systems, designing adaptable systems that can incorporate lower-carbon technologies as they become available. For example, the armoured fighting vehicles *Griffon* and *Serval* run on conventional fossil fuels but can be converted to hybrid, based on an assessment of the optimal balance between the new technologies' cost and their performance in the field.[16] Where alternative technologies are not yet mature, France has incorporated energy efficiency and optimised energy consumption from the design phase to reduce fossil-fuel use across architecture, propulsion, electricity generation and combat systems, with the aim of reducing emissions and powering the growing need for embedded electricity. This thinking stresses the importance of considering energy across the equipment life cycle, including potentially recycling critical minerals from defence equipment to reduce strategic vulnerabilities associated with dependencies on China.[17]

For alternative liquid fuels – including 'drop-in' fuels that can be used interchangeably without engine or fuel-distribution modification in naval, air and land platforms – France is preparing for future supply to be more accessible and affordable. It is relying on NATO to set standards in this area as part of processes underway to update the Alliance's common fuels policy. France does not judge hydrogen to be mature enough for mobility applications given the logistics difficulties related to storage, transportation and distribution, as well as energy-intensive production processes that are currently impractical in the field and may not be carbon-neutral. However, experimentation is underway on hydrogen power sources for other military applications, for example the FÉLIN future infantry combat system for non-mounted soldiers, which would use a hydrogen cartridge and fuel cell to recharge a battery and significantly reduce weight compared to carrying lithium-ion batteries.[18] The French army is also experimenting with an energy-independent installation on the Glorioso Islands, where it has installed a Smart Autonomous Green Energy Station (SAGES) solar power plant and a hybrid battery/hydrogen-storage facility to replace diesel generators.[19]

France is catalysing the transition through research partnerships for innovation. For example, the National Research Agency and the Defence Innovation Agency's 2023 call for projects on energy focuses on linking with industry and accelerating research work on energy storage in extreme environments and energetic materials.[20] Projects include the Air Force Academy Research Centre partnering with the government-funded Innovation Laboratory for Innovation in New Energy Technologies and Nanomaterials (LITEN) to develop a hydrogen drone, which is seen as an opportunity to advance French research and industry positioning on developing all-weather remotely piloted aircraft systems whose technology could be more widely used beyond defence.[21] The Defence Innovation Agency has also established a one-stop shop to facilitate easier access, particularly for start-ups and small- and medium-sized enterprises, so that it can better capture open innovation.[22]

France's focus on research partnerships and defence innovation aligns with an overarching national investment strategy – 'France 2030' – that aims to place the country at the forefront of innovation, including around decarbonisation. Paris plans to allocate 50% of the €54 billion budget to emerging players and 50% to decarbonisation, including projects around hydrogen, renewables, electric and hybrid vehicles and low-carbon aircraft.[23] As a leader in defence-technology exports, France's successful implementation of dual-use innovations for the defence energy transition could be influential.

In terms of institutional infrastructure to implement the broader defence climate strategy, the MoD has established a climate and defence committee chaired by the vice-chief of the defence staff, who is designated as the MoD's point person on climate and supported by a senior adviser for climate. To coordinate action within the ministry, the permanent secretariat on climate is establishing thematic workshops to detail ways to implement the next phase of the climate and defence plan. One workshop focuses on understanding climate impacts on military capabilities, which will help define future requirements and innovation needs; another is on international cooperation in the context of the increasing attention the defence energy transition is receiving within NATO, the EU and other multilateral bodies, as well as the need to engage with countries new to climate and defence or defence decarbonisation.[24]

The MoD has restructured governance of the different parts of the defence enterprise that deal with energy – including installation energy, oil supply and armament programmes – to streamline various aspects of defence energy needs and incorporate a focus on decarbonisation.[25] The MoD engages with the civil and energy sectors, including around issues of energy supply for defence and critical national energy-infrastructure resilience, as part of a cross-government approach.

The MoD is supported by a specialist research institution established by the Directorate General for International Relations and Strategy in 2016: the Observatory for Climate Change Impacts on Defence and Security at the Institute for International and Strategic Affairs (IRIS) think tank. The observatory focuses on risk mapping, analysis and anticipation.[26] The French government's approach to the issue prioritises foresight and anticipation; the MoD is using innovative methods to explore climate and security futures and emphasising improving foresight capabilities. One inventive means of promoting new ways of thinking is the Defence Innovation Agency's recruitment of science fiction writers to work alongside military personnel and scientists to develop scenarios as part of a 'Red Team'. This team has produced the 'Ecosystemic Warfare' and 'Carbonic Night' scenarios, which explore potential futures affected by climate change and security dynamics, complete with graphic-novel-style illustrations to communicate these narratives more widely.[27]

On the international stage, the French are spearheading a 'Climate Change and Armed Forces' initiative through the Paris Peace Forum, which includes 26 states from Europe, North America, the Asia-Pacific and Africa that have agreed a joint ministerial declaration and roadmap focused on anticipating risks, adapting their armed forces, reducing the environmental footprint of defence institutions, and international cooperation.[28] They have also worked to advance the climate security and defence discussion in multilateral forums, such as the South Pacific Defence Ministers' Meeting, Indian Ocean Commission and Indian Ocean Naval Symposium, and the 5+5 Defence initiative for the Western Mediterranean, among others, engaging with countries including Australia, India and New Zealand on climate risk management in the Asia-Pacific.[29]

There is considerable energy behind the defence energy transition in France. Even the most enthusiastic decarbonisers retain a focus on the primary consideration of maintaining secure access to energy, whether fossil or non-fossil, and the goal of decarbonisation exists alongside a clear commitment to military performance standards.

Netherlands

- National target: Net-zero CO_2e 2050 (EU target)
- Defence target: 20% reduction in defence fossil-fuel consumption by 2030, from 2010 levels; 70% reduction by 2050. Camps self-sufficient in energy by 2050
- Key defence-specific policies: Defence Energy and Environment Strategy 2019–2022 (2019), Defence Energy Transition Plan of Action (2021), Sustainability Implementation Agenda (2023)[30]

While the Netherlands' military has not set a net-zero target, the country is subject to EU law on net zero 2050, and the armed forces' approach to the transition provides examples of good practice. The Netherlands is approaching defence decarbonisation by focusing on partnerships, leveraging work across government bodies, and building new relationships to conduct studies and pilot projects on lower-emissions technologies that could be applicable for both defence and civilian use. Notably, the country has unique experience in climate-resilience technologies, and its private sector has a track record of exporting these technologies and knowledge, for example on building sea walls and flood management.

The country's overall aim is to maximise effect while operating within its financial and capacity constraints. Dutch military emissions are split 60/40 between real estate and fuels. Like most militaries, aviation fuel is a major source of emissions, so fuels are an area of particular focus.[31] The Netherlands MoD is conducting trials using drop-in biofuels for air, maritime and land use, aiming for a 30% blend across domains. The air force has new targets for integrating alternative fuels; military aircraft aim to use a 20% blend by 2030, rising to 70% by 2050.[32] A 12MW solar photovoltaic (PV) installation at Leeuwarden airbase will produce green hydrogen and synthetic kerosene for transport (using electrolysers) around 2030 and 2035, respectively.[33]

The Netherlands is also taking an efficient approach to replacing naval support vessels; ten will be replaced by eight multi-functional vessels with dual-fuel systems that will run on methanol (green or grey, depending on availability) or diesel. These ships will be built with one contract by a Netherlands shipyard, which also includes maintenance. Some current vessels will be replaced before the end of their service life. This 'all at once' approach is more efficient and helps to build the Dutch industrial base for these technologies.[34] Other projects include an energy-management and electric propulsion system for a new Combat Support Ship that will be delivered in June 2024.[35]

Defence is working with the 'golden triangle' of industry and knowledge institutes to strengthen its standing in new energy technologies. There is a strong focus on partnerships for innovation – to develop new nodes of collaboration, use existing capacities and initiatives to assist with defence decarbonisation, and allow the military to act as a proving ground for new technologies that showcase Dutch innovation. For example, the military is learning from and drawing on advances in the construction industry – which is working to become more environmentally sustainable – where there are relevant applications for installation emissions reductions. The military collaborates with the Netherlands Organisation for Applied Scientific Research, through which it can borrow and trial technologies like solar panels, and has its own Smart Base Field Lab for exploring energy generation and storage.[36] It is also working with a grouping of academic and government departments, as well as the Netherlands Defence Academy, to conduct a project to trial a hydrogen-powered drone for maritime surveillance.[37] A range of projects focus on defence mobility – particularly around biofuels, energy-independent camps, and the usual efficiencies in the built environment and siting renewables on defence properties – while a further implementation plan for materiel, innovation and real-estate sustainability is under development.[38]

United Kingdom

- National target: Net-zero CO_2e 2050
- Defence target: Net-zero CO_2e 2050; Royal Air Force (RAF) net-zero CO_2e 2040
- Key defence-specific policies: Ministry of Defence Climate Change and Sustainability Strategic Approach (2021), Defence Aviation Net Zero Strategy (2023), Defence Equipment & Support Environmental Strategy (2021), Sustainable Support Strategy (2022)[39]

The UK has taken a leadership position on reaching defence net zero. It has been at the forefront of efforts to integrate this issue across the defence enterprise and overcome issues of institutional inertia. It conducted the first thorough policy exploration of how defence net zero could be achieved.[40] This activity builds on a history of cross-party support for climate action coded into UK law, dating back to the near-unanimous passage of the Climate Change Act in 2008. The act's target of an 80% reduction in greenhouse gas (GHG) emissions by 2050 was strengthened by the government in 2019 – to net zero by 2050. The UK military's target is net-zero CO_2e by 2050 (2040 for the RAF), aligning the MoD with the UK's legally binding national commitments.

Like many militaries' decarbonisation frameworks, the MoD's plan takes a three-phase approach out to 2050. Its initial focus is implementing available technologies and laying the foundations for future action, followed by harnessing emerging and available technologies to steeply reduce emissions in the critical 2025–40 time frame, before rapidly incorporating new technologies to achieve net zero towards mid-century.

The UK is actively engaging industry to accelerate the transition; a key component of the RAF's net-zero strategy is working through the Defence Suppliers Forum Climate Change and Sustainability Aviation Group to send a clear signal on lower-emissions fuels and technologies.[41]

Notable MoD investments in decarbonisation include Programme Mercury, the British Army's effort to accelerate innovation in electrification with a view to using hybrid technologies as a bridge to fully electric tactical vehicles.[42] The UK is committing funding for green-technology exploration for propulsion in the maritime sector, both for developing and retrofitting Royal Navy ships.[43] It may take longer for the winning technologies for naval fuel and propulsion to emerge than for other domains. There are plans to implement low-carbon technologies developed by the Clean Maritime Demonstration Competition on civilian and military ships, including hydrogen and ammonia fuel and electric propulsion.[44]

For aircraft, the RAF has approved using a 50/50 mix of sustainable aviation fuel (SAF) blends. It has conducted various trials – all the first of their kind – involving aircraft powered by SAF, including a military transporter flight with a *Voyager* using 100% SAF; an ultralight powered by synthetic aviation fuel; and an air-to-air refuelling of a *Typhoon* fighter jet and C-130 *Hercules* tactical transport aircraft, using a 50/50 mix.[45] However, as with other aviation users, SAF supply bottlenecks limit their use. With no clear way over the supply hurdle, the UK is working closely with industry and academic partners through the Defence Suppliers Forum Climate Change and Sustainability Aviation Group and its Defence Aviation Net Zero Charter.[46] Moreover, the UK is leveraging international partnerships to address the challenge, including through co-chairing with the US the Global Air Forces Climate Change Collaboration, a forum of 41 national air forces established to exchange information and best practices on decarbonisation.[47]

To deliver the defence energy transition, a MoD directorate is building institutional infrastructure across the enterprise, with a mandate to produce guidance, agitate for change and oversee progress. Each service has its own approach to the issue, with different ownership or governance arrangements. The MoD is creating mechanisms for top-down direction and connection points for communication between services and departments. The aim is to coordinate multiple nodes of activity and resource them to deliver systemic change across defence to an ambitious time frame.

The 2021 Climate Change and Sustainability Strategic Approach and the service strategies recognise that cultural and behavioural change will be necessary to ensure the system change required to quickly transition the military's energy systems. The MoD has focused on facilitating internal communication, increasing climate literacy – including climate-security literacy – among senior and junior staff and building up a community of interest. Less-formal structures, like the Defence Green Network, a community-of-practice platform for UK defence, allow the internal exchange of best practices and other information and enable problem-solving through more direct communication across UK defence. These structures also help to harness and amplify the internal momentum for delivering this agenda and propose ways forward to leadership.

The UK has exercised its diplomatic and political influence in advancing international discussions around decarbonising defence, just as it has in raising awareness of climate security internationally over the past 15 years. UK defence is working to convene internationally on this issue, including through the Global Air Forces Climate Change Collaboration. These bilateral and multilateral partnerships between services are important channels for exchanging information and catalysing technological breakthroughs.

Canada

- National target: 40% CO_2e reduction below 2005 levels by 2030; net-zero CO_2e 2050
- Defence target: 40% below CO_2e 2005 levels by 2025 (infrastructure and light-duty fleet), net-zero CO_2e by 2050
- Key defence-specific policies: Defence Energy and Environment Strategy (2017, 2020), Greening Government Strategy (2017)[48]

Canada's Defence Energy and Environment Strategy sits within an overarching federal framework that supports whole-of-government approaches to emissions reductions and sustainable development. Further work by the services is forthcoming; the Royal Canadian Air Force's (RCAF) Path to Net Zero Strategy is expected to be released at the end of 2023.

Progress is underway on greening infrastructure and electrifying the non-tactical vehicle fleet, while the RCAF is supporting the government strategy on securing SAF, which has included creating a competition for domestic SAF production.[49] The RCAF has not yet trialled alternative fuels; the Defence Energy and Environment Strategy indicates a desire to wait for them to meet NATO standards and become affordable and available, although the RCAF is preparing for this eventuality by modernising aviation-fuel tracking systems. The navy is using lower-emitting fuels and integrating energy efficiency into procurement requirements, including for its future Canadian Surface Combatant ships – the main component of Canada's future maritime combat power. It will procure 15 of these vessels beginning in 2023/24.

Canada's geography, strategic interests and future defence needs have given rise to some unique areas of investigation. The country's Advanced Microgrids towards Arctic Zero Emissions (AMAZE) project seeks to increase the energy independence of remote installations, including those in the High North, through innovation. Arctic installations consume large amounts of energy to generate heat and electricity; the transportation of fuel to an installation by heavy lift aircraft accounts for seven-eighths of the fuel's cost and associated emissions. AMAZE's integrated-systems approach is developing advanced hybrid microgrid systems incorporating variable-speed generators, renewables generation, energy storage and thermal-energy recapturing for heating air and water, and new controls technology.[50] Canada is also exploring hydrogen and ruggedised wind turbines for use in the north.[51] By reducing energy dependence, microgrids or other alternative energy sources could help expand the Canadian military's Arctic presence, which is currently sparse compared to the potential future security demands (both military and constabulary) in the region. They might also be useful for Nordic and US military installations in the

High North, as well as other remote northern communities, some of which support technologies that have dual uses, such as scientific monitoring of the changing climate as well as broader domain awareness across northern Canada.

Other exploratory projects include feasibility assessments of hybrid and all-electric technologies for navy ships, as well as a project to explore using machine learning and a ship energy digital twin to cut ships' fuel use, using data analytics for ship power and energy data to optimise efficiency. Canada's Greening Government Fund is supporting feasibility studies for hybrid-electric and hydrogen-electric propulsion of the air-force fleet, as well as for civilian use by Transport Canada.[52] The Camp Sustain project is exploring efficient deployable camp infrastructure, supported by a 'Pop-Up City' contest for innovation in integrated energy, water and waste systems run through the Department of National Defence's Innovation for Defence Excellence and Security (IDEaS) programme.[53] Non-mounted soldier systems' power management and efficiency is another area of focus.

Canada's integrated cross-government approach to decarbonisation makes defence reliant on other government programmes to meet emissions-reductions targets, for example in the process of sourcing renewable energy, which involves the Treasury and other government procurement bodies.[54] Holistic approaches like this can cut both ways and increase or decrease efficiency and effectiveness. A government progress report highlights the continued need to resource this agenda, noting that affordability and market availability of the required technologies are limited and that '[w]ith no new funding, greening is competing for the same funds as program delivery'.[55]

Like other countries, Canada's strategy depends on successfully sourcing SAF in the future and developing technologies that reduce emissions from naval vessels. Until these challenges are addressed, Canada is pursuing decarbonisation through traditional routes, including greening infrastructure, procuring clean energy and testing hydrogen vehicles. One budget-efficient approach is the widespread use of competitions to develop new technologies like deployable camp infrastructure or SAF.

Canada's strategy does not discuss developing offset projects to assist with emissions reductions, although its landmass may provide more opportunities to invest in permanent land-use change that would make forms of offsetting like biosequestration credible. At present, there is no dedicated budget for this work; as Canada consistently has not achieved the NATO commitment to spend 2% of GDP on defence, the government may struggle to allocate funds for the defence energy transition, especially if drawing from standard maintenance and upgrading budgets.

United States

- National target: Net-zero 2050 CO_2e (by Executive Order)
- Defence target: Net-zero 2050 CO_2e consistent with national target (US Air Force and US Space Force: net-zero installations by 2046)
- Key defence-specific policies: Department of Defense (DoD) Climate Risk Analysis (2021), DoD Climate Adaptation Plan (2021), US Army Climate Strategy (2022), Army Climate Strategy Implementation Plan (2022), Department of the Navy Climate Action 2030 (2022), Department of the Air Force Climate Action Plan (2022)[56]

The DoD has an overarching climate strategy that is complemented by service strategies and an implementation plan prepared by the army. These documents outline plans to deliver the government target of net zero by 2050. The strategies are a continuation of the military's sustained focus – evident since at least 2004 – on climate risk management and energy efficiency. Its focus is owed in part to the United States' global installation footprint – and the physical vulnerabilities of these installations to climate impacts – as well as lessons learned regarding the drawbacks of transporting fuel in-theatre in Iraq and Afghanistan. These strategies state the primacy of the mission while recognising the multiple strategic and operational benefits of the defence energy transition in terms of endurance, cost and strategic advantage.

The US is developing capabilities for multi-domain operations in both the Asia-Pacific and Europe. One emphasis of US fleet modernisation is the development of lighter, more agile, dispersed and less-detectable capabilities with greater mobility and reach. The focus is on reducing logistics burdens in contested logistics environments, improving sustainment and developing the technologies needed in those scenarios.

Decarbonisation has a set of complex interactions and synergies with this agenda. For some time, US defence-technology research has focused on energy technologies that could reduce emissions. However, it has been driven primarily by concerns over effectiveness, with emissions reduction as a co-benefit. New policy direction is placing greater emphasis on the value of emissions reductions. There is potential in shifting the considerable resourcing of US R&D and procurement budgets to help drive technological advancement in this space.

The US military is pursuing a wide range of approaches. This list is not exhaustive but indicates some of the important programmes. On land, advances in electric and hybrid-electric vehicle technologies underpin the army's aim to field hybrid tactical vehicles by 2035 and fully electric tactical vehicles by 2050.[57] The DoD is working with industry and academia to develop new battery technologies that reduce critical-minerals dependencies and strengthen the defence-industrial base.[58] The US is developing next-generation combat vehicles, including a hydrogen-powered Optionally Manned Fighting Vehicle.[59] A tactical wheeled-vehicle strategy is expected by the end of 2023 that will guide future investments.[60]

Biofuels are another area of investment and testing, with US$210 million in Defense Production Act grants awarded in 2014 to biorefineries to scale military-specifications SAF production towards 10m gallons per year. However, production has not yet commenced and will likely be delayed until 2027 due to engineering and other challenges.[61]

In the air domain, the US is developing more efficient adaptive-cycle engines for its Next Generation Air Dominance fighter that could deliver 25% improvements in fuel efficiency, although it opted not to update F-35s with these types of engines due to cost.[62] This highlights a tension in the military's decarbonisation agenda, as the cost of newer energy-efficient technologies are weighed up against the quantity of older equipment in service, with a need to decide which is more important based on the foreseen needs over the time frame that the platform will be in service. Within four years the US will test blended-wing body tanker and cargo aircraft, whose aerodynamic design and more efficient engines could reduce emissions by 60%, a considerable saving given that most of the fuel used by the DoD is for these types of global air support flights.[63]

The US is also unique in the close working relationships between its departments of energy, defence, transport and others on developing new technologies applicable to the military. For example, the DoD and the Department of Energy (DoE) are prototyping a nuclear microreactor to create a portable nuclear power plant that uses air as a cooling media for the first time. These mobile nuclear plants would serve a function similar to naval combatants' nuclear reactors and could power installations or be a field-deployable asset replacing diesel generators (although being significantly more complex to operate and requiring more protection than diesel generators may diminish their utility in some settings). The military is fast-tracking regulation with the Nuclear Regulatory Commission to address the regulatory issues that arise when developing new types of technologies, and setting a range of requirements to work with industry through public–private partnerships. The US government and the DoD's goal is to ensure mutually beneficial projects that strengthen domestic innovation and industry; for the industry partners, building a single prototype for the DoD may not be particularly lucrative but the potential for replicating successful projects for the commercial sector is attractive.

The navy has numerous lines of research into alternative fuels and technologies, including exploring developing green hydrogen for fuelling platforms, and is funding research on a hybrid hydrogen vessel. US military research institutes are also exploring synthesising fuel in situ, including hydrogen, the transport of which is inefficient due to its bulk.[64] The navy has demonstrated a *Hybrid Tiger* solar- and hydrogen-powered uninhabited aerial vehicle (UAV) with considerably higher endurance and lower acoustic and thermal signatures than battery or fossil-fuelled UAVs.[65]

The US is complementing these efforts with a focus on logistics and sustainment, aiming to ensure that this aspect of the energy transition receives appropriate attention. For example, the army field-tested an autonomous electrical vehicle to deliver energy or spare parts in the field, supporting sustainment.

The US is also developing systems and infrastructure to network power use, generation and distribution, including more tools to provide more mobile and flexible power generation and conversion, with systems combining microgrids, generators and energy storage with the aim of enabling vehicles to integrate into tactical microgrids with vehicle-to-grid generating. Microgrids are intended to be more sustainable and resilient to disruption from disaster or adversaries. All branches of the US military have targets for installing microgrids and are conducting exercises to test new energy systems, including 'black start' planned-power-outage and backup-system exercises, to understand their operational implications and vulnerabilities.

The US has begun to use a 'cohort model' to partner with groups of companies to overcome technical challenges and develop commercial technologies for defence applications. An example is the Power Transfer Cohort working on electric-vehicle infrastructure.[66] This non-traditional partnership model enables smaller companies to scale up innovation, with the US military as a customer.[67] The US continues to be focused on using military research institutions to advance technologies that could enable greater step-changes in energy use and military technology. For instance, the DoD is leading on developing laser-power-beaming technology, which transmits energy point-to-point using electromagnetic waves and could enable beaming solar power from space. The Naval Research Laboratory launched the Space Wireless Energy Laser Link (SWELL) to the International Space Station in March 2023 to test power beaming in space.[68]

The recent push to advance the decarbonisation agenda is part of broader US government efforts under the Biden administration, which has set the US government net-zero 2050 targets through Executive Order (EO) 14008 on Tackling the Climate Crisis at Home and Abroad, and EO 14057 on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability.[69] The drive to address the priorities of the executive orders is reflected in the DoD's US$3.1bn spend on climate in FY2023. Approximately two-thirds of this figure is focused on installation energy, resilience and adaptation, reflecting rapid uptake of existing technologies for decarbonisation in installation energy and the United States' large installation footprint.

The EOs established institutional infrastructure that facilitates engagement across government, with a climate security node at the National Security Council and a Climate Working Group at the DoD to coordinate efforts and track implementation. The latter is chaired by a chief sustainability officer and comprises under-secretaries of defense, chiefs of the military services, the chairman of the Joint Chiefs and others, with three-star-level and assistant-secretary representatives.[70] This setup is helping drive cooperation between defence and the DoE on pursuing breakthrough technologies for fuels and energy storage. The US military is also working with defence academic institutions, such as the Naval Postgraduate School's decarbonisation consortium, to study decarbonisation pathways and convening internal subject forums to increase climate-security literacy and build a community of practice across defence.

On the international stage, the US emphasises working with allies and partners to jointly decarbonise, increase interoperability and strengthen alliances and partnerships focused on making the energy transition together. The UK is a close partner and there is strong US–UK alignment on co-chairing the Global Air Force Climate Change Collaboration. The US is also sharing with allies a DoD Climate Assessment Tool for evaluating climate exposure at installations; recipients include Australia, Germany, Italy, Japan, South Korea and the UK. New technologies and future war-fighting concepts are being explored in events like Project Convergence, which aims to build collaboration between the joint forces and international partners by trailing innovative war-fighting capabilities. These events have been conducted with the UK and Australia, with New Zealand and Canada as observers.

The political and policy context is a critical enabler of this complex change process and there may be questions around the future trajectory of US action on defence decarbonisation. The Trump administration was hostile to strong emissions-reductions policies; given the potential for a future administration to deprioritise net zero 2050 or use the phasing out of fossil-fuelled military equipment as a symbolic political target, the current administration places a strong emphasis on building cross-government responses in a deep and comprehensive way while the policy environment is favourable. Nevertheless, the pace of change may vary in the future. EOs are straightforward to create but can also be rescinded by subsequent administrations. For example, the US became party to the 2015 Paris Agreement through executive action by then president Barack Obama; both its 2022 withdrawal and 2023 rejoining were the result of EOs issued by Donald Trump and Joe Biden respectively.

Australia

- National target: 43% CO_2e reduction over 2005 by 2030; net-zero CO_2e 2050
- Defence target: Same as national target
- Key defence-specific policies: Defence Environmental Strategy 2016–2036 (2016)[71]

Australia's defence mitigation targets are a 43% reduction by 2030 (against a 2005 baseline) and net zero by 2050. Defence appears to be on track to achieve the 2030 target. Among the ongoing projects, renewables (mainly PV) at Australian Defence Force (ADF) installations generated around 2.18 gigawatt hours in 2020–21. Moreover, in February 2023, the government committed AU$64m to fund the installation of another 60 megawatts of PV and 25 MW hours of battery storage at ten defence sites over the next seven years.[72] Half of these sites – and the largest projects – are in the Northern Territory. Addressing the ADF's energy- and capability-resilience needs there is assessed to be a high priority and integral for the future defence of the country, given the military's strategic focus on the Asia-Pacific.[73]

To progress towards the harder-to-decarbonise uses, Australia's Defence Renewable Energy and Energy Security Program is leading high-level feasibility assessments on a range of alternative energy technologies, including hydrogen, battery storage systems, micro-grids and alternative liquid fuels.[74] A Defence Future Energy Strategy is under development at the time of writing and expected to be released in 2023; this will address near-, medium- and long-term actions and detail a clear path to achieving net zero.[75] Australia's first National Defence Strategy will be released by 2025 and updated every two years; operational energy will be one of the core lines of effort. The Defence Fuel Transformation Program is also working to improve the fuel supply chain and modernise and standardise infrastructure, alongside which defence is analysing the potential for drop-in alternative fuels and other energy sources, which will be addressed in the forthcoming Future Energy Strategy.[76] Ensuring ADF platforms can operate on alternative fuel blends used by the US and other allies (in order to participate in joint exercises and operations) is another impetus for matching the pace of progress in this space.[77]

There is recognition of Australia's energy vulnerability and the impact this has on defence energy security, given its reliance on energy imports of liquid fuel for air and maritime platforms. As in all countries, defence consumes much less energy than the commercial sector – the air force uses around 6% of the total national aviation-turbine-fuel consumption, for example – so Australia's DoD emphasises partnering with industry to develop alternative fuels and energy-storage technologies for defence.[78] Such partnerships, including with major commercial aviation-fuel users on domestic SAF-production capacities, as well as other R&D, will need to be accelerated as part of a national strategy integrating defence and industrial decarbonisation in order to address the major emissions sources – fuel for naval and air platforms.[79] The ADF's Defence Innovation Hub is changing the procurement model by awarding around 21% of contracts to companies new to the sector.[80] On land, lower-emissions equipment prototypes developed thus far include an electric *Bushmaster* Protected Mobility Vehicle, and a *Boxer* combat reconnaissance vehicle fitted with detachable e-bikes.[81]

Australia is collecting data to establish an emissions baseline and work with, for example, integrated assessment models to enable decision support on pathways for emissions reductions. Across government, Australia is also building up climate and energy-transition specialists and staff with expertise in these areas, including in the services and Joint Operations Command.

The ADF has long recognised how climate change directly impacts operations and contributes to a more tense regional strategic environment. The April 2023 Defence Strategic Review Competition stressed the competition between humanitarian assistance and disaster relief (HADR) and the ADF's core remit; it suggested developing alternative civilian disaster-response capabilities to avoid distracting limited defence resources from focusing on regional security missions.[82] It mentioned the need for defence to focus on the clean energy transition and the opportunities for Australia in the overall energy transition. It did not, however, go into detail on how to achieve the procurement and force strengthening needed to deter or fight a conflict in the Asia-Pacific, particularly since many of the platforms needed to do this would be in service for decades beyond the 2050 net-zero target for defence. In other words, Australia is focusing on accelerating its force generation at a time when the technologies for defence decarbonisation are not yet mature. However, closer security cooperation with the US and UK is likely to foster collaboration on shared aims of defence decarbonisation – beyond the conventionally armed nuclear-powered submarines Australia is acquiring through the AUKUS agreement. In December 2022, the US and Australia agreed to share information and best practices on climate matters between their defence ministries and look at establishing a senior officials' working group on climate risk.[83]

Climate action remains politically controversial in Australia; its net-zero commitment was resisted strongly by the Liberal government (2013–22) and adopted by Labor in 2022. Although this commitment is enshrined in law, the national or defence commitment may be subject to reversal given the domestic political environment.

New Zealand

- National target: 50% CO_2e reduction from 2005 levels by 2030, and net-zero CO_2e 2050
- Defence target: Same as national target, exempting frontline and heavy military vehicles
- Key defence-specific policies: Emissions Reduction Plan (2022)[84]

New Zealand is a regional leader on climate and defence, advancing the discussion on understanding and mitigating risks through its innovative defence climate policies since 2019.[85] National mitigation goals are a 50% reduction from 2005 levels by 2030 and net zero by 2050. New Zealand has a Carbon Neutral Government Programme to achieve carbon neutrality by 2025 that sets standards for defence, although frontline and heavy military vehicles are exempt.[86] The New Zealand Defence Force (NZDF) has a target of 21% GHG reductions by 2024/25 and 42% by 2029/30, against the base year of 2016/17.[87] The NZDF's efforts focus on investigating fuels (including SAF), greener commercial travel and addressing emissions from its estate.

These mitigation targets factor into New Zealand's capabilities acquisition. For example, the new *Polar*-class sustainment vessel HMNZ Aotearoa is a first-of-its-kind naval 'Environship'. It has an efficient wave-piercing ledge bow design and a lower-emission combined diesel-electric and diesel propulsion plant that reduces nitrous oxide exhaust emissions (a long-lived GHG around 300 times as heat-trapping as carbon dioxide) as well as CO_2.[88]

The approach is driven by the relatively modest size of the NZDF, New Zealand's economy and the domestic innovators (or lack thereof) available for defence to partner with, including on SAF production. Partly due to its remoteness from larger-scale SAF producers, the NZDF is using the 'book and claim' system whereby defence purchases SAF credits, the producer supplies the purchased fuel to other aviation users, and the NZDF claims an emissions reduction from displacing fossil fuels. (The system works much in the way that purchasing renewables from a power company ensures a proportional amount of green electricity in the grid, rather than for the individual user.) It is a more sustainable alternative to transporting the SAF from production facilities to be used in NZDF aircraft, which would be both costly and energy-intensive.

The institutional arrangements include NZDF establishing a Climate Change Response Programme with a 'hub and spoke' approach led by Defence Strategy Management. Its relatively small team aims to stimulate thinking and action and empower units throughout the enterprise to deliver different components of the Emissions Reduction Plan.

New Zealand is trialling the adoption of a dynamic adaptive pathways planning (DAPP) approach to coastal risk management, including at Devonport Naval Base. This approach involves identifying ways forward in an environment of characterised by uncertainty around climate change and planning to respond flexibly to changing conditions as needed.

As a smaller state, there is a recognition that the whole country and economy will require coordinated action to transition to newer energy sources and need to work in partnership with other governments, industry and defence organisations to reduce defence emissions. The Emissions Reduction Plan explicitly focuses on what the NZDF can control while laying the groundwork for future uptake of emerging technologies. It is a 'living plan' that recognises implementation and transitional risks, reputational risks, financial and policy-regulation risk, and the risk of stranded assets as the energy transition unfolds.[89]

The NZDF views environmental sustainability as a way to maintain credibility and effectiveness as both a defence actor and a partner state in its neighbourhood. However, with the NZDF being a smaller force, there is tension between sustainability goals and the growing demand for operations, including HADR operations. This demand will continue to increase, given neighbour countries' climate vulnerabilities.

China

- National target: Net-zero CO_2 only by 2060
- Defence target: Unknown
- Key defence-specific policies: Unknown

There have been limited indications that the national net-zero carbon 2060 target might bind China's military, although the country's defence modernisation includes many technologies that are lower-emitting than conventional equipment. A June 2022 People's Liberation Army (PLA) statement that the military is 'developing and using new energy… to achieve the goal of peak carbon dioxide emissions and carbon neutrality' notes efforts to accelerate building a 'modern military energy support system' for new types of weapons and equipment over the 2021–25 period.[90] It emphasises a plan to strengthen field energy support and energy independence for forces stationed on remote islands or border posts. Microgrids incorporating wind, PV, hydropower and other renewables have been installed in some locations.

This focus on military energy security and support capacity accompanies and is contextualised by China's push towards future-warfare concepts and intelligentised warfare, including the development and use of more autonomous uninhabited aerial, surface and underwater systems for a range of capabilities. Chinese scientists have noted the potential for charging uninhabited underwater vehicles (UUVs) with dispersed wave-energy generation systems that would be difficult for an adversary to detect or eliminate.[91] In terms of other novel technologies, China is also leading the development of portable and wearable systems powered by the wearer's motion, body temperature and other processes.[92] China and the US are competing to lead the development of space-based solar power for civilian and military applications. China's domestic battery industry, including for electric-car manufacturing, will likely result in more advanced battery technologies with military applications. For example, incorporating lithium-ion batteries in conventional submarines could enable air-independent propulsion, potentially more than doubling their underwater endurance and increasing stealth by reducing their noise signature, including compared to the United States' nuclear submarines.[93] Given China's naval ambitions, developments in these technologies could be strategically significant in the South China Sea, Taiwan Strait and elsewhere.

However, the focus on new and novel technologies does not necessarily mean the PLA would field fewer fossil-fuelled conventional forces where they are strategically advantageous. China continues to stockpile conventional armaments and purchase fossil fuels from suppliers that are increasingly eschewed by Western countries, including Russia and Saudi Arabia (although it recognises the vulnerabilities of some of these supply lines). Nonetheless, China seems to have fully integrated the argument that new energy sources – as a component of military modernisation – bring strategic advantages, albeit without giving a strong indication in the public domain that it is moving away from also fielding conventionally powered forces. This minimal indication is consistent with China having stopped including climate change and climate security in its defence-policy documents since 2013, prior to which there had been an academic and policy discourse on these threats.[94] China's actions on market domination of critical-minerals supply chains and other renewable energy technologies speak to its recognition of the geostrategic and geoeconomic opportunities of the energy transition, which extends to the defence space. Not publicly committing to including defence in national net-zero targets also fits with China's UNFCCC negotiating positions on differentiated responsibilities for major emitters based on historic emissions.

India

- National target: Net zero (unspecified) 2070
- Defence target: None
- Key defence-specific policies: Indian Navy Environment Conservation Roadmap (2014)[95]

India has in general been averse to linking climate change and security, although the Indian Armed Forces' Joint Doctrine recognises climate change, ecosystem disruption and energy issues as non-traditional threats that can affect conflict, regional stability and the geostrategic environment[96] Nevertheless, the Indian military's consciousness of climate hazards is evident in, for example, the work of the Directorate of Land, Works, and Environment at Army Headquarters on climate resilience and risk mitigation, and assessments on coastal installations and the Siachen glacier near the India, Pakistan and Chinese borders. Climate-security discussions are reportedly increasing at the Headquarters Integrated Defence Staff, which facilitates tri-services integration and could join climate-security risk analysis with broader national efforts on climate adaptation.[97]

Although the Indian Armed Forces have not set a net-zero target, like many militaries, the services have several initiatives to promote sustainability and emissions reductions. The Defence Institute of Bio-Energy Research has trialled biodiesel blends in a range of vehicles, vessels and generators, while the Indian Navy is working with Indian Oil on sourcing less-polluting fuels.[98] The air force has trialled a biofuel-blend aircraft, and, in line with developments in the field, is developing lighter air munitions.[99]

Sustainability policies provide a framework for reducing emissions, particularly the Indian Navy Environment Conservation Roadmap, which includes a focus on energy diversification and efficiency. It commits 1.5% of the navy's works budget to renewables generation and created a Green Cell group in the navy's headquarters in 2016 to direct these initiatives.[100] They include the creation of a 'smart green naval base' at the navy's largest installation in Karwar, Karnataka, installing 24 MW of PV at naval facilities, increasing the use of non-tactical e-vehicles, and building carbon sinks through afforestation.[101]

The Indian military has also undertaken feasibility studies with the French defence and energy company DCNS on an ocean thermal-energy conversion plant to replace diesel generators for naval and air bases on the Andaman and Nicobar Islands. It has conducted a study with the Ministry of New and Renewable Energy on developing a wave-energy plant at Karwar.[102] Along the Line of Actual Control in Ladakh, there have been efforts to deploy weapons systems that are less dependent on diesel, given the difficulties of fuel logistics in the region.[103]

Despite these initiatives, the Indian government and security community generally avoid defining climate change as a security threat. An aversion to doing so may impede the military's broader institutionalisation of measures that would underpin a more substantial defence energy transition, given such a transition would require a high degree of coordination and investment.[104]

Japan

- National target: Net-zero CO_2e 2050
- Defence target: Contribute toward government net-zero 2050 goal; JMOD and JSDF 50% reduction from FY2013 level by FY2030, excluding defence equipment
- Key defence-specific policies: Ministry of Defense Response Strategy on Climate Change (2022)[105]

Climate change is a relatively new area of focus for the Japan Ministry of Defense (JMOD), although the security community has been concerned with energy security (including operational energy in future conflict or other contingency scenarios), opening liquefied natural gas (LNG) trade along the Northern Sea Route, and climate issues like HADR and sea-level rise affecting Japan's coast and submerging outlying territories. JMOD addressed climate explicitly in policy for the first time in the 2021 Defense of Japan white paper.[106] It established a Climate Change Task Force in May 2021 comprised of senior defence officials, which developed a Response Strategy on Climate Change that was published in August 2022.[107] JMOD's recent attention is driven in part by growing cross-governmental coordination led by the ministries who have typically dealt with climate and energy; this joint approach is also evident in how these are integrated into the National Security Strategy 2022.[108]

The Response Strategy on Climate Change acknowledges the risks of fossil-fuel dependence and the need for transition to alternatives. It states a goal to achieve carbon neutrality by 2050 but takes a measured tone on how Japan will approach decarbonisation. Although it acknowledges the long procurement timelines and lifespans of defence equipment, which in practical terms means that new technologies need to be implemented in the next several years, it states that JMOD 'will strategically and steadily promote new initiatives with an eye to the future and with an awareness of timeline, including issues such as how to respond from a long-term perspective… and whether measures need to be implemented now'.[109] For JMOD and the Japan Self-Defense Forces (JSDF), Japan has set an emissions-reduction target of 50% of the FY2013 level by FY2030. This target specifically excludes defence equipment; 2013 is also a high-emissions year to use as a baseline, since at that time fossil fuels were replacing nuclear power plants that had been taken offline following the 2011 Tōhoku earthquake.

Japan's current approach appears to reinforce the need to secure the 'stable and sufficient quantities' of conventional fuels necessary for defence while at the same time acknowledging its vulnerabilities and the need to transition eventually.[110] The Response Strategy on Climate Change emphasises the domestic innovation underway and acknowledges public–private R&D and innovation efforts in Japan around the energy transition. The strategy mentions hydrogen and ammonia – two areas of technology in which Japan has shown leadership, in terms of exploration and development – and sets a target to research, develop, manufacture and procure alternative fuels in Japan, including for military use.

Specific projects include a collaboration with the US on researching a Modular High Power Density Hybrid Propulsion system (a hybrid system driven by both engine and electric motors) for wheeled vehicles.[111] Closer collaboration with the US is likely to yield further integration of alternative energies in Japan's defence energy mix. And from the United States' perspective, increasing its allies' capacities and defence energy diversification – and supporting their energy transition – are strategic interests, not least for future interoperability.

The Maritime Self-Defense Force is also researching and trialling an electrical power unit for small naval vessels. The JSDF plans to phase out attack and reconnaissance helicopter units and replace them with UAVs within 10–15 years, which may contribute to emissions savings, although the shift is motivated by force structure considerations. Amid Japan's defence modernisation plans, the energy transition is a lower priority than changes like the introduction of long-range missiles and integrated operational planning. For the most part, Japan is watching what the US, Europe and the domestic commercial sector are developing, and plans to incorporate those technologies as they become available. As defence modernisation and energy transition processes see room for major changes, there may be an opportunity to better connect with technology developments in the commercial sector and overcome some of Japanese industry's hesitancies to work openly with the JSDF.

4. Multilateral Cooperation for Defence Emissions Reductions

Multilateral cooperation will be key to the defence energy transition, ensuring burden-sharing on technology development and interoperability around fuels and facilities. The European Union and NATO are focusing on defence net-zero objectives (given the need to coordinate larger and smaller militaries' pace of change on making the energy transition to preserve interoperability) and mitigating risks associated with transitioning away from the single-fuel approach. Their focus is on coordinating efforts, leveraging funding for innovation, standard-setting and incorporating technologies from the civilian space.

European Union

- Target: 55% CO_2e reduction by 2030, compared to 1990 levels; Net-zero CO_2e 2050
- Key defence-specific policies: Climate Change and Defence Roadmap (2020), Strategic Compass for Security and Defence (2022)[112]

While Russia's war against Ukraine has created new urgency for decarbonisation in Europe to cut dependency on fossil fuels, before the invasion, the EU was already weaving climate change response and risk management into most areas of planning and policy, including defence. Military decarbonisation receives momentum from major initiatives such as the European Green Deal and regulations that affect Europe-based industries, including those that the defence sector uses, such as steel, and cover supply-chain and Scope 3 emissions.

The EU approach has focused on defining the agenda in broad-brush terms by developing a roadmap recommending actions across the operational domain, capability development, an integrated approach to defence decarbonisation that plans across states and military capacities, and strengthening partnerships and multilateralism. The EU's Strategic Compass calls for member-state militaries to develop multifaceted defence climate strategies that include plans for emission reductions before 2024.[113] The EU is building institutional infrastructure and committing research funding to support member-state militaries and Common Security and Defence Policy (CSDP) missions to move toward net-zero emissions.

One of the most promising components is the Consultation Forum for Sustainable Energy in the Defence and Security Sector, which promotes information-sharing around ways to reduce defence's energy footprint via policy, research and funding development. The Energy and Environment capability technology group (EnE CapTech) explores new technology areas and measures EU militaries' energy needs and consumption. The Incubation Forum for Circular Economy in European Defence is a new group funded by Luxembourg that brings together business, research institutions and defence ministries to apply the circular-economy concept to the defence space. Further projects will assess the links between defence and civilian energy and infrastructure.

The EU funds research for catalysing technological innovation on mitigation and capability development through the European Defence Fund (EDF) and Permanent Structured Cooperation (PESCO) facilities. The EDF and member states co-finance development and member states pay for defence acquisitions, supporting the EU's Defence Technological and Industrial Base. Projects funded under this programme include energy-independent and -efficient systems for military camps, next-generation electrical energy storage for military forward-operating bases, alternative propulsion and energy systems for next-generation air-combat systems, future modular ground vehicles and enabling technologies, next-generation rotorcraft technologies, and modular and multi-role patrol corvettes.[114] The EU is also exploring building a 'hydrogen motorway' across the continent, which could fuel defence energy needs.[115]

While the first progress report indicates that the EU has made a start on the decarbonisation agenda, more remains to be done. It is still establishing guidelines and has only recently begun deploying environmental advisers on CSDP missions.[116] One important aspect of managing change is measuring emissions and progress towards reducing them; while policy states that defence emissions need to be calculated along with others, member states can decide the specific ways they are counted, and some information may remain confidential. Reporting so far has been criticised for remaining opaque.[117] The EDA aims to develop a 'light-touch reporting mechanism' on environmental footprint to improve data collection for emissions reductions.[118]

NATO

- Target: Reduce civilian and military CO_2e emissions by 45% by 2030, net-zero CO_2e by 2050 (for its facilities and assets, vs member states' militaries committing to net zero)
- Key policies and resources: Climate Change and Security Action Plan (2021), Climate Change and Security Impact Assessment (2022), NATO 2022 Strategic Compass (2022), The NATO Greenhouse Gases Emission Mapping and Analytical Methodology (2023), NATO Climate Change and Security Action Plan Compendium of Best Practice (2023)[119]

NATO is establishing itself as an intellectual hub for the defence energy transition to facilitate the uptake of this agenda across the Alliance and preserve interoperability as defence and civilian energy systems evolve, including by adapting the NATO single-fuel policy for a range of lower-carbon energy sources. The NATO Climate Change and Security Plan of Action was approved in 2021, with mitigation one of four pillars alongside adaptation, raising awareness, and outreach. The 'Military Energy Transition by Design' initiative leverages NATO's platform to move forward together as much as possible; one of the outcomes of the July 2023 NATO Summit in Vilnius was a commitment to develop an implementation plan.[120]

To institutionalise the Plan of Action NATO is standing up a Climate Change and Security Centre of Excellence in Montreal. It was established at the Vilnius summit and should be operational by late 2023. It aims to combine efforts and share innovation across the Alliance, with the NATO Climate Change and Security Action Plan Compendium of Best Practice a product in this direction. Its focus also includes understanding climate impacts on the NATO mission, which spans climate-affected geographies from the Arctic to the Horn of Africa.

Structures for fostering and capturing emerging technological innovation include the Defence Innovation Accelerator for the North Atlantic (DIANA), a new entity focused on bringing start-ups and defence buyers closer together, and the NATO Innovation Fund, a €1 billion multi-sovereign venture-capital fund for dual-use emerging technologies – the first of its kind. Energy resilience is a priority for DIANA in 2023. Energy and propulsion are priorities for the NATO Innovation Fund, which was launched at the summit.[121]

NATO has developed a basic methodology for measuring defence emissions, which will be expanded to measure over the entire equipment life cycle and account for offsetting through carbon sinks.[122] Emissions calculability remains difficult; current estimates are based on fuel and energy purchases, which are an imprecise gauge. Establishing a baseline and building tools like energy dashboards are essential for decision support on ways forward. One open question is what level of detail is appropriate for military emissions data in the public domain, given that it may indicate where forces are operating or other sensitive information. Another question concerns what defence emissions calculations should include – for example, whether defence or other industrial actors should be responsible for emissions from supply chains and procurement processes.

NATO leadership recognises that it is in a unique position to set standards for lower-emissions technology and coordinate or streamline research and developments efforts among member states. Its key challenge may be levelling out some of the differences between members, such as varying defence budgets and capacities to invest in transitioning to net zero and differing views as to the urgency of decarbonisation in the near to medium term, given the security situation in NATO's neighbourhood and the need to present a credible deterrent.

NATO is building the structures to help ensure consistent transatlantic attention is dedicated to decarbonisation despite its member states' changing governments and varying levels of political will for addressing climate risk. NATO and the EU have committed to closer cooperation to address the security implications of climate change.[123] Many member-state defence ministries will be looking to multilateral climate-security efforts to make major decisions on emerging technologies. NATO and the EU have sent a strong signal on decarbonisation that is all the more impactful given their combined defence-industrial and military power. The challenge, however, will be to avoid delays and backsliding given member states' competing priorities and political differences.

5. Outlook – Reaching the Future of Defence Energy

For countries that have made radical emissions-reduction commitments and are putting the most resources into the defence energy transition, the pace of change is still set by technological, institutional, financial and political limitations. How steeply defence can bend the curve on its major sources of emissions – particularly aviation and maritime fuels – will be determined by how long the needed technologies will take to develop and scale, how affordable they will be and what new trade-offs or strategic vulnerabilities they might entail that could influence their uptake. Geostrategic competition drives this agenda but could also complicate implementation, particularly around defence technology components and critical-minerals supply chains. France estimates that China supplies 58% of its defence sector's raw materials, and all countries are keen to avoid trading fossil-fuel dependencies for new strategic vulnerabilities.[124]

All countries committed to defence net zero and delivering a major change programme face institutional inertia, even with a strong top-down signal and growing internal infrastructure to catalyse the technical developments and change culture around the energy transition. Sufficiently staffing these initiatives will be key. It remains to be seen whether the research and development funding for these initiatives will deliver the technologies within the time frames needed. For equipment that will be in service past mid-century, the technologies need to be available in the near term. How well political will for net zero will hold is another open question, particularly in the United States' case given the polarisation around mitigation: Department of Defense (DoD) climate action became a 2024 presidential campaign issue early-on, while the FY2024 Defense Appropriations Act, a congressional bill that, among other things, sets the US defence budget, targets the DoD's move towards electric vehicles and other climate-security measures.[125]

Nevertheless, countries like the United Kingdom and France are establishing climate directorates and building relationships with industry and research institutions to foster innovation, thereby making substantial progress towards creating the structures and conditions required to deliver radical reductions in the critical middle phase of the net-zero 2050 plans. The scale of the United States' work on new energy technologies for defence is far greater than that of many countries with potentially more politically durable net-zero commitments, such as New Zealand and the Netherlands. The direction of travel on the energy transition is clear, and the US defence industry will continue to drive the technology forward even if there is backsliding on the mitigation target or timeline between administrations. The substance of many other countries' strategies is essentially a commitment to implement the technologies once they are developed. As these states may not have the industrial base to make major breakthroughs, they are relying on allies or the private sector. How well they lay the groundwork now to be able to make the changes institutionally and politically, despite competing priorities over the next decade in both security and fiscal terms, will determine the pace of the uptake.

NATO and EU standard-setting and focusing of investment will be among the most effective catalysts for technology development and for bringing along member countries where political will and prioritisation of net zero is weaker. However, few countries appear to have fallback plans should their estimates prove overly optimistic that the technologies will emerge within the anticipated time frames and be within reach cost-wise. This lack of fallback options is also a concern with regard to civilian mitigation plans, which defence relies on to provide, among other things, greener electricity from the grid. Trusting that offsetting technologies will be capable of permanently removing atmospheric greenhouse gases is another vulnerability for both military and civilian net-zero plans.

Technology breakthroughs are key to ensuring that countries can respond less incrementally and more radically. So too, is winning the argument that transitioning does not come at the expense of operational effectiveness – which will largely rely on proving the technologies.

Warfare evolving alongside technological innovation, as is happening in Ukraine, will demonstrate the utility of new ways of fighting that can be powered by lower-emissions assets, like drones. It will also show the importance of, and current lack of an alternative for, conventionally powered heavy equipment and weapons. Disruption to fossil-fuel supplies from security crises, such as the war in Ukraine or other geo-economic shifts, will continue to sharpen the case for the strategic advantages of energy independence, given the vulnerabilities created by a reliance on these supply chains.

It is likely that the imperative of achieving net zero within the time frames science indicates will need to be navigated alongside growing demand for response from militaries, including in the form of humanitarian assistance and disaster relief (HADR) operations and responses to more complex crises that blend climate shocks and/or stressors with conflicts of varying intensities. The pace and severity of disasters may increase so significantly that governments engage non-military entities with adequate lift and logistics capabilities, as Japan plans to do, rather than using war-fighters for disaster response. The requirement for defence to decarbonise, the growing demand for HADR and the need to respond to a more tense geostrategic environment could increase political divisions about defence priorities and resourcing. The political climate around this set of issues is likely to become more polarised, with contentions emerging around using remaining carbon budgets for military purposes – and devoting government resources to defence – as climate impacts accelerate and the gaps grow between climate finance needs, commitments and delivery. The geostrategic implications of this gap and other shortfalls in climate response, including for HADR, are increasingly evident and should not be underestimated.

Defence leaders must work urgently on three key areas to accelerate radical decarbonisation. Firstly, they must leverage partnerships and investment to catalyse the technology breakthroughs. While NATO is setting up the structures to lead on this issue, any domestic or 'minilateral' opportunities for collaboration, including non-traditional partnerships, should be maximised. Secondly, institutional infrastructure and culture change will be crucial to lay the groundwork internally for devoting finite budgets to decarbonising, which will likely involve tough choices. Encouraging defence actors to depart from business as usual and make climate-risk-management decisions based on longer-term horizons rather than near-term planning horizons requires structural facilitation and supportive processes and frameworks. Building and integrating climate-security literacy into defence education are important measures to drive culture change and build expertise on a nuanced issue – and counter media narratives that often mischaracterise the climate-security literature.

Thirdly, defence leaders must address the political challenges to acting more radically, including through better communication. Defence decarbonisation will need to be navigated within a complex set of constraints; preparing the ground politically for sustained commitment and resourcing is critical, particularly in countries like Australia, Canada and the US, where climate mitigation may remain a deeply partisan issue. Communication is a key component of this effort, though there is a balance to strike between making the case to those concerned about decarbonisation limiting military effectiveness, and being attuned to sensitivities that have played out in UN forums and elsewhere about military 'takeover' of the climate issue, which could be counterproductive. In more straitened times or in the face of competing priorities, sustained political commitment will be necessary to preserve momentum for decarbonisation, particularly in scenarios where there are divisions over how best to use military capabilities. Communicating targets, progress and resource needs could support the political will to stay the course, particularly as some technologies will require high initial investments, not all of which will produce results, and public appetite for such investments may be limited.

It is mainly NATO member states that have made defence net-zero commitments, although a growing number of countries no longer exempt military emissions from their mitigation commitments. If the US and other NATO members work with allies like India, Japan, South Korea and Taiwan to demonstrate proof of concept, as the technologies emerge onto the market these states will likely take them up – which would likely strengthen their security relationships with the countries that have made defence net-zero commitments.

At present, however, there is little indication from these militaries of forthcoming net-zero commitments for mitigation's sake. China will continue developing alternative defence energy technologies but will likely retain conventionally powered platforms. Russia likewise will continue to use new technologies and operating concepts where they are advantageous but is unlikely to bring defence under any mitigation targets. Middle Eastern, Southeast Asian and other militaries will likely purchase the technologies once they are on the market. However, as long as fossil fuels are available and more affordable than the alternatives, there is not a strong enough incentive to replace or retrofit their equipment, despite the strategic advantages the technologies may confer. While the number of countries that have substantial change programmes on radical decarbonisation is small, together, they have the geopolitical and industry standing to change the defence technology landscape significantly, provided the structures created to pursue breakthroughs yield implementable results in the next several years, and the political will for resourcing defence's needs to get to net-zero holds.

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The International Institute for Strategic Studies – UK
Arundel House | 6 Temple Place | London | WC2R 2PG | UK
t. +44 (0) 20 7379 7676 **e.** iiss@iiss.org www.iiss.org

The International Institute for Strategic Studies – Americas
2121 K Street, NW | Suite 600 | Washington, DC 20037 | USA
t. +1 202 659 1490 **e.** iiss-americas@iiss.org

The International Institute for Strategic Studies – Asia
9 Raffles Place | #49-01 Republic Plaza | Singapore 048619
t. +65 6499 0055 **e.** iiss-asia@iiss.org

The International Institute for Strategic Studies – Europe
Pariser Platz 6A | 10117 Berlin | Germany
t. +49 30 311 99 300 **e.** iiss-europe@iiss.org

The International Institute for Strategic Studies – Middle East
14th floor, GFH Tower | Bahrain Financial Harbour | Manama | Kingdom of Bahrain
t. +973 1718 1155 **e.** iiss-middleeast@iiss.org