
[dstl]
The Science Inside
Climate Change and Defence
A Dstl biscuit book
Ministry of Defence

Why we think you should read this Biscuit Book!

"The character of warfare is changing fast; so is the climate. Both issues are changing the way our military fight, live and train in unfamiliar ways. Linking these issues together, they both demand that we adapt to the new circumstances that we face and take transformative action now."—Lt Gen Richard Nugee, Foreword, Climate Change and Sustainability (CC&S) Strategic Approach

Climate change will affect all of us, every region of the world and every part of society, including every part of Defence and its business.

Climate change will deeply affect the tasks our Armed Forces undertake; the way we protect the UK, operate and fight.

Defence and every person in the enterprise can work together, play a significant part in helping the Government address climate change and achieve the UK's legal commitment of Net Zero by 2050.

This Biscuit Book aims to give you a brief introduction to climate change with an understanding of the impacts, and how Defence might mitigate our contributions to and adapt to climate change.

It also highlights examples of how science and technology can support Defence, and, we hope, will inspire you to consider how you might also make your positive impact.

What is Climate Change?

Climate change results from long-term shifts in the Earth's temperatures and weather patterns. The main driver of climate change is the changing levels of atmospheric gases, known as 'Greenhouse Gases'.

Greenhouse gases let sunlight pass through the atmosphere and heat the earth's surface, but absorb some of the heat radiated from the earth's surface and redirect it back to the surface. This reduces heat loss from the Earth keeping it warm.

The more greenhouse gases present in the atmosphere, the more heat is radiated back, thereby increasing the average surface temperature of the Earth. Carbon dioxide is one of the main greenhouse gases.

Since the industrial revolution, human activities have been the main driver of climate change. This is mainly a consequence of both burning fossil fuels and releasing the carbon dioxide stored in them, and reducing the natural carbon dioxide stores (e.g. through deforestation, intensification of land-use for farming and the depletion of large animal communities on land and sea which are needed to maintain the ecosystems).

This has resulted in the Earth's carbon dioxide concentration, and therefore its temperature, rising faster and higher than at any time in at least the last two thousand years.


Change in frequency, distribution and intensity of storms
Increased air temperatures
Desertification
Glacier melt raises seawater levels and reduces sources of fresh water
Increased risk of sand and dust storms
Reduced water availability
Increased risk of wildfire
Crops affected leading to famine
Access routes affected
Change in risk from disease
Increased intensity of rainfall over short periods increases flooding
Increased land temperature
Seawater penetration contaminates groundwater and damages crops
Flooding due to sea level rise and storm surges
Coastal erosion
Increased sea temperature
Melting sea ice opens new sea routes but increases iceberg formation
Increased biofouling
Sea ice melt affects deep ocean currents and affects weather patterns

Defence Opportunities and Challenges

Climate Change and its Effects on Defence

Climate change exacerbates current issues and is creating new ones.

> *"Violent conflict mainly occurs where unaddressed regional pressures (for example, sharp population growth, resource scarcity and weak states) overlap with global challenges (such as, climate change, pollution and inequality)."* - *Global Strategic Trends, p23*

Defence has an impact on climate change and climate change has an impact on Defence. The effects of climate change are not limited to temperature rise, it has a number of direct and indirect effects and consequences from them. Defence's interest in these will be with respect to the impact they have on Defence and the operating environment but also how Defence contributes to these effects. Dstl see these as being group into three tiers: primary, secondary and tertiary effects based on how increasingly indirect these effects are.

Primary Climate Change Effects.

Change in Temperature Patterns

The average global temperature has changed across both land and oceans in most areas. However, the rate of change is not the same everywhere. Generally, the land has warmed more than oceans, and the Arctic has warmed twice as fast as the rest of the world.

Change in Water Distribution

Increasing temperature is causing sea-level rise, due to thermal expansion of oceanic and land ice (including glaciers and permafrost) as it melts. Changing rates and amounts of melting sea ice could slow ocean currents that regulate global climate.

Change in Weather Conditions

A warming atmosphere will lead to heavier rainfall events in many places due to increases in the air's capacity to hold moisture. At the same time drought could occur in many tropical and subtropical land areas due to reduced precipitation. These short-term and regional variations are likely to become more extreme and enduring.

Warming seas can cause an increase in intensity of tropical storms. When coupled with sea level rise, storm surges are likely to increase.

Secondary Climate Change Effects

Desertification and wildfire

Desertification (the process of fertile land transforming into desert) is accelerating in Africa, with Australia and the Middle East also being critically vulnerable. This will lead to an increased risk of sand and dust storms and change the global distribution of land fertility. Extreme and long-term elevated temperatures leading to drier conditions could lead to an increased risk of wild fires.

Land and sea access routes

The melting Arctic will expose new shipping routes on a seasonal then permanent basis. However, increased iceberg formation at both poles presents an additional risk to shipping. Lack of rainfall has already affected river transport with seasonal low water levels in the Panama Canal and River Rhine reducing shipping traffic.

Flooding

Increased intensity and frequency of rainfall will increase the risk of inland flooding with potential for landslides. Sea level rise increases the risk of flooding in coastal areas, including causing soil erosion.

Accessibility and Availability of Natural Resources

Changing environmental and political landscapes, plus new resource demands, will alter physical and geopolitical access to resources, including minerals, rare earth elements and fossil fuel deposits.

Availability of Fresh Water

Freshwater storage, including glaciers, permafrost and snow has dropped while salinization of freshwater aquifers from seawater intrusion has increased, leading to a reduction in the availability of freshwater. Access to clean water may be impacted further due to pollution from sediments, pathogens and pesticides caused by higher water temperatures and more frequent floods.

Distribution of Flora and Fauna

Altered climates are driving increasingly rapid changes in the distribution of flora and fauna across our planet. Shifting distributions of animal and human populations driven by climate change will bring species into increased contact. Shifting insect and animal populations are changing terrestrial landscapes, agricultural production and harvests.

Tertiary Climate Change Effects

The consequences of the primary and secondary climate change effects will affect Defence's ability to operate and influence the threat, thereby altering where and how Defence needs to operate.

Damage to Infrastructure

Increased severity, frequency and distribution of floods, droughts and extreme weather will increase the risk of damage to infrastructure (including buildings, transportation networks, energy provision, information technology and communications).

Migration

Climate change could result in many people migrating within their countries, mainly being pulled to urban areas, and cross border migration. This is due to effects including desertification, flooding and access to freshwater and other essential resources. This migration has potential to exacerbate socio-economic pressures and contribute to the risk of conflict at all levels.

Competition for Food and Water

Geographic changes to productivity of crops, animal and fish stocks will affect livelihoods, raise prices and increase the risk of famine in some areas. Where there are already tensions over water and food availability, climatic pressures will exacerbate the potential for and intensity of conflict.

Increased Risk to Health

People may be exposed to either new diseases or diseases new to their area due to: increased contact between animal and human populations increasing the potential for zoonotic diseases to cross between species; equatorial diseases spreading pole-wards; and melting permafrost potentially releasing trapped viruses and bacteria. These will put stresses on healthcare systems and could include infectious agents humans are not prepared for, or have immunity to. Extreme temperature and weather will increase the

risk to human health through physical harm, psychological harm and loss of life through injury.

Increased Competition for and Control of Land and Sea

Changes to land and sea accessibility will result in shifts in global trade routes, and potential increase in competition to secure and access such routes.

Increased Competition for Natural Resource Deposits

Changes to the accessibility and demand for natural resources may result in increases to stockpiling and deliberately limiting the supplies of scarce resources for geopolitical or financial gain. New alliances may be forged to ensure secure access to resources.

Preparing UK Defence for Climate Change

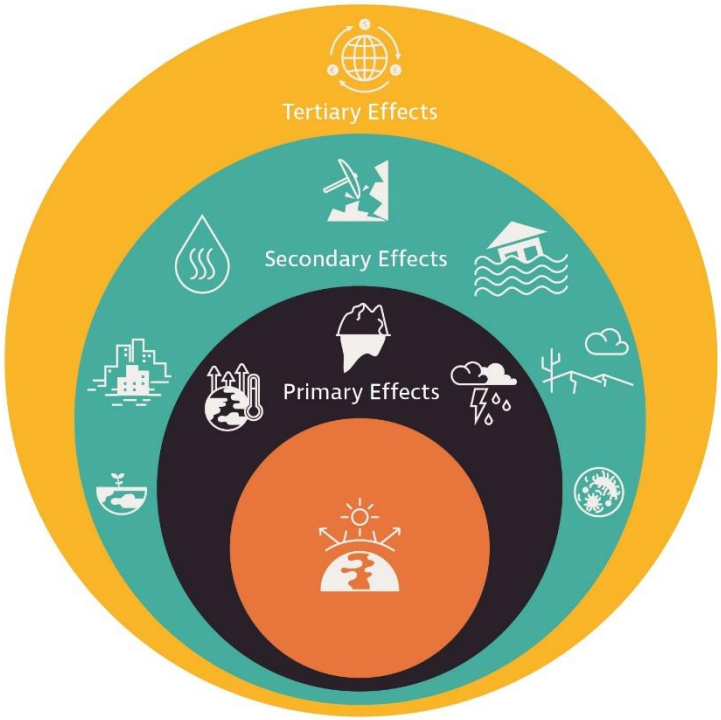
Preparing UK Defence for Climate Change will help the UK maintain - and potentially improve - operational effectiveness, provide new economic opportunities, and aid the UK to reach Net Zero by 2050.

Preparing the UK to operate in a climatically changed world opens new opportunities and challenges for UK Defence.

Defence's impact relies on the following.

- UK Defence's role in global leadership of climate change
- Reducing Defence impact on climate change
- Adapting Defence to climate change
- Enablers to allow Defence to address climate change

The next sections of this book explore each of these roles for Defence in more detail.



Tertiary Effects

- Increased migration
- Increased competition for and control of land and sea
- Increased competition for food and water
- Increased risk to health
- Destruction and damage of infrastructure
- Increased competition for and control of natural resource deposits

Secondary Effects

- Flooding
- Changes to accessibility and availability of natural resources
- Reduced availability of fresh water
- Changes to land and sea access routes
- Change in distribution of Earth flora and fauna
- Desertification

Primary Effects

- Change in temperature patterns
- Change in water distribution
- Change in weather conditions

- Increased concentration of greenhouse gases (GHGs) in atmosphere

Leadership and Direction

Defence has a key role to play in climate change both nationally and in global leadership, from the very top of Defence and all levels below, to champion and role model the expected culture and behaviours.

It is important that leaders at all levels across the Defence Enterprise have the skills and expertise needed to drive this change.

Partnership

Defence is likely to operate in cross-government and international missions to respond to climate related challenges. This requires cross-sector collaboration with other government departments, industry, academia and international partners.

Cross Government

Many of the climate change issues and international tensions because of climate change are outside of Defence's direct control and require a whole of government response, such as through Humanitarian Assistance and Disaster Relief (HADR) or Military Aid to the Civil Authority (MACA). This will utilise cooperative mechanisms with different types of partners at home (e.g. the emergency services) and abroad (e.g. Non-Governmental Organisations (NGOs)), which can be achieved through joint exercising and shared experience cross government and with NGOs and multinational partners.

International Partners

Partnerships will need to be formed with many international partners. One of the key mechanisms to form partnerships in this area is through the North Atlantic Treaty Organisation (NATO) and key allies. The NATO Agenda on Climate Change and Security is a baseline from which the UK can build in a changing future landscape.

Industry

Good partnerships with industry on climate change issues will ensure the supply chain for Defence capability can keep pace with demand; to harness work in the civil sector without competing for the same products and to ensure sufficient support to fossil fuel based Defence capability that is still in use.

Setting Policy and Strategy

Defence policy and strategy reflects international agreements and the national commitments. Climate change is a whole of Government Issue. UK Defence contributes to influencing and shaping national security policy and strategy with respect to climate change across government.

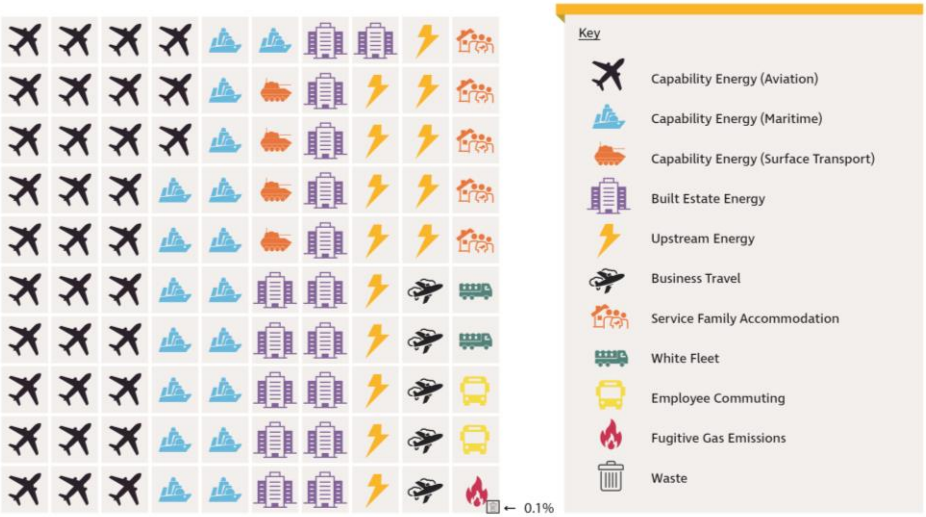
Defence's high level Climate Change strategy is "Climate Change and Sustainability - a strategic approach 2021". It is supported by further functional and organisational Climate Change strategies such as the "Sustainable Support Strategy". Strategies and plans across Defence reflect the greening Defence, Net Zero and the Climate Change risks to Defence.

Reduce Impact of Defence on Climate Change

The Impact by Defence

Defence's total reported greenhouse gas emission footprint between April 2022-23 was 3.1 million tonnes of carbon dioxide equivalent (a standardised measure of how different greenhouse gases contribute to global warming compared to carbon dioxide) making up 50% of UK central government carbon dioxide emissions and 1% of total UK emissions.

Proportion of UK Defence Carbon Dioxide Emissions



(1 square = 1% of total emissions)

Defence emissions comprise contributions from all areas of Defence. There are some areas where the emissions are significantly larger than others, for example in military aviation.

Defence emissions fall into three scopes related to the level of control Defence has over those emissions.

- Scope 1 – Greenhouse gas emissions that defence makes

directly – e.g. fossil fuels used to heat buildings, drive vehicles or operate military capability.

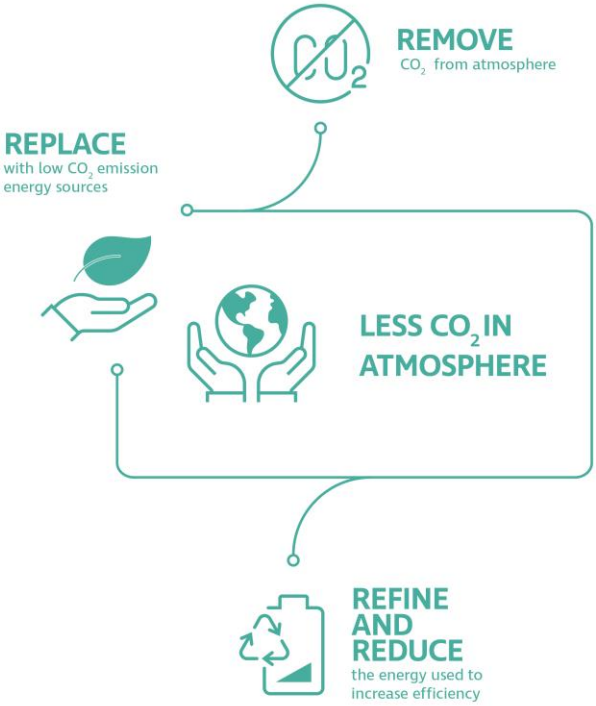
- Scope 2 – GHG emissions made indirectly from generation of purchased energy – e.g. electricity bought from national supplier.
- Scope 3 – GHG emissions that are indirect emissions from activities upstream and downstream of the organisation e.g. purchased goods and services, business travel, employee commuting and waste.

Defence can fully exploit opportunities to reduce Scope 1 emissions but must work with others to influence Scope 2 and Scope 3 emissions. For instance, the hybridisation or electrification of many capabilities will reduce Scope 1 emissions but Defence must also consider how the electricity is produced, stored and transported - all Scope 2 emissions.

Opportunities for Defence

The actions and choices made by UK Defence are critical to the success of UK Greening Government commitments with respect to emission reduction and helping the UK government achieve its legal commitments to be Net Zero by 2050.

UK Defence aims to reach an irreducible minimum of greenhouse gas emissions from its operational capability, only using fossil fuels where unavoidable. Environmental sustainability cannot be allowed to compromise operational effectiveness. This requires an understanding of Defence's current and future energy demands.



Replace

Defence requires energy both to support operations and for business as usual. This includes for infrastructure, vehicles and equipment in the UK and overseas, some of which will be operating in dangerous, austere or extreme environments.

Defence can lower its emissions of greenhouse gases through the replacement of fossil fuels with alternative energy sources

In some areas, especially bespoke military vehicles, it will not be possible to move entirely to alternative fuels in the short term. However, fossil-fuelled capabilities with a long in-service lifespan, risk becoming ‘stranded assets’ or capabilities which are

increasingly expensive to fuel, difficult to maintain and unaffordable.

The future energy market anticipates there will be a move in both the civilian and defence sectors towards alternative energy sources. The individual choice of alternative energy, especially fuels, will depend on many factors including security of supply and having the infrastructure to support the supply in place (e.g. storing, refuelling and recharging).

Potential Solutions/Opportunities

Aviation forms a high proportion of Defence's fuel consumption. The RAF, working in collaboration with UK industry, are leading Defence development and use of both Synthetic and Sustainable Aviation Fuels. Many aircraft could get 50% or more of their energy from sustainable aviation fuel sources in the future, depending on cost and availability, significantly reducing harmful emissions.

In the maritime environment, commercial shipping is considering the use of ammonia, biodiesel, or methanol as a fuel for ships. However, while commercial ships often move from point to point along scheduled routes, naval ships need more flexibility. This requires adaptable supply, and potentially, engines and fuel storage that are fuel flexible if this becomes more widely feasible in the future.

Land based vehicles can run on electricity, but current battery energy density limits their range compared to liquid fossil fuels. Electric vehicles already offer a realistic alternative for the non-tactical (or 'white') fleet, but are currently less feasible for many combat or specialist vehicles. Hybrids may offer some benefit for combat and specialist vehicles.

Generation of electricity for infrastructure needs, both on the Defence estate as well as within deployed bases, could use proven technologies such as solar panels and wind turbines plus nuclear micro-reactors.

In addition to reducing emissions of greenhouse gases, this will also provide other benefits.

- Supporting the move for operations to be more self-sustaining.
- Reducing the deployed logistics demand for fuel resupply convoys reduces the 'tooth to tail' ratio and reduces the risk to life.

Increased resilience can be achieved by using diverse renewable and non-renewable energy production sources and creating micro grids that combine localised generation and storage. Using multiple fuel sources could help increase resilience and allow use of fuels of opportunity but limited availability such as waste fats and oils. However, this will likely complicate support and logistic demands.

Greener Platforms and Vehicles

Examples

- RAF set a Guinness World Record with the first flight using 100% synthetic fuel in an unmodified light aircraft without affecting performance.
- An RAF Voyager strategic air transport flight demonstrated the military viability of 100% alternative aviation fuels made from waste-based sustainable feedstock, such as used cooking oil.
- The Army have tested hybrid technology retrofitted to MAN SV, Foxhound and Jackal vehicles, providing energy efficiency and tactical benefits, including silent running, lower thermal profile and the ability to power additional battlefield systems.
- Offshore Patrol vessels HMS Tamar and HMS Spey have selective catalytic reduction systems to reduce nitrous oxide emissions by up to 97%

Alternative Energy Generation

Examples

- As part of the Ministry of Defence's Net Carbon Accommodation Programme, the blocks in Nesscliff Training Area have air source pumps and generate electricity from solar panels installed on the roof.
- Portsmouth Naval Base has increased use of electric vehicles, installed wind turbines and the Queen Elizabeth class Logistics Centre has over 750 solar panels.

Alternative Technologies

- Nuclear micro-reactors - A truck portable nuclear reactor that can generate up to 20 megawatts of thermal energy to generate electricity. These could have utility at deployed military bases to provide a dense power source.
- Microgrid - A self-sufficient energy system that serves a discrete geographic footprint, containing one or more kinds of distributed energy (solar panels, wind turbines and potential small nuclear reactors) that produce its power. It can also contain energy storage, and charging points.

Refine and Reduce

Issue

There is an ever-increasing demand for energy within Defence, driven by increasing use of technology that underpins Western Defence. This will lead to an increasing need for energy efficiency across Defence and on military operations – refining how we use Defence energy to avoid wastage. In addition to reducing Defence's impact on climate change, energy efficiency will reduce cost, reduce the need for dismounted soldiers and tactical vehicles to carry ever-larger batteries; reduce the frequency of fuel and supply convoys that risk lives and consume military resources; and enhance capabilities by enabling longer operating ranges.

Potential Solution/Opportunities

Ways to Increase Efficiency of Equipment include:

- improving the fuel efficiency of power sources;
- ensuring that equipment is operating optimally;
- reducing the consumable burden of equipment to reduce the frequency of supply;
- changing the physical design (for example, reducing weight and/ or drag); and
- considering energy efficiency when matching the right equipment to the job.

Modelling and simulation offer opportunities to improve efficiency of platforms including using digital twins to aid design and to assess performance in a broad range of different scenarios to identify how to reduce fuel usage.

Increase Efficiency of Infrastructure

People work, train and live on the Defence estate, so optimising the efficiency of infrastructure and promoting behavioural change have a large impact. Some of the highest energy consumers within

defence infrastructure are heating, air conditioning and refrigeration. Simple changes such as replacement of traditional lighting systems by LEDs can have significant impact by reducing energy usage as well as lowering heat emissions, thereby reducing the air conditioning requirement. Reducing the loss of energy from buildings by increasing insulation. More radical changes present new opportunities, such as the potential to reuse waste heat from equipment to heat buildings or provide power.

Understanding energy requirements and consumption will inform optimisation and reduction of energy usage. The use of Artificial Intelligence (AI) could improve this further and enable control and monitoring of heating and cooling systems to adjust to outside conditions.

Changing Behaviours

Key to saving energy is developing a new culture and helping people to make more informed choices. Actions as simple as turning off a light switch or walking rather than taking the car can have a big cumulative impact. Setting the right goals in the first place, in this case reducing greenhouse gas emissions are key.

Alternative Ways of Working

These can range from simple changes such as a reduction in travel, whether to attend meetings, exercises or training, by using virtual approaches instead.

Synthetic Environments (SE); Augmented Reality (AR) and Mixed Reality (MR), are immersive technologies that have potential to be used for training and exercises. These technologies have multiple benefits including:

- reducing the travel required to and from exercises and training;
- reducing the use of operational vehicles during training;
- providing reproducible training opportunities; and

- allowing greater opportunity for experimentation with international partners.

These technologies offer an alternative rather than a replacement for live training, as there is still a need for first-hand experience and to demonstrate our capability to others. However, while this will reduce energy burden over live training, simulated environments come with their own energy burden.

The use of autonomous systems (across land, air and maritime environments) may also offer opportunities to lower carbon emissions through reduced size and weight.

The Circular economy is an economic system designed with the intention that maximum value is extracted from resources and minimum waste is generated for disposal. This will help with self-sustainment by reusing or repurposing items alongside increasing the robustness and lifespan of equipment, increasing the ability to repair on site and fabricating parts using advanced manufacturing mechanisms such as 3D printing.

Energy Efficiency

Examples

- The Net Carbon Accommodation Programme (NetCAP) buildings are equipped with smart building technology, uses interconnected automated technologies to control the building's operations enhancing the efficiency, operability, safety, and comfort of the building**.**
- Applying antifouling paint to Type 26 frigates will limit marine growth and together with the hydrodynamic redesign will ensure efficiency.

Artificial Intelligence (AI), Machine Learning and Data Science

These are a family of related technologies that exploit computer processing, algorithm development, data availability, gathering and storage, and electronic connectivity.

- **Artificial Intelligence:** Machines that perform tasks normally requiring human intelligence, especially when the machines learn from data how to do those tasks.
- **Machine Learning:** Computer algorithms that can 'learn' by finding patterns in sample data and then apply this to new data to produce useful outputs.
- **Data Science:** The processing of large amounts of data in order to provide insights into real-world problems.

Climate-relevant applications in Defence, include:

- Optimising performance through the real-time monitoring of data about people, equipment and the environments they're operating in to predict problems and target appropriate interventions such as repairs, rest, or training;
- Protecting our people from harm by automating tasks in hostile environments;
- Extending the life of equipment and consumables, and reducing holdings, logistic burden and waste through predictive maintenance, improved stock management and resupply.
- Managing buildings and facilities to optimise energy management and reduce carbon dioxide emissions.

Remove

Carbon sequestration is the removal and storage of carbon dioxide (carbon dioxide) from the earth's atmosphere.

Carbon sequestration can happen in different ways.

- Biological sequestration, where carbon dioxide is stored in the natural environment, this includes 'carbon sinks', such as forests, grasslands, soil, oceans and peat or wetlands.
- Geological sequestration when carbon is stored in places such as underground geological formations or rocks.
- Technology/ industrial options including direct air capture and pre and post production capture.

As UK Defence owns 1% of the UK landmass it has the potential to use rural management practices to restore, enhance or develop natural and long-term biological carbon sinks. This may enrich both biodiversity and military utility by providing a wider range of environments in which to train but it may make some land less productive or less viable for armoured warfare training.

Defence Adaptation

Global heating and associated climate changes are already happening and would continue even if greenhouse gas emissions ceased today. The speed at which these changes are occurring cannot be precisely predicted, so we must ensure operational capability remains effective and Defence retains (or increases) operational advantage and freedom of manoeuvre. Defence must adapt.

Understanding Defence's current level of resilience to climate change is key to developing appropriate and assured adaptations.

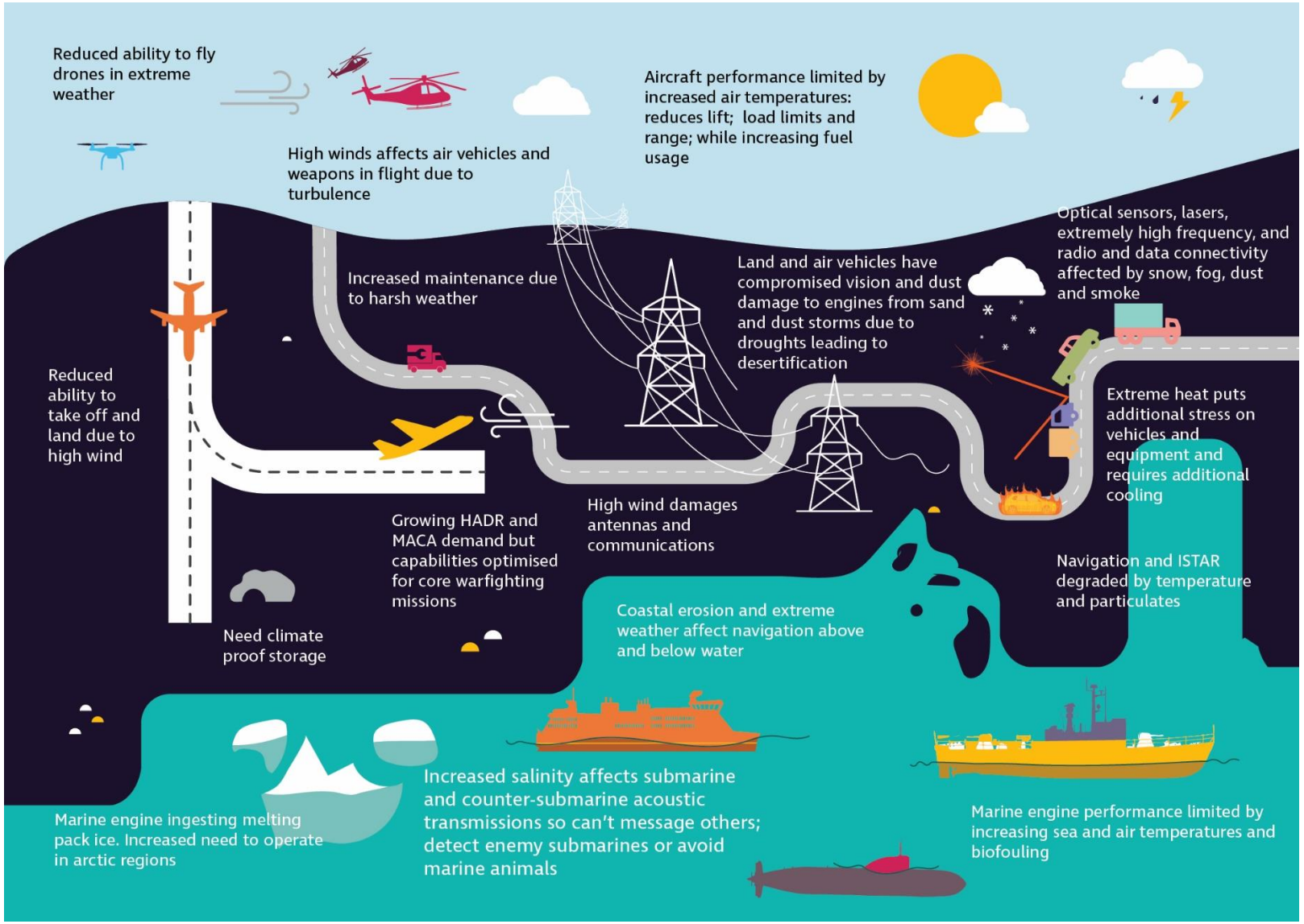
The people and equipment that constitute Defence capability must be prepared to fight and win in all climatic zones and in increasingly extreme weather conditions against peer adversaries more familiar with operating in local environmental conditions.

There are three ways in which climate change will affect Defence.

- **Change in Threat.**
    - Changes in global and regional freedom of access and manoeuvre.
    - Change in national and international acceptance of Defence's impact on climate change.
- **Change in Mission Demand.**
    - Increase in need for HADR and MACA.
    - Physical or geopolitical changes may require operations in new environments.
    - Increase in need for peacekeeping operations.
- **Change in Operating Conditions.**
    - Ability to switch rapidly between increasing climatic extremes.
    - Ability to operate in prolonged extreme weather and temperature events.

- Increase in risk of degradation of equipment and personnel.

Ensuring Equipment Is Optimised for Climate Changed World



Issues

Climate change has a wide range of impacts on military equipment.

- Extreme weather – such as high winds - can affect aircraft, especially at take- off or landing; cause damage to communications and infrastructure for storing equipment; and cause sea and river erosion affecting navigation above and below water.
- Increased temperatures can affect aircraft performance by reducing lift, lowering load limits, reducing range and increasing fuel usage; put stress on land vehicles and equipment, increase the need for cooling of equipment and vehicles; melt sea ice causing marine engines to be damaged from ingesting melting ice pack; degrade maritime navigation and ISTAR and limiting marine engine performance.
- Dust and sand storms from desertification can compromise vision in air and land vehicles; damage land and air vehicle engines and equipment, increasing maintenance burden, and affect equipment operations including optical sensors, lasers, EHF, radio and communications.
- Increased salinity can affect submarine and counter submarine operations by affecting acoustic transmissions.
- Increase the need for HADR and MACA operations. However as these are not the operations driving capability development they cannot shape procurement, which may result in use of capabilities, not optimised for these missions. In addition while military equipment and personnel are engaged in HADR and MACA they are not available for their primary tasks of warfighting and deterrence.
- Increased temperature and extreme weather will increase degradation of most materials and equipment, increasing support demand due to higher failure rates in equipment requiring maintenance.

Solutions

In a world where harsher climates and extreme temperatures are increasingly common, equipment will need to be adapted to operate effectively anywhere in the world across an increasing range of operational conditions. The UK already operates in extreme temperatures, but rather than having assets to specialise in specific climatic zones, future equipment must be flexible enough to switch between cold and heat with little time to adapt or acclimatise.

Platforms/Vehicles options.

- New capabilities, such as icebreakers to navigate passage in the high north.
- Retrofitting or enhancing current capabilities.
- More temperature tolerant equipment including greater cooling power for hotter environments.
- Electrified maritime and air platform fleets with associated large-scale recharging facilities.

Military Equipment Options.

This will need to be flexible to ensure rapid adaptation between different climate extremes and could employ the following.

- Open architectures to take advantage of rapid advances in technology or changes in environment.
- Modular system of systems to tailor equipment for missions.
- Operating and computing 'at the edge' where there is a limited amount of front-end process and decision making undertaken to overcome loss of connectivity from extreme weather.
- Increased use of robotic and autonomous systems to reduce the risk to personnel from hazardous weather and extreme temperature.

Maintenance and Storage Options:

There are a number of ways to reduce the time equipment is out of service from climate effects.

- Predictive and conditions-based maintenance to reduce failures including AI and digital twin technology.
- Forward spares production and repair using advanced manufacturing technology.
- Making repairs simpler and training people with the skills needed.
- A focus on robustness to extreme weather and temperature during acquisition of equipment and consumables.
- Climate-proof storage to extend life and limit damage from temperature, moisture, light and dust.

Spotlight on Digital Twins

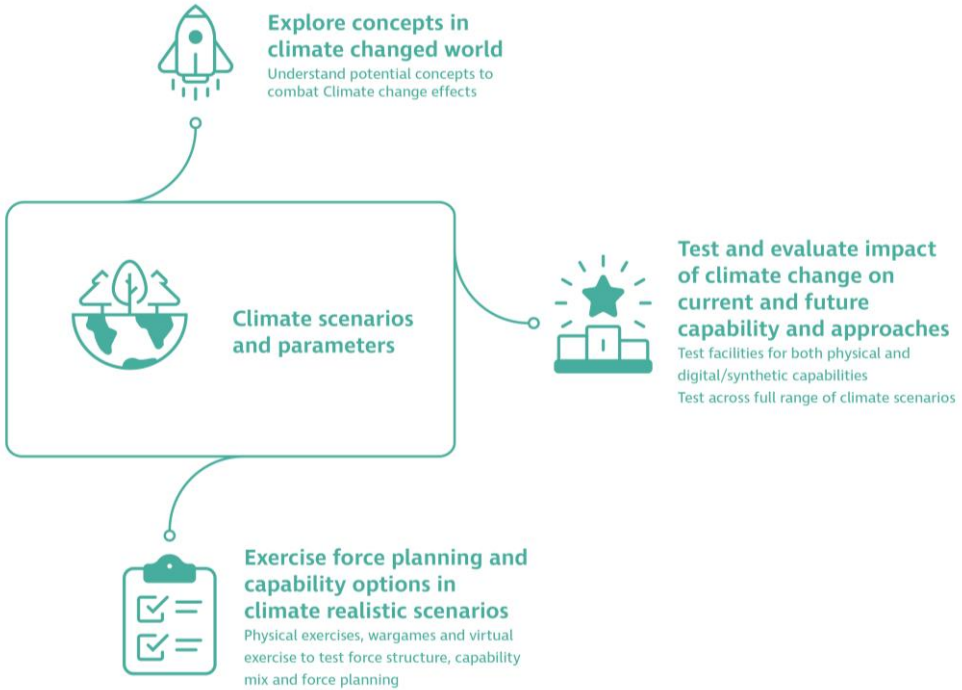
A digital twin is a virtual model of a real world entity, system or process used to predict performance. It includes a live two-way data flow into and out of its twin in the physical world.

Digital twins mimic, in real-time, their real world counterpart in all aspects, and can be used to experiment and rapidly iterate potential interventions to understand their likely impact.

Digital twins can:

- predict and reduce energy use, emissions and waste, extend object or system life, and increase performance, sustainability and circularity; or
- model how unchanged capabilities, organisations or systems will cope in a climate changed world.

Explore, Test, Exercise and Evaluate Capability and Approaches for Climate Changed world



Ensuring Resilient Infrastructure

Issue

Climate change will impact both fixed and deployed Defence Infrastructure and UK national infrastructure upon which Defence is reliant.

In the short-term the UK based Defence infrastructure will face local extremes of temperature and weather but these will be less extreme than those faced in the overseas territories and on deployment. The local extremes and associated risks such as flooding can still cause disruption.

The impact of climate change on infrastructure could impact across basing, headquarters, warehousing, transportation hubs, training grounds, testing facilities, energy provision including from national infrastructure, IT, communications and materials production or extraction; both through direct damage and through loss of access.

Solution

Moving current infrastructure and planning climate change into the choice of site and engineering specifications for future developments can avoid the impact of extreme weather events, such as relocating coastal installations due to potential sea rises. This is not always practicable, so there are a number of other ways to achieve greater resilience of infrastructure.

- **Structural adaptation** - making the structure itself more resilient, through engineered or natural approaches.
- **Non– structural adaptation** - such as early warning systems or increased monitoring.
- **Dispersion** – ensure assets are not all based in one location.
- **Ease of repair –** where it is not possible or economically viable to protect the asset from climate change impacts.
- **Redundancy –** balancing between keeping only the infrastructure needed whilst retaining flexibility to respond to changing needs.

Ensure the Health and Wellbeing of Defence People

Issue

Defence people (and our working animals) will operate in a broader range of temperatures and more extreme weather. This will have implications on their health and wellbeing and their ability to train and work effectively.

Extreme Temperatures

People will be required to train and operate in extreme temperatures more often, affecting their productivity, increasing the risk of heat or cold stress and jeopardising operational effectiveness. Monitoring of personnel to ensure that they do not suffer from heat or cold stress is important. In the case of heat stress this becomes an even greater issue when wearing protective equipment such as Chemical, Biological, Radiological and Nuclear suits and explosive ordinance disposal suits or operating in already hot or confined environments.

There are a number of considerations to reduce the impact of extreme temperature on personnel.

- Acclimatisation.
    - Supporting training or operations in extreme temperatures or conditions.
- Human augmentation.
    - Reducing both physical and cognitive burden e.g. exoskeletons.
- Personal protective equipment, e.g. cooling vests, sun cream, thermal clothing.
- Change ways of working.
    - Reducing time working in extreme temperatures conditions and also reducing number of people exposed.

- Increased and regular hydration for extreme heat.
    - Potential solutions to tackle water shortage include technologies such as portable desalination, water harvesting and water purification.
- Increased use of air conditioning or heating in accommodation.
- Accepting this comes with an associated increase in power burden.

Increase in Diseases

Warmer temperatures are more favourable to the transmission and survivability of disease. The movement of disease vectors such as insects with warming temperatures and an increase in water borne diseases from contaminated flood water will lead to an increase in prevalence and diseases being seen in areas they have not previously been encountered. Deployed forces' likelihood of exposure to disease in more places may increase. The medical capability will need to deal with the changing risk from disease.

Increase in Air Pollutants

Desertification and drier conditions lead to increased air pollution and more cases of respiratory illness affecting people's ability to work, and increases the need for respiratory protection and treatment of respiratory diseases.

Monitoring

The key to reducing the risk to military people will be the ability to spot signs of ill-health early. Wearables that allow all aspects of a person's physiology to be recorded to understand how a person is performing and, when problems arise, may provide opportunities for early intervention.

Access

The ability to move equipment, resources and personnel could be severely impacted by climatic effects on the physical environment and from political or legal constraints. This will both affect the freedom of movement of our deployed forces and the ability to resupply. One-off or predictable physical events can be planned for, but the increasing frequency of unpredictable events will affect operations.

Runways and roads can be impacted by extreme weather causing objects to be blown onto them, snow and ice storms or extreme temperatures melting their surfaces.

Terrestrial access could be restricted by areas being subject to flooding and wild fires.

Rising sea level could affect port access and a ship's ability to dock.

Reduced permissiveness of access can also be caused by political or legal constraints. Nations may choose to limit the UK's ability to deploy if by so doing, the UK would be adding further stress to the local community. For instance, if a deployed force is dependent on regional local support, in conditions of scarcity local communities may contest the use of local resources, increasing the risk of conflict.

Countries may refuse access if for instance UK forces are not meeting environmental sustainability criteria.

Climate change disruption to supply chains can occur due to damage to access routes affecting Defence's ability to acquire capability. Also, conflicts driven or prolonged by climate change may impact supply chains and costs increasing the length and scope of disruption.

The melting Arctic will expose new shipping routes on a seasonal then permanent basis, and open up new trade routes, providing new economic opportunities, but potentially increasing competition for resources. This competition coupled with

increasing tensions between Arctic nations could increase the likelihood of conflict. In the Antarctic melting ice may open up competition for fossil fuel deposits, mineral deposits and fisheries.

Enablers

There are a number of enablers which underpin Defence's approach to climate change. These are key to ensure Defence is able to operate effectively within constraints and boundaries and that it is working from the correct data to make sound decisions.

Defence forms part of the UK response to meeting national climate change initiatives. In adapting to climate change, it can bring together views and shared investment from across government, and the private sector to solve some of the difficult problems.

Developing, Influencing and Implementing Standards

Defence has a role to play in both meeting and influencing the setting of internationally recognised standards for climate change technologies and approaches. These set the constraints within which Defence is able to prepare and operate both nationally and internationally.

Consideration is also required of societal and ethical standards and norms to meet expectation across the UK population and internationally of how the UK operates with respect to climate change.

Embedding Climate Change Culture

Climate change presents an opportunity to engage all Defence people in a common theme, which is important nationally and globally. It can form an intrinsic part of Defence's culture and activities by everyone in Defence having an awareness of climate change and its implications for Defence.

Communication of Defence's approach and the need for action on climate change, internally and externally, will provide inspiration to our people, the wider public, industry and international partners and be important for future recruitment and retention.

Ensuring Defence People have the Right Skills Attributes, Experience and Training.

For Defence people to operate effectively in a climate-changed world, they will require additional skills, attributes and experience. This is due to:

- changes in operating conditions;
    - e.g. Medical skills for extreme temperatures and for increased disease; self-sustainability skills including: desalination and water harvesting; maintenance of non-fossil fuel equipment and legacy equipment; and forward repair, adaptation and manufacture.
- potential changes in the type of operations being undertaken;
    - e.g. responding to natural disasters may require different engineering skills.
- increases in use of digital technology; or
    - digital skills including AI; Digital twins; immersive and synthetic environments; and Simulation and modelling.
- the introduction of new capability.
    - e.g. autonomous capability

These reflect the changes being seen within the civil sector, so these skillsets maybe in high demand. Future training and recruitment will need to reflect these changes.

These changes offer opportunities to make greater use of immersive technologies such as AR and Virtual Reality (VR). These allow people to train without exposing them or equipment to hazardous conditions and to undertake activities multiple times, in multiple different environments to meet the changing situation from climate change. The use of VR for training while still requiring energy to operate usually requires less equipment and hence is less energy intensive.

Extended Reality (XR) is an umbrella term encompassing AR, VR and MR.

- **AR** adds layers of virtual objects or data to the user's experience of the physical environment**.**
- **VR** is a 3D experience where a user is fully immersed in a computer-generated virtual world.
- **MR** is an AR/VR hybrid, where users can interact in real time with both physical and digital objects.

XR technology is already used across many application areas, such as medical, education and construction, with technology becoming increasingly commercially available.

XR technologies bring the potential to radically transform how individuals and organisations operate in and interact with the physical and digital world.

Opportunities to Exploit XR

- Reducing the use, cost and impact of physical resources, lowering time and fuel burdens and increasing the availability of defence people and operational equipment.
- Coupling XR with robotics so that operators can perform dextrous and complex tasks remotely, reducing the risks of hazards in extreme environments.
- Learning and honing new skills through training in realistic simulations of complex and hostile scenarios.
- Optimising planning and execution of missions by rehearsing tactics in representative synthetic environments.
- Augmenting the capabilities of operators in front line roles with remote specialist contributors.

Effective Decision Making

A ‘climate lens’ must consistently and appropriately be applied across defence decision-making, based on evidence-informed assumptions of a climate changed world.

Data and Predictive Data Analysis

Climate change is a global and cross Government Issue. Informed decisions require consistency of climate change data at international and national levels. Data should include multiple relevant climate change sources, including those outside the traditional intelligence gathering community.

UK Defence should include climate change factors into all its threat assessments and horizon scanning. Machine learning/ AI or Big Data offer capabilities to improve climate and security threat modelling. However, AI and Big Data comes with additional energy demands that mean the benefit they provide need to be balanced against the detrimental affect they have.

Defence Climate Assumptions/Scenarios and Operational Analysis

Defence Climate Assumptions are required for capability development due to the dynamic and changing nature of climate change. These allow the development of scenarios based in a climate-changed world, which will allow immersive exploration of the ability of Defence to meet its objectives.

Analysis used to enable strategic choices and decision-making must reflect climate change, and account for the “deep” uncertainty that a future with climate changes holds. This includes modelling, simulation, high-level operational analysis and immersive exploration, including Table Top Exercises and war gaming.

Wrapping up

We hope you found this book helpful.

Climate change is becoming increasingly important across government and within every part of Defence. This book provides an introduction to climate change highlighting some of the key issues and some potential approaches Defence can look at to mitigate and adapt to climate change, and help the UK meet its obligations and agreements.

We hope this book has helped you to understand the importance of considering climate change and ways in which you can contribute to this area.

Further reading

If you want to learn more about climate change or Defence's approach to it see the following further reading.

United Nations Intergovernmental Panel on Climate change Sixth assessment Synthesis Report (March 2023)
https://www.ipcc.ch/report/sixth-assessment-report-cycle/

- This report summarises the state of knowledge of climate change, its widespread impacts and risks, and climate change mitigation and adaptation.

Global Strategic Trends - The Future Starts Today (6th edition)
https://www.gov.uk/government/publications/global-strategic-trends

- This provides a strategic context for those in the Ministry of Defence (MOD), and wider government, through highlighting changes and trends that are likely to become threats. An identified trend which requires action is the increasing environmental stress including climate change.

MOD Climate Change & Sustainability strategic approach
https://www.gov.uk/government/publications/ministry-of-defence-climate-change-and-sustainability-strategic-approach

- This report provides MODs overarching climate change and sustainability strategic direction. It explains why climate change is relevant to Defence, what Defence's current position is and where it is aiming to get to with respect to climate change both in terms of mitigating and adapting to climate change. It states Defence's strategic ambition for CC&S out to 2050.

Defence Sustainable Support Strategy
https://www.gov.uk/government/publications/sustainable-support-strategy

- This Strategy provides Defence Support's initial response to the challenges climate change poses. It outlines how they plan to reduce emissions; increase the sustainability of operations and how to maximise the opportunities.

DSTL/PUB154268