Impacts of **climate change** on defence-related critical energy infrastructure

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Abstract

This study, which for the first time addresses the climate change-energy-defence nexus, provides a set of concrete recommendations for defence decision-makers on climate change mitigation and adaptation. To achieve this, it assesses the impacts of climate change on defence-related critical energy infrastructure, military infrastructure and military capabilities, identifies options to strengthen climate resilience and multinational collaboration, while contributing to the EU's efforts towards climate neutrality by 2050. The study was produced within the context of the third phase of the Consultation Forum for Sustainable Energy in the Defence and Security Sector to support the efforts of EU ministries of defence to strengthen climate resilience, particularly with respect to disruptions associated with defence-related critical energy infrastructure. The study contributes to the implementation of the EU's *Climate Change and Defence Roadmap* and supports the development of national strategies by EU Member States to prepare the armed forces for climate change, as called for in the EU's *Strategic Compass for Security and Defence*.

Foreword

Climate change is the most urgent challenge characterising the 21st century. It is increasingly shaping the security landscape and affects every aspect of our societies. This includes our security and defence, both in terms of the threats we face and the manner in which we prepare ourselves to address them.

As the EU advances towards a resilient *Energy Union* and seeks to become the world's first climate-neutral continent by 2050, the role of defence in this transition grows in importance.

To safeguard the overall performance of our military, we must ensure that climate change adaptation and mitigation are implemented across all military branches, including our planning, operations, training, but also when it comes to our decisions on capabilities, investment and procurement.

No single country or ministry of defence can tackle climate change on their own. It needs constant cooperation among all Member States, EU institutions and international partners.

This landmark study was conducted under the Consultation Forum for Sustainable Energy in the Defence and Security Sector – an initiative run by the European Defence Agency and gathering Europe's largest defence energy community. It offers, for the first time, valuable insights into how EU defence, energy and climate change are inter-linked and how we can best address the challenges that the climate crisis will bring.

It highlights the crucial role of defence in strengthening the climate resilience of critical energy infrastructure and the need to address excessive dependencies and vulnerabilities in this area. It gives the EU and the ministries of defence a solid basis to address knowledge and capability gaps concerning the effects of climate change on defence infrastructure, services, equipment, transportation, and personnel.

The central message that emerges is clear: there is no time to waste, we must act now. Taking into account the effects of climate change, the volatile energy security landscape and geopolitical uncertainty, it is critical to prepare our armed forces for all possible scenarios, including at operational level.

I welcome this study and the efforts of ministries of defence in developing their national defence strategies to prepare their armed forces for climate change, as called for in the *Strategic Compass*. EU institutions will continue to support this important endeavour. The upcoming EU Joint Communication on the nexus between climate change, environmental degradation, security and defence will be a key milestone in advancing towards a European Union that is better able to tackle the security and defence implications of climate change.

Josep Borrell
High Representative of the European Union for Foreign Affairs and Security Policy
Vice-President of the European Commission
Head of the European Defence Agency

Foreword

The ongoing conflict between Russia and Ukraine has significantly impacted Europe's energy system, reinforcing the need to reduce our reliance on fossil fuels and increase energy autonomy.

Since 2015, the European Commission Directorate-General for Energy and the European Climate, Infrastructure and Environment Executive Agency have been supporting EDA's work to promote sustainable energy, improve energy efficiency, and increase the use of renewables.

Together with EDA, we have recently launched a *Horizon Europe* project called Symbiosis to foster co-existence between defence activities and offshore renewable energy installations, demonstrating the defence sector's important role in advancing the energy transition.

This study demonstrates our commitment and coordinated inter-institutional approach to advance sustainable energy solutions in defence. It is an excellent example of our joint efforts to prepare the armed forces for the cascading effects of climate change and to ensure sustainability. The energy transition is only effective with the defence sector on board.

While the study emphasises the need to balance the defence sector's requirements and the goals of the *European Green Deal*, it recognises that operational effectiveness is inextricably linked to energy resilience. It provides guidance for ministries of defence on climate-proofing and investing in energy-efficient infrastructure, and it outlines how the EU can complement their efforts. It also highlights the need for a long-term perspective to address these challenges comprehensively and effectively.

The study is an essential resource for policymakers, practitioners and scholars who seek to understand the challenges posed by climate change in the context of the defence sector. Through collaboration of the military and civilian sectors, we can build a more sustainable and secure future for all, and this message has been adequately conveyed in this study.

The armed forces can demonstrate leadership in this transition as the EU advances towards a resilient *Energy Union*.

Kadri Simson
Commissioner for Energy
European Commission

Preface

Only few known threats, such as climate change, put society and our very existence at stake. The current greenhouse gas emissions trajectory brings the world closer to climate breakdown. There is no choice but to concertedly reduce emissions and adapt societies without further delay for which research and innovation are key.

EU defence is no exception to this, including via its dependence on critical energy infrastructure. The sector has recognised the limitations of fossil fuels and is ramping up its efforts to implement sustainable energy solutions.

Furthermore, Russia's war against Ukraine has only stressed what was already clear: the security of EU citizens and our European way of life depend on capable and climate-resilient European defence and energy sectors.

Recognising the lack of a systematic approach to address climate change in EU defence, this ground-breaking study of the European Commission's Joint Research Centre and the European Defence Agency describes for the first time the climate-energy-defence nexus, highlighting its importance.

The study provides key recommendations for EU defence on climate change mitigation and adaptation with respect to the operational dimension, capability planning and development, governance, multi-stakeholder engagement, and R&I. It provides scientific evidence to support the development of national strategies to prepare the armed forces for climate change, in line with the EU's *Strategic Compass for Security and Defence*.

In times of crisis, European research and innovation play a decisive role, underpinning policies and decisions that protect EU citizens and their livelihood. EU security research must continue its path of excellence, enabling the right decisions at the right time, and to inspire the talent that will develop the much-needed solutions.

The Joint Research Centre is at the forefront of this endeavour by providing independent, evidence-based knowledge and science, supporting EU policies to positively impact society.

I congratulate the Joint Research Centre and the European Defence Agency for the important work done in this joint study which is an important stepping stone in the wider effort of the EU towards achieving climate resilience and neutrality.

Stephen Quest
Director-General
JRC - Joint Research Centre

Executive **Summary**

Climate change can affect military infrastructure, military capabilities, missions and operations. Climate-related hazards can damage or destroy military assets or render them unfit for purpose in certain operating conditions, result in health and safety risks to military personnel, higher costs associated with infrastructure inspection, maintenance, repair and overhaul (MRO), but also increase the demand for civilian emergency operations.

Climate change is a growing concern for European Union (EU) security and defence. In addition to direct impacts, climate change can also affect civilian entities that operate critical energy infrastructure (CEI) and provide the energy services on which the military rely (e.g., electricity, heat, fuel). The disruption of these services may cascade to military installations, possibly with severe consequences for the operational effectiveness and readiness of the armed forces.

Often unaccounted for, climate-related hazards may also trigger technological accidents, such as oil spills, fires and explosions, phenomena that are particularly relevant in military installations and CEI that handle dangerous substances (e.g., oil and gas).

In support of the EU's *Climate Change and Defence Roadmap*, the first EU action plan to address the links between defence and climate change, and of the EU's *Strategic Compass for Security and Defence*, this joint study of the European Commission Directorate-General Joint Research Centre and the European Defence Agency aimed to:

1) assess the impacts of climate change on defence-related CEI, military installations and military capabilities, including via dependencies;
2) identify gaps and propose options to strengthen resilience to climate change in defence-related CEI, military installations and military capabilities;
3) suggest ways forward for defence to reduce its climate footprint and increase its sustainability.

The study shows that not acknowledging and anticipating the direct and indirect impacts of climate change on EU security and defence, particularly on military installations and CEI, and acting upon them, can have major costs. These mostly preventable costs will be orders of magnitude higher if a disaster or a crisis hits us unprepared, if no prior action has been taken, such as improving risk management, climate-proofing, resilience, sustainability (in alignment with the *European Green Deal*), energy security, and preparing for the energy transition. Thus, it is crucial to ensure that the armed forces' operational effectiveness is not compromised due to climate change.

Multiple existing gaps identified

The study identified multiple gaps related to the operational dimension, capability planning and development, multi-stakeholder engagement, governance, and research and development (R&D). For example:

1) Military installations may be operating with unknown climate risk.
2) There is insufficient integration of climate concerns and considerations in defence capabilities planning, investment lifecycles, procurement criteria and R&D.
3) The EU has not yet developed a strategy for energy and climate in defence.
4) EU energy systems, including those of the military, may require modernisation and investment to strengthen resilience to climate change and advance towards low greenhouse gas (GHG) emissions.
5) As CEI is owned and operated mostly by civilian entities, EU ministries of defence (MoDs) are limited in managing the associated climate risk and strengthening resilience.
6) Civilian-military cooperation needs strengthening. The dependency on civilian energy services should encourage EU MoDs to interact with civilian entities more closely.
7) Civilian CEI owned by foreign entities may pose a security threat and limit civilian-military cooperation.
8) Civilian entities operating interdependent critical infrastructure (energy, water, telecommunications, transport etc.) often do not coordinate efforts with MoDs to manage risk across sectors.
9) A sparse implementation of innovative technology projects in defence may not lead to the structural changes required to fight climate change.
10) There is a paucity of quantitative studies on the impacts of climate change on military installations, guidance for assessing climate risk and resilience, and decision support tools to compare different climate change adaptation and mitigation options.

Climate-proofing EU defence

Strengthening resilience to climate change requires implementing a set of measures across geographic scales, from national (e.g., MoD, CEI operators) to EU level, which should be based on the best available science. In this regard, this study provides concrete recommendations for EU defence decision-makers across the same five dimensions for which gaps were identified: operational, capability planning and development, multi-stakeholder engagement, governance and R&D. For example:

1) Consider developing an *EU Defence Strategy on Climate Change*.
2) Set up an *EU Multi-stakeholder Forum* for defence, energy and climate, to strengthen risk reduction and increase resilience to climate change, and to address the energy transition in defence.
3) Define a CEI strategic framework for EU defence.
4) Coordinate civilian-military response and recovery on- and off-site at the onset of a climate disaster or an energy crisis.
5) Review risk management plans to identify gaps in integrating climate-related hazards in EU MoDs' defence capability planning.
6) Develop specific guidelines for the assessment of climate risk in defence.
7) Incorporate climate considerations in military planning, investment lifecycles, procurement criteria, military training and evaluation testing and R&D.
8) New and existing infrastructure, including CEI, should be brought up to standard (modernised) where necessary, considering site-specific climate risk.
9) Establish an EU permanent programme to advance R&D and innovation on the various dimensions of climate change and defence.
10) Consider establishing an EU-led *Competence Centre for Defence, Energy and Climate*, to support MoDs in addressing the intersection of these fields and inform policy and decision-making in climate change mitigation and adaptation.

Introduction

01

In its *Sixth Assessment Report*[1] (AR6), the Intergovernmental Panel on Climate Change (IPCC) reaffirms that greenhouse gas emissions (GHG) associated with human activities are unequivocally warming the climate at an unprecedented rate, and that climate change is contributing to changes in both extreme weather and extreme climate events[2] (hereafter referred to as climate extremes), affecting inhabited regions (IPCC, 2021). The issue is so pressing that the United Nations Secretary-General called it a "code red for humanity"[3].

Western and Central Europe are expected to experience more floods and droughts (Naumann et al., 2021)[4], while in Eastern Europe more frequent pluvial flooding[5] and fire weather[6] is expected. The Mediterranean will likely be affected by a combination of several drivers of impacts (increase in temperature, heatwaves[7], drought, fire weather and coastal flooding[8]; decrease in precipitation, snow cover and wind speed). Furthermore, at high latitudes (e.g., Finland, Sweden) and altitudes (e.g., Alps), glacier melt and permafrost thawing[9] are expected to intensify, while snow cover and its seasonal duration are expected to decline (IPCC, 2021). However, extreme cold weather events will remain a significant hazard in the next decades[10]. Although severe windstorms[11] have increased in terms of reported numbers over Europe, it is still unclear if any trend can be associated with climate change (Spinoni et al., 2020), but new evidence is emerging that indeed suggests a link (e.g., Kerry, 2021; Reed et al., 2022).

In the 32 countries of the European Economic Area, total economic losses due to weather- and climate-related events occurring between 1980 and 2020, amount to EUR 450-520 billion (adjusted for 2020), and around 3% of these events account for 60% of the registered losses[12]. Every tonne of CO_2 emitted to the atmosphere will increment global warming, which will result in more widespread and more pronounced climate-related impacts[13]. Limiting global warming to a different mean global temperature increase[14] (preferably 1.5 °C – *Paris Agreement*[15]) will produce adverse impacts of different and possibly catastrophic magnitude (IPCC, 2021).

Climate-related hazards know no borders, may interact, cover wide spatial and temporal scales (e.g., Gill and Malamud, 2014), and their impacts are indiscriminate. It is, however, possible and necessary to slow global warming, halt environmental degradation and avoid even worse threats, such as climate tipping points (Armstrong MacKay et al., 2022; Lenton et al., 2008), from which we may not recover. This can be achieved through a concerted reduction of GHG emissions and adopting environmental measures to protect or enhance carbon sinks (e.g., soils, forests, oceans) that accumulate and store GHGs.

Nonetheless, this alone is insufficient, as past GHG emissions, unavoidably, have locked in different climate change impacts that are already unfolding. It is therefore necessary that the EU defence sector, like other sectors, effectively manages climate risk[16] and strengthens climate resilience[17].

With energy security[18] being essential for defence and crisis management (EDA, 2014), and energy use being the largest source of GHG emissions[19], measures directed to strengthen the resilience and efficiency of CEI[20] can be seen as strategic[21]. At the same time, the growing complexity, connectivity, interdependency and large spatial footprint of CEI may lead to a higher potential for disruptions that may cascade to military installations.

1.1. Context

In June 2019, the Council of the European Union (the 'Council') underlined the critical effect that environmental risk and climate change have on EU security and defence and welcomed a reinforced EU climate action that ensures a more sustainable and resilient EU security and defence through adequate climate change mitigation, adaptation and risk management[22]. The Council also acknowledged the impacts of climate change in assessing global threats and challenges, among others, on military capability planning and development.

In June 2020, the Council invited the High Representative to propose, together with the European Commission (EC) and the European Defence Agency (EDA), and in close dialogue with Member States, a set of concrete short-, medium- and long-term actions addressing defence and climate change. This initiative is part of the wider climate-security nexus, notably in the areas of civilian and military *Common Security and Defence Policy* (CSDP), capability development, multilateralism and partnerships[23]. As a follow-up, the EU's ***Climate Change and Defence Roadmap*** (EEAS, 2020) was issued by the European External Action Service (EEAS) in November 2020.

In February 2022, the European Commission published a communication[24], which outlines its plans and initiatives to **contribute to European defence**, boost innovation and address strategic dependencies. In this respect, the Commission focuses on enhancing European resilience by addressing, among others, climate change challenges for defence. Hence, **the Commission's objective is to establish a policy framework** to contribute to reduced energy demand and increased energy resilience of critical technologies used by civilian security actors and armed forces, and **to develop concrete climate-resilient solutions** in this context.

More recently, in March 2022, the EU's ***Strategic Compass for Security and Defence***[25] **recognised climate change as a driver of insecurity and instability and has set resilience and climate neutrality as important goals**. Specifically, this strategic document tasked EU Member States, in view of fully implementing the EU's *Climate Change and Defence Roadmap*, to develop national strategies to prepare the armed forces for climate change by the end of 2023.

Climate change is one of the 14 megatrends[26] identified and monitored by the European Commission Directorate-General Joint Research Centre (JRC) and analysed during the EU strategic foresight exercises[27], aiming to future-proof EU policymaking by fostering participatory and forward-looking governance in Europe. The impacts of climate change have been integrated into numerous documents of reference, such as the *European Strategic and Policy Analysis System*s report (ESPAS, 2019), as a key determinant of the future security landscape and a priority for EU policymaking.

Given the number of threats to defence infrastructure and capabilities that may emerge or may be exacerbated by climate change, **the EU defence sector must ensure sustainability and strengthen resilience** (King, 2014). Furthermore, regional changes in climate and climate-related hazards in Europe (e.g., heatwaves, floods, droughts, wildfires, thawing permafrost) may negatively impact the security of energy supply, increase energy demand abruptly and magnify the risk of an energy crisis (Tavares da Costa and Krausmann, 2021). Thus**, it is crucial to ensure that the armed forces' operational effectiveness and readiness are not compromised due to climate change impacts on the CEI on which they depend.**

On the other hand, sustainability goals for the EU defence sector should be aligned with the *European Green Deal*[28], under which the European Commission proposed in 2020 to reduce GHG emissions by at least 55% by 2030[29], compared to emissions in 1990. The stepping stones towards climate neutrality by 2050 (*European Climate Law*[30]) are: making buildings in the EU more energy efficient, increasing the share of renewable energy, improving energy and resource efficiency and management, incorporating clean transport and dual-use technology, integrating the concepts of circular economy[31] and green public procurement (GPP) (Paquot, 2017), and contributing to cutting-edge research and innovation.

Against this background, and considering the volatile energy security landscape[32] and the fast evolution of energy systems[33], on which military installations and military capabilities depend, **EU defence must be prepared for all possible scenarios**[34]. Accordingly, it is imperative for EU defence to:

1) address knowledge and capability gaps concerning climate impacts on assets;
2) develop concrete plans, informed by science, to strengthen resilience and reduce GHG emissions, especially considering the opportunities (e.g., prosumership[35]) and challenges (e.g., cybersecurity) of an evolving energy system.

Consequently, the JRC and EDA conducted this study in the context of the third phase of the Consultation Forum for Sustainable Energy in the Defence and Security Sector[36] (CF SEDSS) to assess the impacts of climate change on CEI and military capabilities. The study identifies policy options to strengthen the resilience of CEI to climate change, enhance multinational collaboration, and contribute towards the EU's climate neutrality.

1.2 Scope and objectives

This study proposes a **set of concrete actions** to address the links between defence, energy and climate change as part of the wider climate-security nexus, notably **in the areas of defence planning, including at policy level, capability development, research and technology and awareness raising.** In this respect, **it explores the impacts of climate change on the EU defence sector, particularly via impacts on CEI,** to address emerging and future requirements. The **goal** is to provide **recommendations for EU defence decision-makers for climate change mitigation and adaptation, including climate-proofing, to ensure sustainability and resilience.**

Complementarily, the study discusses **how EU ministries of defence (MoDs) can contribute to the EU's approach to address climate change** from a politico-strategic, infrastructure and military capability perspective and follows up with concrete recommendations to this end. By doing so, the study supports the implementation of the EU's *Climate Change and Defence Roadmap* (EEAS, 2020) and the *Strategic Compass for Security and Defence*[25], to address the links between defence and climate change.

The key **objectives** of the study are the following:

1) Assess the impacts of climate change on CEI, military installations and military capabilities, including via dependencies.
2) Identify gaps and propose options to strengthen resilience to climate change in CEI, military installations and military capabilities.
3) Strengthen multinational collaboration and contribute towards EU climate neutrality and resilience.

While climate change is considered a threat multiplier, exacerbating environmental pressures on security beyond the EU homeland and potentially creating new challenges (e.g., violent conflict) (King, 2014), this dimension is excluded from the scope of this study. Likewise, the impacts of climate change on expeditionary military operations or missions (i.e., outside the EU) are excluded. Instead, **this study is limited to the territories of the 27 EU Member States in mainland Europe, including the defence building stock (fixed infrastructure, installations, military camps), equipment (material, services), non-tactical vehicles and personnel.**

In the following chapters, the study introduces the impacts of climate change on defence, including via dependencies, provides an overview of CEI vulnerability to climate-related hazards, and uses a real-life case study to demonstrate this. It analyses gaps and barriers in the resilience of CEI, military installations and military capabilities to climate change and concludes with recommendations to enhance resilience and reduce GHG emissions in defence.

Methodology and assumptions

02

The present study was carried out jointly by JRC and EDA based on in-house expertise, horizon scanning[37] and on contributions and exchange in the scope of the CF SEDSS, Working Group 3 (WG-3) on the protection of CEI[38] (PCEI). The CF SEDSS represents the largest European defence energy community, providing a unique platform for EU MoDs and other relevant stakeholders to share knowledge and promote collaborative defence research and technology innovation in the field of sustainable energy while contributing to implementing the EU's *Climate Change and Defence Roadmap* (EEAS, 2020) and the *European Green Deal*[28]. In particular, the CF SEDSS WG-3 PCEI focuses on strengthening research on the resilience and protection of CEI, including the cascading effects of climate change, and it also addresses hybrid and asymmetrical threats.

The study was complemented with information gathered from publicly available literature (including from, but not restricted to, the EU and NATO – North Atlantic Treaty Organization), consultations with experts outside the CF SEDSS and stakeholder meetings. In some cases, newspapers were accessed to confirm findings, and provide intuition and context. Moreover, a non-EU case study was put together, based on information that is publicly available, in order to demonstrate the risks and extrapolate the lessons to be learned to the EU context.

It is assumed that any existing energy system (civilian or military), military installation and military capability is or may be to some extent affected by climate change, be it through slow-onset (e.g., sea level rise, drought) or rapid-onset (e.g., severe weather) events. The realisation of impacts depends on numerous factors that are not limited to the physical process of the climate-related natural hazard in question. The location of a military installation and of the energy systems on which it depends, determines the exposure to locally and regionally variable impacts. The level of protection, characteristics and condition of components, and configuration and management of energy systems will determine which parts of a system may fail given an impact. Dependence on civilian energy systems, their own interdependency, and the presence of dangerous substances[39], either in military installations (e.g., OME – ordnance, munitions and explosives) or in any part of the energy supply chain (e.g., oil and gas, nuclear materials, chemicals), may result in unexpected cascading effects in case of natural hazard impacts (e.g., hazardous substance releases, fires, explosions), which can exacerbate overall consequences. Equipment and preparedness plans may not be available or function according to design in these situations. The readiness of personnel to respond to an energy crisis may also prove to be inadequate.

Furthermore, it is generally assumed that historical events provide good insights into future challenges. There is no questioning that the analysis of historical events is key. However, it is essential to acknowledge that past events may not always be representative of the future. This is especially the case with climate change, black swans (Taleb, 2007), and considering the evolution of energy systems (e.g., Bellasio et al., 2021).

Climate change impacts on **security and defence** – an overview

03

Climate change is a growing concern for EU security and defence, as it can affect military installations, damage physical assets and supplies, and disrupt military operations. Impacts on military installations and CEI can compromise military capability directly (e.g., equipment damage) or indirectly (e.g., power outages), especially force structure and operational readiness, but also operational effectiveness. It may lead to higher costs due to unplanned MRO of infrastructure and equipment, which is particularly true in the absence of effective climate risk management and resilience measures.

From an international perspective, climate change may exacerbate or create new sources of instability and conflict or, in other words, it can be a threat multiplier (e.g., NATO, 2017, 2022). New tensions may arise due to a prolonged open water season in the Arctic, enabling the frequent use of a shorter trans-Arctic shipping route to the detriment of the Suez Canal in Egypt, and the disruption of economies that benefit from its use. Disputes may increase due to a warming Arctic that opens new opportunities for commercial fishing, and the exploration of previously inaccessible (shared or un-demarcated) or uneconomic oil, gas and minerals. Some countries may observe rising prices of electricity; for example, in East Africa, a decrease in hydropower due to drought and shorter rainy seasons may lead to the costly dispatch of thermal power plants and forced disruptions, with effects on the economy (Ebinger and Vergara, 2011). In fragile states, particularly those that heavily rely on primary sectors, climate change may contribute to conflict escalation through scarcity in the availability of or accessibility to water and food. This is of great concern in regions such as those south of the Mediterranean, the Middle East and Sahel that have a long history of drought, instability and conflict in some of their countries. It may lead to implications, such as a rise in involuntary migration[40], disruption of supply of critical raw materials, components and parts, price fluctuations (e.g., oil, gas, food) and spillover effects to neighbouring economies.

In addition, climate policy may have its own security risks. For example, economies highly reliant on fuel exports, or those that will benefit from global warming, are likely to clash against climate action and the energy transition. A transition that, in turn, may also have unintended side effects, reshaping supply chains, the job market and geopolitics, potentially exacerbating disputes over land and property, raw materials (including those critical for the energy transition such as rare-earth elements) and technology (e.g., Bazilian et al., 2019; Bobba et al., 2020; King, 2014; NIC, 2022; Tavares da Costa and Krausmann, 2021). All these developments are already at play, will continue to shape the EU security landscape and may challenge the armed forces.

Moreover, some actors, particularly those empowered by information and communications technologies, may subversively exploit vulnerabilities to undermine, polarise, confuse, or compromise policy and decision-making with the purpose of gaining a specific advantage, something that is known as hybrid threats (Giannopoulos et al., 2020). Climate change, disaster conditions and conflict may potentiate chaos and confusion, rearrange spheres of influence and create the right opportunities to launch hybrid attacks. Climate change intersects with energy matters, and energy can be weaponised and used as a tool for hybrid warfare (Rühle and Grubliauskas, 2015).

Finally, the armed forces may need to prepare for the challenges and opportunities associated with developing new capabilities, presented by a transitioning civilian energy system (e.g., Bellasio et al., 2021; IEA, 2020, 2021a). In addition, they need to prepare for more frequent support requests in civilian operations due to climate-related disasters, such as civil protection, including search and rescue and evacuation, and humanitarian aid.

In the following sub-sections, an overview of the direct and indirect impacts of climate change on EU defence is presented. Most information in Section 3.1 was developed based on the study *Impacts of natural hazards* and climate change on *EU security and defence* by Tavares da Costa and Krausmann (2021), unless otherwise stated.

3.1. Impacts on defence infrastructure and capabilities

Military installations are the backbone of operational readiness. They support evaluation testing, MRO and deployment of weapons systems, training and mobilisation of combat forces, combat operations, as well as staging platforms for humanitarian aid and more. In general, they often procure a broad set of products, equipment and services to meet the requirements of these tasks.

Besides personnel, each military installation houses common facilities (e.g., administrative buildings, training and testing grounds, storage of OME, fuel depots, medical, lodgings, firefighting) and specific facilities according to operation type, such as land-based (e.g., vehicle MRO and storage), air-based (e.g., runway, taxiways, helipads, traffic control, spaceport, aircraft MRO and storage, missile silos) and naval (e.g., anchorage area, dry docks). They also house tactical and non-tactical vehicles, vessels and aircrafts, equipment, dangerous (e.g., OME) and non-dangerous supplies (e.g., spare parts) of different types and in different quantities.

Figure 1. Illustration of a military installation showing on-site critical systems, some of which could be civilian owned and operated through rights-of-way easement, for example. A military installation can be contiguous or outlying, including individual buildings, camps, stations, etc. (image design using vectors from Freepik.com).

Facilities within a military installation depend on several critical systems such as electric power, oil and gas distribution, water distribution (including for firefighting), stormwater and wastewater collection and treatment, lighting (including emergency and visual light aids), telecommunications, heating, ventilation and air conditioning (HVAC), life-safety and security (Figure 1).

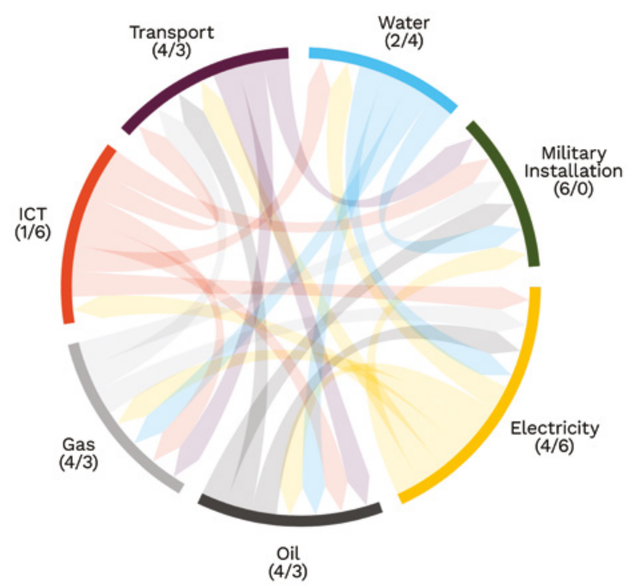
Climate change poses numerous direct threats to military installations and capabilities. It can transform normal operating conditions of facilities, transportation and equipment and of personnel by, e.g., increasing temperatures, changing patterns of precipitation and sea level rise. It may result in simple disturbances or lead to serious disruptions over time, if not properly addressed. Examples include equipment malfunctioning, more frequent MRO, higher energy consumption, less training and evaluation testing, more water restrictions, limited access to sites and/or facilities, military land degradation (e.g., thermokarst[41], permanent flooding, desertification), poor health and well-being of personnel.

On the other hand, climate change may also drive a change in seasonality and an increase in the frequency, intensity and duration of some severe weather events. This can result in a higher risk of harm to personnel, damage to military installations and equipment, and in the prolonged disruption of missions and operations (e.g., frequency and nature of offensive, defensive, and stability or support deployments), logistics and supply chains. Furthermore, **since the military store, handle or transport dangerous substances, secondary hazards must also be considered, since natural hazards[42] may trigger technological accidents** (known as Natech accidents). Natech accidents involve the release of dangerous substances, which can amplify overall natural hazard impacts (e.g., by causing fires, explosions, toxic air releases, oil and chemical spills) on- and off-site (Krausmann et al., 2017, 2019).

In Table A 1 (Annex) the potential impacts of climate change on military installations, and more specifically on facilities, equipment and personnel are summarised. Note that **for all climate-related hazards there may be an increase in demand for securing critical infrastructure (e.g., during a prolonged blackout), MRO, a higher need for supplies, spare parts and staffing[43], limited access to facilities and equipment, delayed operations[44], degradation and loss of military land, reduced readiness, reduced cognitive performance of personnel, and higher operational costs.**

Although Table A 1 (Annex) groups climate change impacts by natural hazard type, it must be noted that the **climate-related hazards discussed may happen simultaneously and self-reinforce** (compound events[45]). A wildfire, for example, may be triggered by lightning and aggravated by a windstorm, leading to multiple impacts associated with different hazard types. On the other hand, **the accumulation of dried-out vegetation near facilities or equipment increases the potential for fire damage in case of wildfire. Snow or ice-covered soil and limited infiltration** (e.g., post-fire vegetation cover and soil properties) **and drainage** (e.g., clogged water systems) **increase flood hazard.**

Figure 2. The dependency of military installations on services provided via interdependent critical infrastructure. In parenthesis the count of incoming followed by the outgoing provision of services (ICT: Information and Communication Technologies).



3.2. Cross-sector dependencies and potential for cascading effects: energy supply

Military installations often rely on the uninterrupted provision of different services (e.g., electricity, gas, fuel, water) by civilian entities that operate critical infrastructure. Security of supply of these services is often crucial to the military (e.g., gas supply to heat buildings, fuel supply for vehicles, vessels and aircrafts). Their disruption, for example, because of natural hazard impacts or cascading effects, may significantly impair operational effectiveness, readiness and sustainability.

However, only a small fraction of the critical physical assets and systems (e.g., electric power distribution) are located, (possibly) owned, and operated by the armed forces. Thus, there is only so much they can do alone to manage climate risk and strengthen resilience to climate change. To overcome this challenge, collaboration with operators and regulators of critical infrastructure is necessary.

Critical infrastructures are interconnected and interdependent (e.g., energy systems need telecommunications and vice-versa) complex systems or systems of systems (ENTSO-E, 2019b). They can be spatially distributed covering vast geographical areas, managed by multiple entities, and serving multiple customers simultaneously, often in a competitive market. These characteristics may further expose military installations to the indirect impacts of climate change. In Figure 2, the dependencies of a military installation on different critical infrastructures, and their subsequent interdependencies, are mapped.

Electric power, oil or gas systems are characterised by key elements, such as production, conversion, storage, transport in the case of oil and gas, and transmission and distribution to large-volume (e.g., industry, military installations and airports), commercial or residential end-users.

In particular, the **electricity supply chain** is characterised by bulk electricity generation (e.g., hydroelectric power plants, thermal power plants, wind turbines, PVs – photovoltaics), transmission (e.g., step-up transformers, high-voltage transmission lines), conversion (electrical substations, step-down transformers) and distribution (e.g., low- and medium-voltage distribution lines, transformers) to end-users. End-users may also be non-utility producers (individual or aggregated) connected to the electrical power grid.

The **oil supply chain** is characterised by on- or offshore production, refining, transport (via pipelines, tanker trucks, tank wagons, oil tankers), short- and long-term storage, blending and distribution.

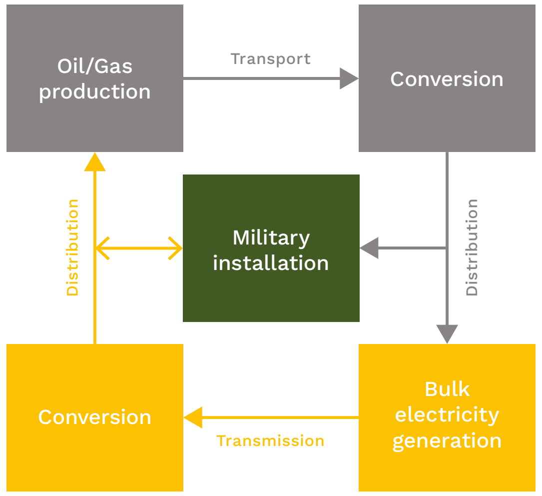


Figure 3. Military installation depicted as a large-volume end-user (also potentially producer, e.g., via renewable energy) of electricity, oil and gas within interdependent CEI.

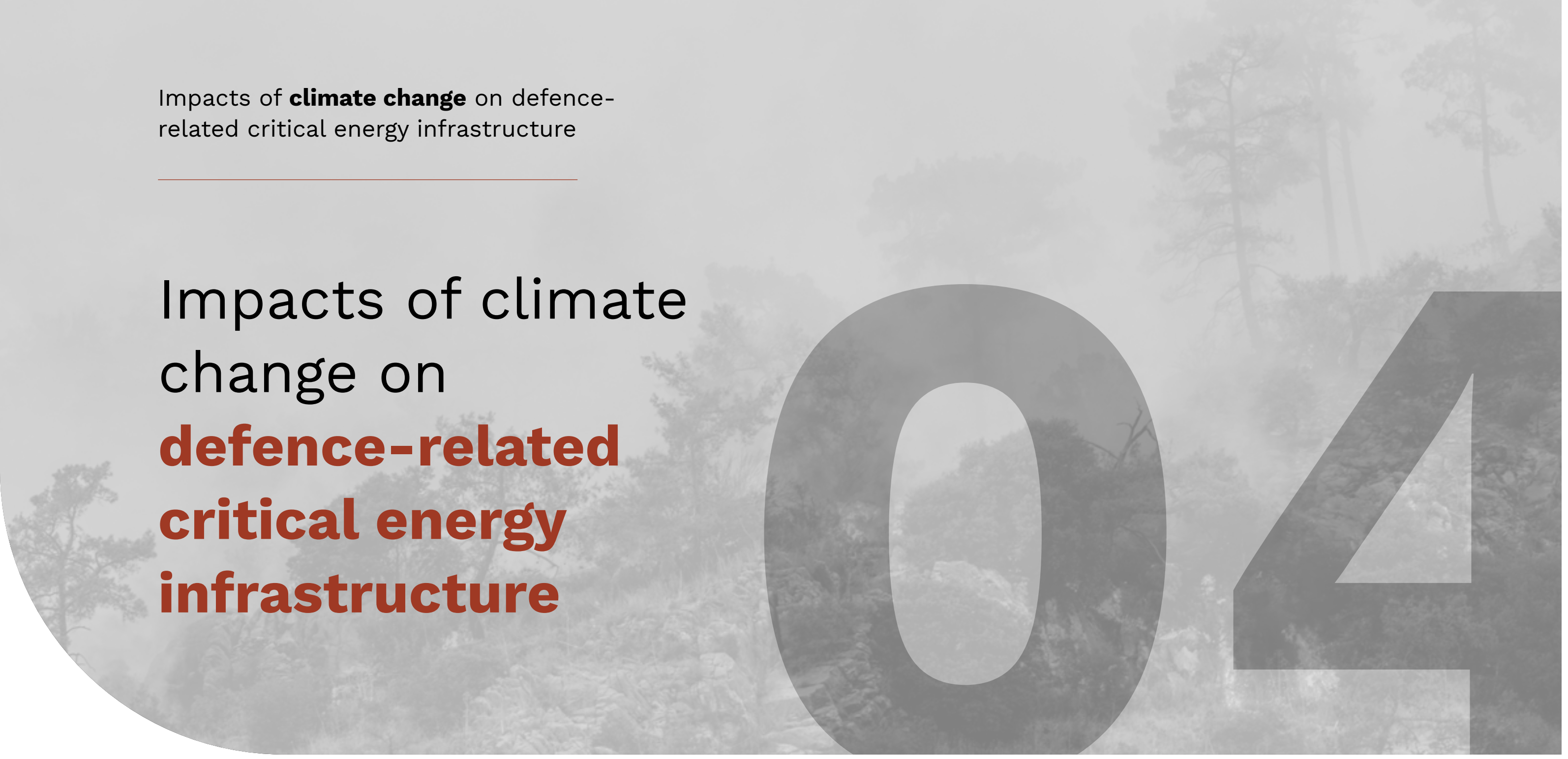
The **natural gas supply chain** features gas processing at the wellhead before transport (and fractionation after), and it may incorporate liquefaction and regasification for transport, and compressor stations for periodic pressurisation in case of pipelines.

Energy systems may also include other vital elements such as storage facilities (e.g., storage tanks, underground gas storage, batteries[46] and dams), metering units and control systems (e.g., SCADA – supervisory control and data acquisition system). The complexity of energy systems stems from their organisational and structural diversity, and different design approaches, which is further increased with connectivity and interdependency. Figure 3 illustrates an interconnected and interdependent CEI, with the military installation depicted as a consumer of electricity, oil and gas.

An energy system of systems has components with different degrees of vulnerability (e.g., narrow operating limits). If a single or multiple components fail or trip[47] because of climate extremes, and countermeasures are not in place or effective, a disturbance may quickly propagate within an energy system and eventually result in a large-scale service disruption. For example, in November 2006, the intentional but insufficiently coordinated, transmission line switch-off in an EU Member State led to the overloading and automatic disconnection of other lines and the splitting of the Central Europe Synchronous Area. A generalised blackout cascaded across sectors and EU Member States[48] (BNetzA, 2007; ERGEG, 2007; UCTE, 2007) and beyond EU borders (van der Vleuten and Lagendijk, 2010). Several other examples of large-scale power outages in Europe exist and are well documented (e.g., EC, 2018; ENTSO-E, 2010, 2021b; OECD, 2019; OSCE, 2016; Schläpfer and Glavitsch, 2006; Stefanini and Masera, 2006).

If CEI can be disrupted by human error at scales that extend beyond national borders, then they may also be disrupted by climate change with its regional or even global impact, potentially affecting military installations. Moreover, the risk of disaster or an energy crisis may increase as a result of economic and population growth (greater demand and exposure), changing operating conditions, climate extremes, ageing infrastructure and lack of investment, as well as inadequate planning and coping capacity. These conditions may also constitute an opportunity for some actors to use energy supply for economic pressure, and as a tool to gain political leverage or strategic advantage.

From a resilience standpoint, it is important to assess CEI resilience to climate change considering the increasing connectivity and interdependency of energy systems, and their respective supply chains. This assessment should include not only elements that relate to infrastructure, but also to socio-economic and environmental aspects, as they all play a role in strengthening resilience (Vamanu et al., 2021).



Impacts of climate change on **defence-related critical energy infrastructure**

04

Although energy is at the heart of tackling the climate crisis[49], and crucial for socio-economic development, the impacts of climate change on energy systems have not received enough attention from the scientific community (IEA, 2020). Not only will energy supply chains face increasing pressure to reduce GHG emissions, but they must also strengthen their resilience to the challenges ahead (e.g., rapidly changing operating conditions).

The armed forces, on the other hand, require uninterrupted energy supply for their installations, tactical and non-tactical vehicles, vessels and aircrafts, and equipment to function. For military installations, the tendency is to establish contracts with civilian energy providers, which creates a dependency on external sources, over which the military have limited control (Tavares da Costa and Krausmann, 2021). Without an adequate supply of energy, all energy-dependent military capabilities are at risk. Climate change creates or exacerbates challenges for the reliability, security, efficiency and resilience of CEI.

Although **data on cascading impacts of CEI on military installations in Europe is not available, in the US, the Department of Defence (DoD) *Annual Energy Management and Resilience Report* provides a yearly overview of utility outages** (DoD, 2020). **In 2020, DoD military installations experienced 3 018 unplanned utility outages** (electric power, gas, steam, water and wastewater), with **ca. 97% corresponding to energy outages**, and 649 lasting more than 8 hours, of which 40% were caused by equipment failure and **25% were due to severe weather.** In privatised systems, 643 outages were reported, with ca. 91% being energy outages, and 111 lasting more than 8 hours, with equipment failure and severe weather being the main causes.

4.1. Vulnerability of CEI to climate change

Each climate-related hazard produces different types of stress over different components of an energy system, which may result in different types of damage and disruption. As a result of comprehensive research[50], the impacts of climate change on CEI are summarised in Table A 2 (Annex) as a function of climate-related hazard.

To avoid duplication in Table A 2, **impacts that are common to all climate-related hazards are listed here and include: the possibility of loss, limited access to or unavailability of tools, means and/or facilities[51], an expected increase in MRO and response and recovery operations, in delays, staffing, parts and equipment needs, operational costs, energy bills and the danger of stranded assets**[52].

For electricity infrastructure, impacts that are common to all climate-related hazards include:

- overloading of transmission and distribution lines;
- forced changes in the topology of the electrical power grid[53];
- reduced import/export capacity;
- violation of the N-1 criterion[54];
- shutdown of substations and power plants[55];
- reduction of reserve capacity;
- adequacy problems[56];
- frequency degradation;
- load curtailment and shedding[57];
- violation of voltage standards;
- electric power quality issues[58];
- higher potential for power outages[59];
- frequent use of backup power;
- economic losses and risk of bankruptcy[60];
- rise in prices.

Similarly, **for oil and gas infrastructure, impacts that are common to all climate-related hazards include:**

- violation of the N-1 formula[61];
- economic losses and risk of bankruptcy;
- fuel supply disruption[62], including for electricity generation, supply crunch and rise in prices.

In the same way as for climate change impacts on military installations (Table A 1), **compound events may occur and impact CEI**, e.g., dried out vegetation near CEI may ignite, increasing the potential for fire damage; covered, saturated or impervious soil and limited drainage increases flood hazard.

Impacts on CEI may also occur simultaneously in multiple parts of a system, propagate to other critical infrastructures (e.g., water, telecommunications), **and indirectly affect military installations**. It is also important to note the specific interdependency of energy systems, where **a disruption of one energy system may easily result in another disruption**. For example, thermal power plants need a continuous supply of fuel, while at the same time oil and gas production, conversion and transport need uninterrupted access to electricity from the power grid to operate.

Climate processes also affect the availability of renewable resources, and the prospects of extended periods of scarcity are a serious issue (*e.g., droughts, dunkelflaute events*[63]). Under a baseline warming scenario (RCP6.0 – Representative Concentration Pathway 6.0; van Vuuren et al., 2011), Europe is expected to experience an increase in the technical potential of bioenergy (considering CO_2 fertilisation[64]) and solar (PV and CSP). At the same time, a decrease in hydropower is expected towards southern Europe, while wind power shows a complex pattern with localised increases and decreases across Europe (Gernaat et al., 2021).

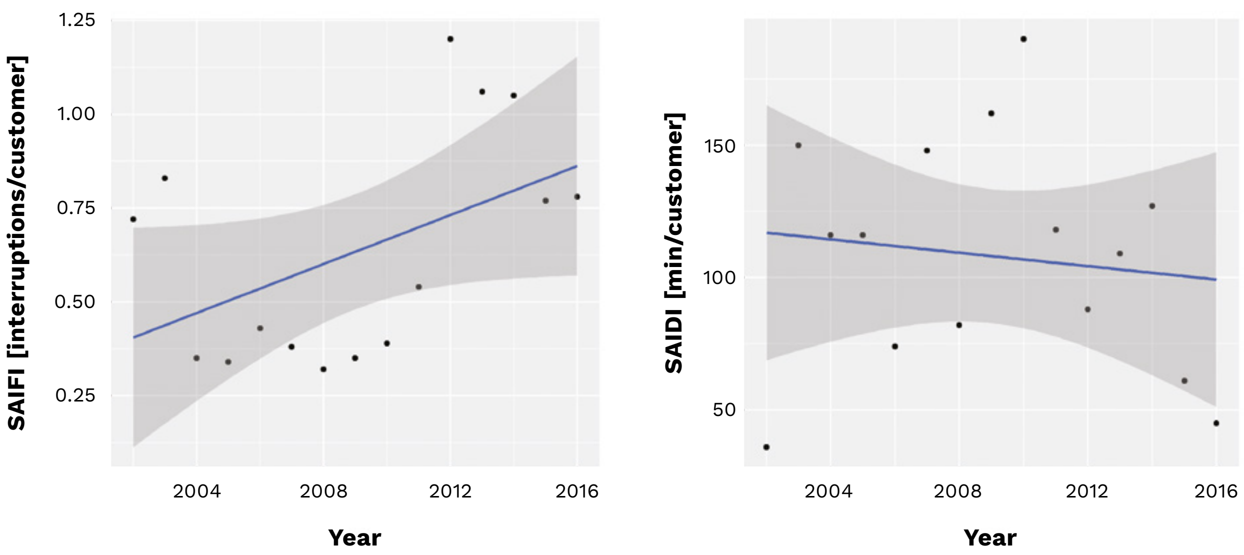
4.1.1. EU electrical power interruptions

From 1965 to 2019, natural hazards have been one of the main causes (mostly windstorms and lightning) of power outages[65], particularly in developed economies (Rentschler et al., 2019), and an increasing trend has been observed in the last decades (e.g., Alhelou et al., 2019; Bompard et al., 2013; CRO Forum, 2011; DoE, 2017; OSCE, 2016; Rahman et al., 2016). Some studies recognise that this trend may be bound to continue, and that the duration of power outages may increase, particularly due to ageing infrastructure and climate change (e.g., IEA, 2021b; OSCE, 2016).

Blackouts are often long-lasting, but also infrequent. In Europe, from 2002 to 2014, severe weather contributed to a yearly variation of 10 to 1 100 min duration of unplanned long interruptions (including all events) (CEER, 2016). Rentschler et al. (2019) computed from 2000 to 2017 an average interruption duration of 540 min, and an average annual interruption of 8 100 min for Europe due to natural hazards. Between 2010 and 2016, Hallegatte et al. (2019) estimated that **power outages triggered by natural hazards lasted ca. four times longer than those attributed to non-natural causes** and were responsible for ca. 37% of total outage duration in the considered European countries.

Power outages are often linked to disruptions of the distribution network. However, disruptions of the transmission network, an infrastructure that may be central to the energy transition, often lead to widespread outages (EC, 2018). To assess the electrical system's reliability[66] towards unplanned interruptions from exceptional events[67] in Europe, the difference between reliability indices reported in CEER (2018) for unplanned interruptions, including and excluding exceptional events, was calculated and averaged over the EU27+UK[68]. In Figure 4, the System Average Interruption Frequency Index (SAIFI) obtained shows a significant increase between 2004 and 2016, while the System Average Interruption Duration Index (SAIDI) slightly decreases. This shows that, **on average, system interruptions are becoming more frequent in Europe**, due to unplanned interruptions from exceptional events, but slightly shorter as well[69].

Figure 4. Average electrical system reliability indices for unplanned interruptions from exceptional events for the 27 EU Member States and the United Kingdom. a) System Average Interruption Frequency Index (SAIFI); and b) System Average Interruption Duration Index (SAIDI). Based on data from CEER (2018).



According to the latest ENTSO-E (2021b) report, between 2016 and 2020, only one frequency degradation event was attributed to environmental causes (in 2019). Similarly, only one violation of standards on voltage (in 2018), only one event involving loss of tools, means or facilities (in 2020), and two N-1 violations (in 2018) were attributed to environmental causes. In contrast, environmental causes were the second most important cause of events involving transmission system elements (231 in 2018, 266 in 2019, and 306 in 2020). No events associated with power generating facilities and involving the reduction of reserve capacity were attributed to environmental causes in the same period[69].

According to the European Commission (2018), in terms of electricity supply disruptions, the average number of significant forced disruptions[70] per customer was 1.9 for the period 2010 to 2014, with an average duration of ca. 84 min. The average total minutes lost per year per customer were 175 min. **Of all recorded disruptions in electricity supply, 33% were due to natural hazards. Finally, the 20 largest disruptions between 2010 and 2016 led to ca. 70% of total electricity not being supplied, with causes mostly attributed to natural hazards or equipment failure**[69].

According to the same study (EC, 2018), a total of 18 408 power generation interruptions were recorded in 2016 and 2017 for the EU27+UK, 35% of these occurring in the UK alone, with more than half being forced. An average of 41 MWh of total electricity per installed capacity was not generated. **Most outages and non-generated electricity occurred in fossil fuel power plants. Thermal power plant outages (including nuclear) resulted in significantly larger affected capacity. Renewable energy, on the other hand, caused relatively fewer outages than non-renewable sources.**

4.1.2. EU oil incidents

Concawe (2022) has collected oil spill data on European cross-country oil pipelines from 1971 to 2020, with nearly 36 000 km length transporting ca. 615 million m^3/year of crude oil and oil products. In the Concawe database, there were 508 oil spills recorded over this period from all causes (excluding those related to theft), with an overall oil spill frequency of 0.43 oil spills/1 000 km•year. A decreasing trend has been observed over the years.

Natural hazards have been one of the main causes of large oil spills recorded, most occurring in the pipe run (80%), but also in small-bore connections and joints. Causes of oil spills are different for hot (mostly corrosion related) and cold pipelines. Natural hazards (mostly landslides, followed by subsidence and floods) account for 3% of major oil spills in cold pipelines, out of 440 incidents from all causes (excluding theft). This corresponds to an average of 0.3 oil spills/year due to natural hazards.

4.1.3. EU gas interruptions and incidents

The same approach used in assessing electrical system reliability was used to assess gas system reliability[71] in the face of unplanned interruptions from exceptional events in Europe. As can be seen in Figure 5, both SAIFI and SAIDI decreased between 2010 and 2016. This shows that, on average and over time, gas systems are experiencing fewer interruptions and that these are of shorter duration. As before, this interpretation must be taken with care, particularly because very few data points are reported for gas, while gas systems have much higher technical requirements, and gas can be stored, influencing operational decisions (CEER, 2018). It should also be noted that due to undergrounding of pipelines, and thus less exposure to climate extremes, SAIDI values are lower for gas than for electricity (CEER, 2018).

The European Gas Pipeline Incident Data Group (EGIG, 2020) collects incident data on 142 711 km of onshore gas pipelines every year from 17 gas transmission system operators in Europe. In its database, 1 411 pipeline incidents were recorded from 1970 to 2019, with ca. 5% igniting. The overall failure frequency in this period is ca. 0.29 incidents/1 000 km•year, and a decreasing trend has been observed over the years.

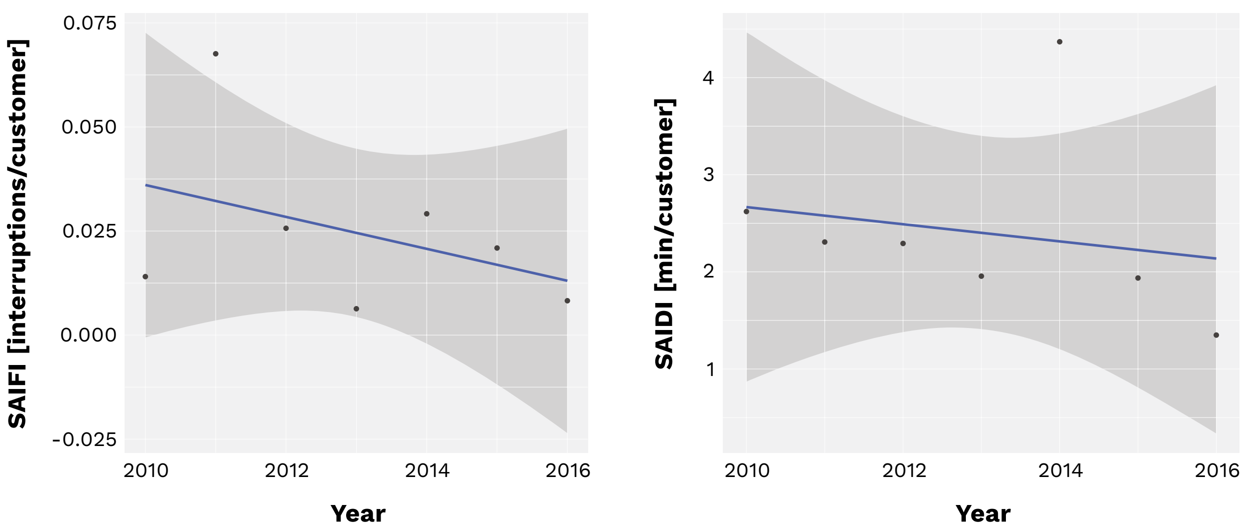


Figure 5. Average gas system reliability indices for unplanned interruptions from exceptional events for the 27 EU Member States and the United Kingdom. a) System Average Interruption Frequency Index (SAIFI); and b) System Average Interruption Duration Index (SAIDI). Based on data from CEER (2018).

In the same database, the cause category that most relates to natural hazards is "ground movement", covering anything from dike breach, erosion, flood, and landslide, to mining and unknown events. In the last 10 years this category was responsible for 16% of all pipeline incidents recorded and its failure frequency of 0.025/1 000 km•year has stayed fairly constant. Incidents in this category (mostly due to landslides and floods) are characterised by severe consequences, and failure frequencies tend to decrease with increasing pipeline diameter. Incidents in the "ground movement" category are responsible for 48% of all leaks associated with ruptures and ca. 22% with holes. In the "other and unknown" category, ca, 29% of incidents are associated with lightning, representing a failure frequency of 0.0066/1 000 km•year, which tends to decrease with increasing wall thickness.

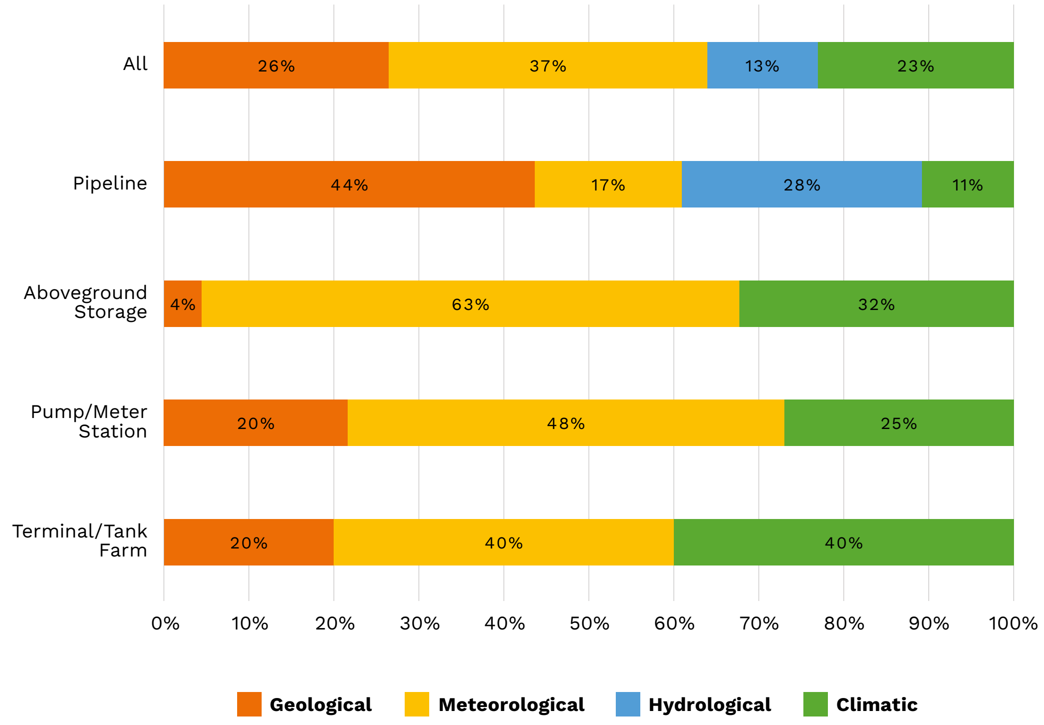


Figure 6. Share of natural hazard categories of Natech accidents per hazardous liquid pipeline system element in the PHMSA database, data from 1986 to 2012 (Girgin and Krausmann, 2015).

4.1.4. US Natech accidents

Since there is a paucity of detailed public European data on oil and gas incidents, a brief overview of the US Pipeline and Hazardous Material Safety Administration (PHMSA) incident data is provided based on previous studies (Girgin and Krausmann, 2014, 2015, 2016). The PHMSA database covers a total onshore hazardous liquid[72] pipeline network length of 299 674 km, reporting 387 incidents triggered by natural hazards from 1986 to 2012, which corresponds to 5.5% of all incidents reported.

The identified Natech accidents in this period led to ca. 50 510 m^3 of hazardous liquid spills (mostly at pipelines, followed by above ground storage tanks), resulting in ca. US$597 million of economic loss mostly associated with hydro-meteorological hazards. Although less frequent (5.5% of incidents from all causes), Natech accidents had more severe consequences and resulted in higher economic damage (18% of economic losses from all causes).

The main trigger of the identified hazardous liquid spills due to natural hazards in the PHMSA database were meteorological hazards (37%; mostly lightning, followed by heavy rainfall and storm), geological (27%; mostly subsidence, followed by frost heave), climatic (23%; mostly freeze, followed by cold weather) and hydrological hazards (13%; mostly floods, followed by erosion).

Furthermore, the identified incidents in the PHMSA database show that hazardous liquid pipelines were mostly affected by geological hazards, followed by hydrological hazards. Aboveground storage tanks suffered damage mainly due to meteorological and climatic hazards (also confirmed by Necci et al., 2018). Meteorological hazards were the main accident trigger in pump and meter stations. Finally, tank farms and terminals were mostly affected by meteorological and climatic hazards (Figure 6).

4.2. Case study: US winter storm and Texas energy crisis in 2021

A weak polar vortex[73] in February 2021 led to one of the coldest winter storms on record in the US (coldest and snowiest February since 1979)[74,75]. The cold front arrived at the north-western counties of Texas on 11 February with sleet and freezing rain. On 14 February, hard freeze and wind chill warnings were in effect and on 15 February most of Texas was covered in snow and ice[76,77]. Record snowfall of ca. 13 cm was observed at Dallas-Fort Worth Airport[78], with temperatures of ca. -17 and ca. -9 °C and a total number of frozen hours of 222 and 112 in Dallas and Houston, respectively[75]. The winter precipitation and cold temperatures (ca. 20 °C below normal[79]) persisted until 20 February.

Although there is high confidence that climate change is making cold events less frequent and less severe in the long-term (IPCC, 2021), their occurrence may continue in the next decades and it is not well understood yet how events such as the winter storm that affected Texas relate to climate change (Cohen et al., 2020). One theory points out that because warming is happening faster in the Arctic, there may be a more unstable polar vortex and wavier jet stream and, thus, a higher chance that cold weather reaches mid latitudes (Cohen et al., 2021).

4.2.1. Impacts on the energy supply

The winter storm of February 2021 resulted in the concurrent disruption of natural gas, electricity (Figure 7), water supply and transportation for several days (Doss-Gollin et al., 2021)[80]. This led to knock-on effects on military installations.

Electricity supply was unable to match demand, which was ca. 14% underestimated (UTA, 2020) (Figure 8), due to outages or derating (i.e., operation below net maximum capacity[81]) of a reported 1 796 electricity generation and storage resources[82,83].

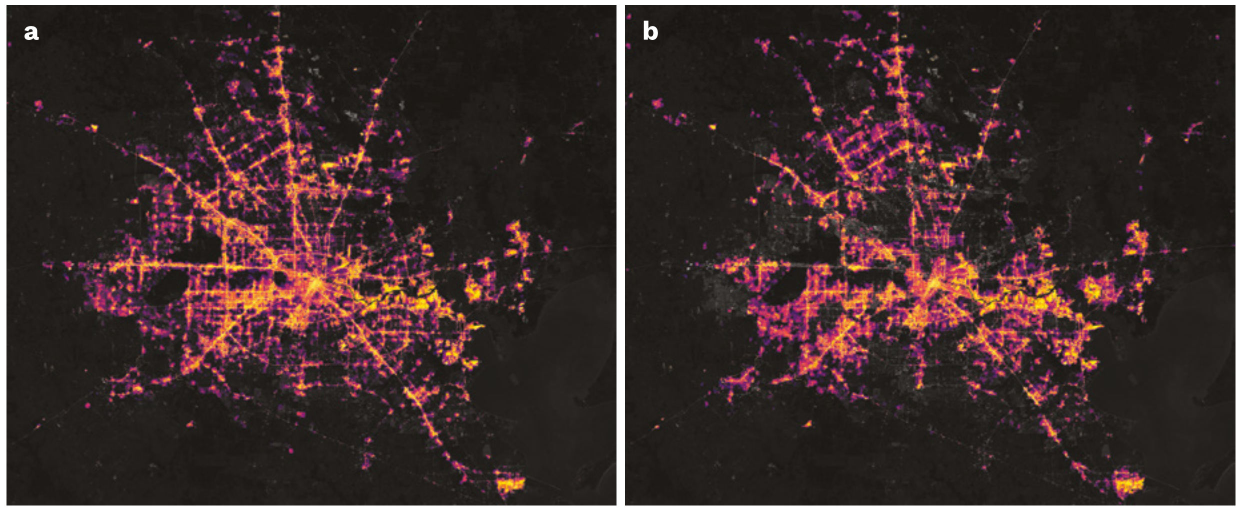


Figure 7. Satellite imagery of night-time lights in Houston, Texas, US. a) before (7 February 2021); and, b) after (16 February 2021) the power outage. Source: NASA

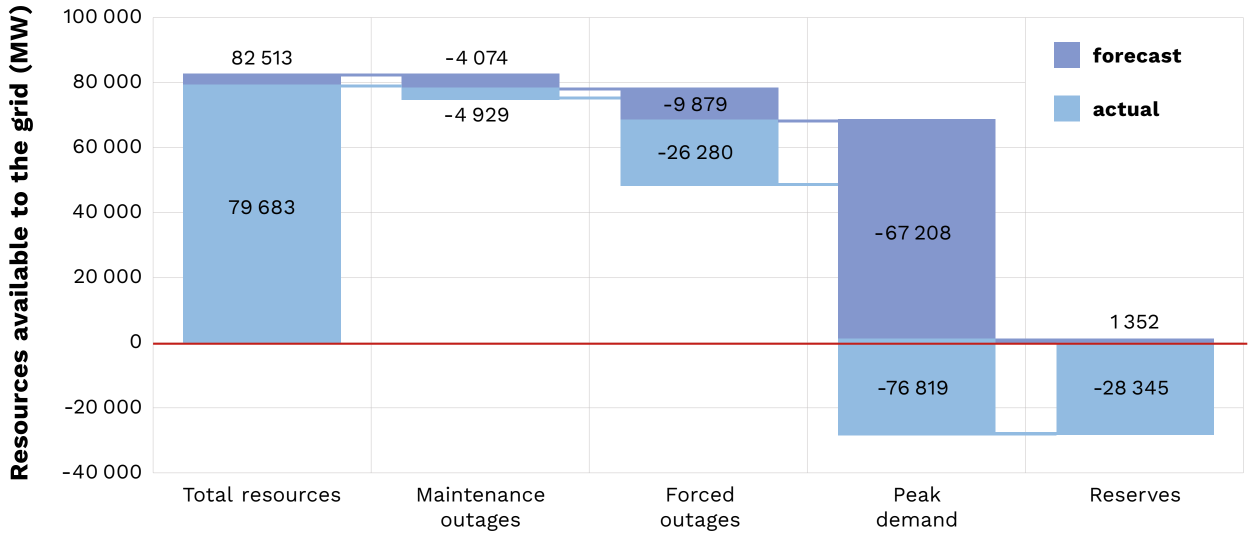


Figure 8. Waterfall chart showing the discrepancy between forecast resources, outages and extreme peak load for 2020/21 and actual resource availability on 16 February 2021 at 9 am, where there was an insufficient capacity reserve (shortage of 28 345 MW versus a reserve forecast of 1 352 MW) to manage an emergency. Data source: ERCOT

Feed-in shortfall was ca. 48.6% (52.3 of 107.5 GW Texas grid's total installed capacity), most of which was related to cold weather (e.g., frozen equipment, frozen water and sensing lines, wind turbine blade icing)[84], followed by not-weather-related equipment issues (e.g., trips and derates due to control system failure or excessive turbine vibration), fuel issues (e.g., shortage and supply instability, contaminated fuel), and to a lesser extent transmission loss and frequency fluctuations[83,85].

In the early hours of 15 February, frequency dropped well below the utility nominal frequency of 60 Hz (demand exceeding combined generation capacity, which must always be in balance) putting the grid at risk of complete collapse (Figure 9). Load shedding was used by grid operators to restore system stability and prevent a blackout.

In terms of fuel type, most outages and derates were related to natural gas shortfall (due to high demand, ca. 85% production drop on 16 February due to outages, forced shut-ins, frozen pipelines and well-heads, and near depletion of stored gas), and to a lesser extent coal and wind (Doss-Gollin et al., 2021; UTA, 2020)[80,85,86] (Figure 10).

Moreover, the South Texas Nuclear Generation Station Unit 1 shut down for more than 60 hours due to low steam generator levels resulting from the loss of two feedwater pumps attributed to a false signal from freezing conditions[87,88].

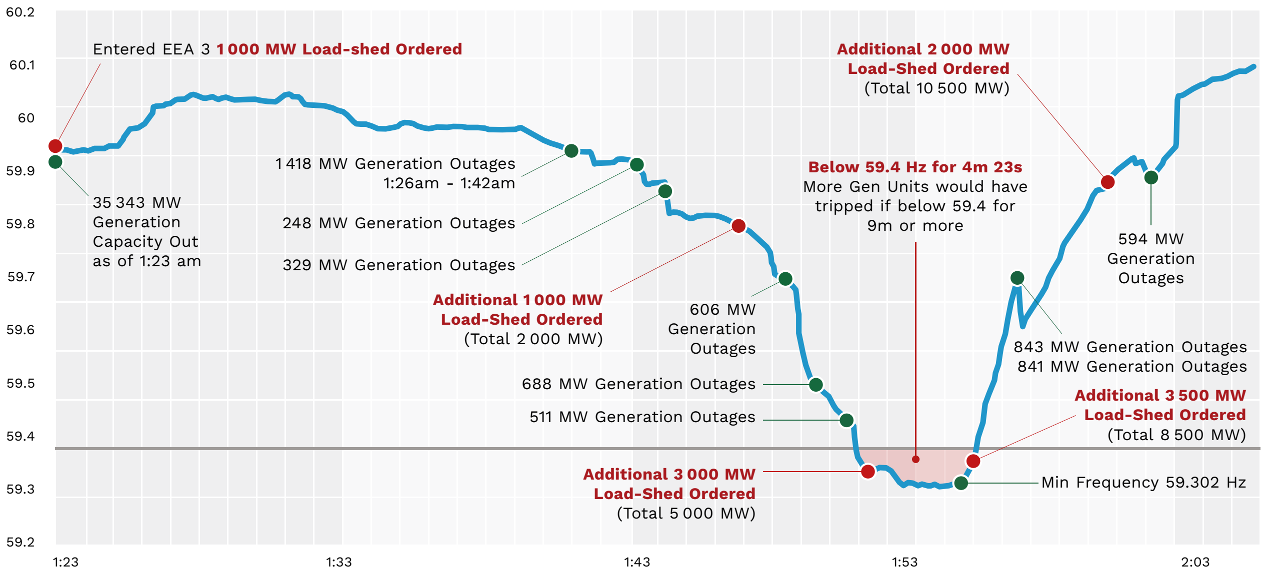


Figure 9. Frequency drop on 15 February 2021 due to a rapid decrease in generation. Source: ERCOT

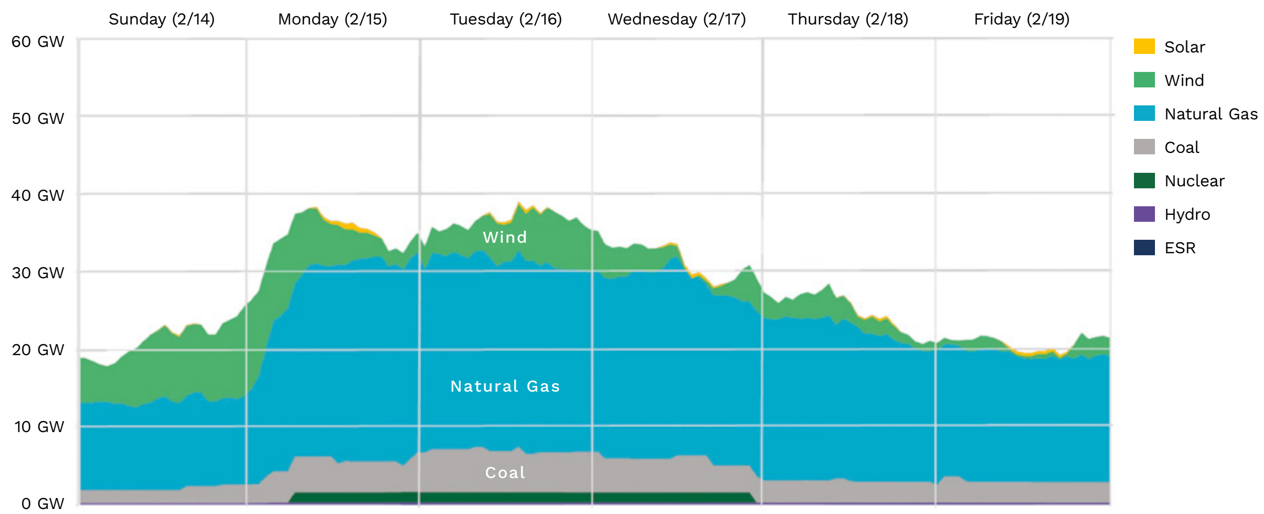


Figure 10. Net generator outages and derates by fuel type from February 14 to February 19, 2021. Wind and solar values are based on the estimated output that was lost due to outages and derates. ESR means energy storage resources. Source: ERCOT

4.2.2. Causes of the energy supply disruption

Based on the documents published by the US Federal Energy Regulatory Commission[85], the Electric Reliability Council of Texas[83,86,89], Doss-Gollin et al. (2021), UTA (2021) and the International Energy Agency[80], a number of factors were identified as contributors to the disruption of energy supply, such as:

- The winter storm timing and severity was underestimated.
- Peak demand during the winter storm was underestimated.
- Electricity and gas facilities were vulnerable to cold weather.
- Load shedding affected gas facilities that relied on electrical power.
- High reliance on gas and competing gas consumption (e.g., exports, power plants, residential, commercial, and small industry increased their consumption, while only large industry decreased).
- There were constraints in natural gas supply to power plants.
- Frequency dropped due to a rapid increase in demand and a decrease in generation capacity.
- Rolling outages were limited due to high number of circuits with critical loads.
- Electricity provided via the intra-state grid was affected due to limited interconnections.
- Separate regulatory oversight for gas and electricity was in force, possibly leading to fragmentation in monitoring and emergency planning.

4.2.3. Consequences for military installations

The US winter storm and Texas energy crisis in 2021 resulted in numerous severe consequences for military installations, such as:

- Several military installations in Texas were heavily impacted (directly and indirectly) by the winter storm, some of which were down to mission-essential personnel only[90,91,92,93,94,95,96].
- The US Air Force faced ca. US$72 million in damage[97] and saw 28 of its military installations in the US impacted by the winter storm (e.g., Minot Air Force Base had to rely on backup power generators for part of a nuclear missile field)[98].
- Military installations in Texas that kept using grid electricity during the winter storm faced very high utility bills (e.g., Fort Hood received a utility bill of ca. US$35.9 million for February, when it normally would have been ca. US$1.2 million[99,100]).
- Military installations in Texas also faced high water-related economic losses associated with pipe breaks and clean-up activities (e.g., Fort Hood faced ca. US$12 million in repairs[100]).

In Figure 11, the effects of the US winter storm and Texas energy crisis in 2021 are illustrated through a series of photographs taken by the US Department of Defence (DoD).

Figure 11. Effects of the US winter storm and Texas energy crisis in 2021, US. a) US Army Corps of Engineers hydroelectric power plants helped to stabilise the electrical power grid; b) Laughlin Air Force Base under severe weather; c) B-52H bomber idles as Airmen get ready to fly at Minot Air Force Base; d) pipe damaged at Joint Base San Antonio. Sources: a) Edward Johnson/DoD; b) Airman 1st Class David Phaff/DoD; c) Senior Airman Dillon Audit/DoD; d) Sarayuth Pinthong/DoD

4.2.4. Lessons learned

The US winter storm and Texas energy crisis in 2021 resulted in some important lessons[80]:

- Markets alone do not seem to provide enough incentive to reduce risk and strengthen CEI resilience to natural hazards and climate change.
- The weatherisation of energy systems needs firm and coordinated oversight.
- Demand-response and rolling outages need a more granular approach (e.g., identification of critical loads) and better prioritisation.
- Energy systems require more flexibility (e.g., energy efficiency, interconnections, storage, distributed and dispatchable generation, optimised backup power generators, demand reduction, smart microgrids).
- Multi-stakeholder involvement in scenario building and crisis gaming would be advantageous.
- Curtailment of gas exports may be introduced as a mitigation measure and this may impact importing countries (e.g., EU Member States).

Stakeholder awareness of climate change **impacts on defence and readiness to act**

05

As illustrated in the previous sections, there are numerous reasons why climate change is a growing concern for EU security and defence. This has officially been acknowledged by several EU Member States (e.g., BMU, 2002; IRSEM, 2011), by EDA in its CF SEDSS and Energy and Environment Capability Technology Group, which provides technical advice and guidance to MoDs on energy matters, by the EU in the *Strategic Compass for Security and Defence*[25], the EEAS in its *Climate Change and Defence Roadmap* (EEAS, 2020), and also by NATO in its *Green Defence Framework*[101], its *Climate Change and Security Action Plan*[102], and in article 12 of its *Madrid Summit Declaration*[103].

EU MoDs are also aware of the implications of climate change and have reiterated their ambition to tackle it in multiple documents, including by adapting national policies and strategies, supporting concrete initiatives and exchanging best practices. For example, some EU Member States have acknowledged the challenges of climate change in their national security policies (e.g., *Die Bundesregierung*, 2016; *Governo de Portugal*, 2013; NCTV, 2019; *Regeringskansliet*, 2017). France defined a strategy for sustainable development in defence in 2012[104], and created the Defence and Climate Observatory[105] in 2016, which has produced significant research since its inception (e.g., IRIS, 2014, 2021a, b). At the 2021 Paris Peace Forum, a *Joint Statement on Climate Change and the Armed Forces*[106], which includes a concrete roadmap for action, was signed by 26 countries from all continents (*Ministère des Armées*, 2021).

Some EU MoDs (e.g., *Ministère des Armées*, 2020; *Ministerie van Defensie*, 2021; *Stato Maggiore della Difesa*, 2019) have also defined an energy strategy for their armed forces and have made commitments for higher energy efficiency and lower GHG emissions (e.g., van Schaik et al., 2020). In general, the goal is to move towards more resilient energy models that are less dependent on external entities, more able to withstand and recover from energy crises, more flexible, allowing the integration of new technologies, easily maintainable, and less carbon intensive.

Regarding concrete initiatives, some EU Member States are carrying out innovative projects in their armed forces. For example, Portugal is applying circular economy principles in the recovery and reuse of materials for the maintenance of jets, the Netherlands is applying the same principles for the recycling of work-wear fibres[107]. Cyprus, through its environmental committee established in 2004, implemented the Eco Management and Audit Scheme (EMAS) in several military camps[108], and Portugal has two air force bases with EMAS implemented. On the other hand, some EU Member States are also fostering sustainability through project funding. This is the case of Luxembourg that co-funded with EDA the Incubation Forum for Circular Economy in European Defence[109], or France that recently funded a feasibility study for low carbon military camps[110], a project conceptualised in the context of the CF SEDSS project.

In this context, the integration of renewable energy is key and contributes to climate change mitigation and climate adaptation – i.e., reducing GHG emissions (and environmental degradation) to help counter global warming, but also strengthening resilience and energy security through optimised use and the diversification of energy sources. However, emphasis until now has been more on reducing GHG emissions than on adapting existing infrastructure, which means that the policy of EU MoDs could still benefit from a better integration of climate risk management (IRIS, 2021b; Miro et al., 2021; van Schaik, 2020).

As demonstrated in this study, but also in Tavares da Costa and Krausmann (2021), some of the impacts of climate change are already unavoidable and hardly any infrastructure is immune to climate risk. Each climate extreme will have a specific geographic footprint, intensity and duration, potentially exposing infrastructure to damage or disruption, depending on the fragility/vulnerability of each of its components. Military installations and the CEI they depend on are no exception to this.

Thus, reducing risk and strengthening resilience in military installations may require new levels of hardening and physical protection for systems, but also fault tolerance[111], and the enhancing of preparedness, response and recovery. These steps are more effective when site-specific risk assessments exist and have a solid scientific basis. To give a concrete example, Finland restricted new buildings to areas with terrain elevation three meters above mean sea level, to avoid flooding that may possibly be aggravated by sea level rise (FMN, 2016; van Schaik et al., 2020). This type of technical recommendation is only sensible when local conditions – and how they may change due to global warming – are assessed; otherwise it may lead to unnecessary costs or even climate change maladaptation.

Finally, **three stakeholder levels could benefit from more awareness raising:**

1) MoD actors, when aware of climate change implications, will support the definition of action plans and will demand more action from military staff. In this regard, MoDs should also consider more interaction with other ministries (e.g., energy, environment, infrastructure) to be more informed and aware of opportunities.

2) Military staff with a clear understanding of climate change will support and facilitate reducing GHG emissions, preventing environmental degradation, reducing risk and strengthening resilience. This is crucial, particularly when a strong involvement of personnel is needed (e.g., behavioural changes in resource conservation, reskilling, etc.). Environmental and energy management systems could help in this regard.

3) Civilian entities operating CEI are aware of how climate change may result in service disruption and have a high level of preparedness. However, it is unclear if all the potential impacts are accounted for, particularly cascading ones, and if they are locally accurate. For example, the lack of coordination and integrated planning between CEI entities (electricity, oil and gas), but also with critical consumers, such as the armed forces, suggests a disregard for the role of interdependencies in service disruption.

06 Strengthening climate resilience in defence-related critical energy infrastructure and military capabilities

Climate change, and in particular climate-related hazards, cannot be deterred, know no borders, may cover wide spatial and temporal scales, and produce indiscriminate impacts. This global challenge cannot be tackled by a single country alone; it requires the proactive involvement of the whole society. For defence, this implies that actions to help counter global warming, reduce risk and strengthen resilience to climate change must be considered across EU MoDs and military departments and be country- and site-specific.

It also implies that actions must be coordinated with critical entities that provide the services on which the armed forces depend. **These dependencies often stand out when CEI fail during a disaster or a crisis, affecting military installations that support military field operations and logistics**, including remotely, and that face the challenge of energy security and costs. Command and control, intelligence, surveillance and reconnaissance, or operating defence systems, are examples of functions that require a reliable and continuous energy supply, which, during a disaster or a crisis, can only be temporarily ensured by redundant and diverse emergency power systems.

While risk reduction focuses on reducing exposure and vulnerability of physical assets to prevent impacts, resilience focuses on the operational continuity of an energy system in a degraded state, response efficacy for immediate remedial action and stabilisation, swift recovery of functionality, and the resources available for each of these actions.

As such, the attributes of resilience can be summarised as robustness[112], fault tolerance, resourcefulness[113], and response and recovery[114]. From a military installation perspective, being prepared for a climate-related disaster or crisis should be strategic for EU MoDs as it implies minimising mission impacts and ensuring energy independence. Conversely, inaction may entail not being ready to operate during such an event or in a substantially different technological landscape due to:

- energy transition (e.g., energy system modernisation, including diversification of energy sources, flexible and interconnected energy markets);
- rise in electricity demand;
- ageing, inadequate MRO and obsolescence (e.g., shortage of legacy spare parts);
- new and emerging threats;
- limited capabilities.

It may also entail not being ready to handle unexpected burdens (e.g., ad-hoc requests to participate in humanitarian aid).

6.1. Analysis of barriers and gaps

This study identifies a series of barriers and gaps in the path towards a more resilient EU defence. Emphasis is given to the resilience of military installations and CEI to climate change and on the environmental sustainability of EU defence in five dimensions (operational, capability planning and development, governance, multi-stakeholder engagement, and R&D).

1) Operational dimension

a) **Military installations may be operating under unknown climate risk.** Climate-related hazards, changing operating conditions, Natech risk[115], and cascading effects due to the dependency on CEI, themselves interdependent, may not be accounted for when managing climate risk in EU defence.

b) **EU MoDs may be limited in their ability to manage risk, strengthen resilience and increase sustainability due to most CEI being owned and operated by civilian entities**, some of them foreign, over which they exert no control in terms of infrastructure development, resilience and protection decisions.

c) **The resilience of military installations may be hampered by relying too strongly on a limited number of energy sources and energy providers to cover all energy needs** (e.g., NATO's single fuel policy[116] or overreliance on the civilian power grid).

d) **The high energy use of some military installations may constrain energy systems** (e.g., contractual or physical congestion), contribute to a possible disruption of the electricity supply, and may lead to higher costs and GHG emissions[117].

e) **Mission-critical loads of military installations may not be thoroughly identified.** Distinguishing critical loads from those that are non-critical within military installations serves the purpose of strengthening resilience by providing flexibility, optimising onsite energy systems, including emergency power systems[118], and by potentially providing ancillary services to the electrical power grid.

f) **It is unclear if data with an appropriate level of detail,** used for example in the assessment of risk, resilience, energy and GHG emissions**, is systematically collected by EU MoDs**[119]. Data is essential to provide empirical knowledge and research-supported evidence for decision-making.

g) **Incident data collected by CEI entities often does not provide the level of detail/disaggregation necessary to better understand the impacts of climate change and learn from past incidents.**

2) Capability planning and development

a) **There is possibly not enough integration of climate considerations into military planning, investment lifecycles, procurement criteria**[120] **and R&D.**

b) **The systems approach to risk management within EU MoDs could be strengthened** by considering CEI interdependencies and integrating climate and energy foresight.

c) There are **no clear alternatives to the use of civilian CEI and fossil fuels**,

even though electrification and new technologies have enabled higher self-sufficiency and sustainability (e.g., on-site renewable energy generation, storage and utilisation). External dependencies expose EU MoDs to energy security[121] threats and climate-related impacts.
d) The large number of physical assets owned by EU MoDs delays the implementation of risk reduction, resilience building and sustainability measures.
e) Efforts to reduce GHG emissions may be impaired by the continuous increase in energy demand associated with the introduction of new military capabilities, or by sudden changes in priorities due to a changing security landscape.

3) Governance

a) There is no integrated EU strategy for energy and climate in defence.
b) National defence energy and climate strategies, and commitments, are usually inconsistent, and there are not always mechanisms for progress monitoring and reporting on energy and climate matters.
c) EU policy acts usually exclude military installations from their scope. It is unclear if national policies or standards are sufficient to protect infrastructure and assets against climate change, strengthen resilience and drive environmental sustainability in EU defence.
d) EU energy networks may require substantial modernisation and investment[122] (e.g., interconnections, electricity two-way flows, reverse flow pipelines, repurposing of gas system) to strengthen resilience and advance towards low GHG emissions (ENTSO-E, 2021a; ENTSO-G, 2020). Since CEI entities are mostly profit-oriented, investments will only occur when the cost of dealing with a disaster or crisis is higher than preventing it, thus, new incentives may need to be designed.

4) Multi-stakeholder engagement

a) Civilian-military cooperation needs to be structured and strengthened. The dependency of military installations on CEI should encourage EU MoDs to interact with CEI entities to share knowledge, define requirements, and develop solutions for risk reduction, resilience and sustainability.
b) The coordination of risk management efforts between CEI entities should be strengthened, especially considering their interdependency[123]. Risk reduction and resilience measures, in the context of increased connectivity, require close coordination, to ensure their effectiveness, and resource optimisation via integrated infrastructure planning and management, to avoid duplication of efforts and unnecessary costs.

5) Research and development

a) A sparse implementation of innovative technology projects may not lead to the structural changes required to respond to climate change in defence, particularly within the ambitioned timeframes.
b) There is a paucity of quantitative studies on the impacts of climate change on military installations, guidance for assessing GHG emissions, climate risk and resilience, and decision support tools to evaluate different climate change adaptation and mitigation options.

6.2. Actions for managing climate change risk in EU defence and defence-related CEI

Managing climate risk in EU defence requires EU MoDs to act on two fronts:

1) **Climate change adaptation,** which focuses on preventing or minimising losses, increasing the ability to bear losses, or offsetting losses through insurance. It aims at bringing risk associated with climate-related events and changing operating conditions to an acceptable level, including from potential direct impacts on physical assets and indirect impacts via CEI dependence, and responding to and recovering more efficiently from a climate-related disaster or energy crisis. Actions should be implemented according to the criticality of each location, asset, function and process.

2) **Climate change mitigation,** which focuses on reducing GHG emissions and their atmospheric concentration to help counter global warming and prevent further aggravation of climate change, including to the point of no return (e.g., climate tipping points) (Armstrong MacKay et al., 2022; Lenton et al., 2008).

Climate change adaptation and mitigation should cut across military departments, planning, operations and activities, training and evaluation testing, assets and capabilities, investment and procurement, without affecting the operational effectiveness of the armed forces, perhaps even improve it in some cases (e.g., electric powertrains and fewer MRO needs). **The following sections highlight actions that could be adopted at the level of policy and legislation; research, innovation and technology; data sharing and knowledge exchange for strategic foresight; through-life capability management; and multi-national and multi-stakeholder collaboration.**

6.2.1. Policy and legislation

6.2.1.1. Climate change, security and defence

In 2008, a ***Paper from the High Representative and the European Commission to the European Council***[124], **described climate change as a threat multiplier**. Since then, the inclusion of climate change in EU security and defence policy has increased, of which an important development is the EU's ***Climate Change and Defence Roadmap*** (EEAS, 2020) and its proposed actions, which are summarised in Table 1.

For the first time an EU roadmap with concrete short-, medium and long-term actions aims to enhance and enable the MoDs' transition to climate neutrality in compliance with the *European Green Deal*[28] while increasing defence energy resilience and autonomy.
The roadmap aims at strengthening resilience to climate change. It is aligned with the:

1) ***European Green Deal***[28], which recognises the need for all EU actions and policies to play a role in achieving climate neutrality.
2) ***European Climate Law***[30], which sets binding targets of at least 55% GHG emission reduction by 2030 and of climate neutrality by 2050. It also requires the adoption of an EU strategy on adaptation to climate change, as well as national strategies based on robust climate change and vulnerability analyses.

Table 1. EU's Climate Change and Defence Roadmap actions to strengthen resilience and sustainability (EEAS, 2020).

Operational dimension	Short Term	Integrate existing early warning and forecast systems, and conflict and mission analyses, to improve situational awareness and understanding, and develop strategic foresight on climate change and environmental implications.
		Mainstream climate change and environmental considerations into planning, implementation and reporting.
		Review the Military Concept to make sure that implementation is monitored.
		Improve civilian-military humanitarian cooperation, including preparedness and response to disasters.
		Examine the possibility to fund projects through the European Peace Facility, in support of climate change and environmental considerations.
	Mid Term	Develop operational guidelines and standard operating procedures for climate and environmental implications.
		Deploy environmental advisors.
		Collect data and best practices.
	N/A	Improve knowledge sharing on resource security (including energy and water) and environmental best practices (including conservation of biodiversity on military land).
Capability planning and development	Short Term	Integrate climate change and environmental considerations into training and exercises.
		Understand the impact of EU energy-related directives on military installations, including green procurement.
	Mid Term	Improve scenarios and strategic planning assumptions by integrating climate risk.
		Fund R&D of new technologies to strengthen resilience and operational efficiency, taking into account circular economy considerations.
		Implement dual-use transport infrastructure projects.
		Study the feasibility of an EU platform for sharing knowledge on energy matters in defence.
		Study the impacts of climate change on European defence infrastructure and on the resilience of critical energy infrastructure to hybrid threats.
	N/A	Integrate climate and environmental considerations in procurement, building and renovation, and staff awareness.
		Monitor the implementation of energy efficiency.
		Establish climate-related objectives.
		Develop technologies to strengthen resilience and operational efficiency via Permanent Structured Cooperation, and support climate and defence projects from the European Defence Fund.
Multilateralism and partnerships	Short Term	Address the links between climate change, environmental aspects and security.
		Exchange experience and best practices with the UN on climate, energy and environmental aspects.
		Explore cooperation with NATO on climate and defence.
		Explore cooperation with the African Union on climate and environmental aspects in training and awareness raising.
		Strengthen response to disasters and civil protection in African partner countries.
	Mid Term	Include climate change and environmental aspects in the UN-EU partnership on peace operations and crisis management.
		Include climate change and environmental aspects in security and defence policy dialogues with third countries.
		Include defence and CSDP considerations in climate security, adaptation and mitigation efforts.
		Increase the understanding of the impacts of climate change and environmental degradation on defence and crisis management.
	Long Term	Maintain leadership in climate and environmental policy.

Note: N/A means that a specific timeline is not available.

Furthermore, in January 2021, the ***Council Conclusions on Climate and Energy Diplomacy***[127] recognised the threat of climate change and environmental degradation and its importance for security and defence, as well as the centrality of energy in achieving climate neutrality. It called for an increase in the uptake and system integration, including interconnections, of renewable energy, and the strengthening of renewable hydrogen production and imports. It also recognised the impacts that the energy transition may have on economies reliant on fossil fuel exports, the need to avoid dependencies on critical raw materials and technologies, and the need for resilient supply chains, cybersecurity, and protection and adaptation of critical infrastructure to climate change.

In May 2021, the ***Council Conclusions on Security and Defence***[128] also recognised the impacts of environmental issues and climate change on security and defence, and stressed the need to strengthen resilience and preparedness, civilian-military capability development, operational readiness, and coordination for disaster response and humanitarian aid.

In February 2022, **the European Commission published a communication on its contribution to European defence**[24]**, where it, inter alia, outlined its plan and initiatives to address climate change** by:

- assessing climate and defence initiatives implemented under existing Commission-led instruments to enhance potential synergies;
- establishing a policy framework to reduce energy demand, increase energy resilience of critical technologies, and develop concrete climate-resilient solutions in this context;
- exploring the potential of enhancing the impact of energy-related directives on military infrastructure, including GPP principles, as part of the *European Green Deal*[28].

In March 2022, the ***Strategic Compass for Security and Defence***[25] recognised climate change as a driver of insecurity and instability and the important role that the armed forces may have during complex crises. The document sets forth the goal to strengthen resilience to climate change, specifically to climate-related hazards and technological accidents, but also to strive for climate neutrality, by:

- fully implementing the EU's *Climate Change and Defence Roadmap* by 2023;
- enhancing the ability of the armed forces to support civilian authorities in emergencies.

It also identifies the need to increase energy efficiency, the capability to operate in non-permissive environments, develop common benchmarks and standards for reducing the environmental footprint, integrate renewable energy and strengthen the resilience of CEI. For the first time, **EU Member States agreed that "by the end of 2023, in view of fully implementing the EU's *Climate Change and Defence Roadmap*, Member States will develop national strategies to prepare the armed forces for climate change."** In this context, EEAS and EDA organised in November 2022 a joint workshop on supporting the MoDs to develop national strategies to prepare the armed forces for climate change. While some Member States already have national strategies, or are well-advanced in their drafting, others are at the beginning of the process. Hence, the workshop aimed at facilitating a coordinated approach among Member States to maximise the effect of national strategies, and allowing national efforts to be coherent with and connected to a shared EU-level framework that provides for synergies and collaborative opportunities.

Although the above-mentioned Council Conclusions, Strategies and Roadmap mostly focus on external action, **it is important to acknowledge the internal dimension of security and defence, e.g., the uninterrupted functioning of military installations of EU Member States that support field operations and logistics, including remotely, and face the challenge of energy security, energy transition and costs.**

6.2.1.2. Climate change and CEI

The ***Energy Union*** strategy[129], launched in 2015, aims at providing secure, sustainable, competitive and affordable energy, to encourage the transformation of energy systems, and to promote energy efficiency, cost savings and renewable energy. Its **five dimensions** are: **energy security, energy market, energy efficiency, decarbonisation, R&D and competitiveness**, for which each EU Member State needs to define objectives and contributions in the national energy and climate plans. In 2018, the ***Governance of the Energy Union and Climate Action***[130] was devised to align the *Energy Union* with the commitments of the ***Paris Agreement***[15], setting a binding target of 40% reduction of GHG emissions by 2030[126], a long-term goal to keep global average temperature rise below 2 °C[131], and to strive to limit it to 1.5 °C[131]. Also, with the ***EU low GHG strategy* submitted to the *United Nations Framework Convention on Climate Change***[132] the objective of achieving climate neutrality by 2050 was set. As a step forward in its implementation, the ***Clean Energy for all Europeans*** package was introduced to overhaul the existing energy policy and help to reduce GHG emissions associated with the EU's energy system, comprising the following directives and regulations:

- ***Directive on the Energy Performance of Buildings***[133] – lays down the requirements for energy performance, national plans for nearly zero-energy buildings, certification and inspection, and requirements for long-term renovations.
- ***Renewable Energy Directive***[134] – sets the binding target of at least 32% in 2030 for the share of renewable energy in the EU's gross final consumption of energy, of at least 14% of renewable energy in transport, of which 7% is binding for advanced biofuels, and lays down general rules for the use of renewable energy.
- ***Directive on Energy Efficiency***[135] – sets an overall target of at least 32.5% energy efficiency by 2030, lays down the rules for its achievement in the energy supply chain, establishes an energy savings obligation of 0.8% of annual final energy consumption, and the requirement to report energy efficiency contributions in the integrated national energy and climate plans. The Commission has proposed to revise the current EU-level target for energy efficiency from 32.5% to 36% for final energy consumption, and 39% for primary energy consumption[136].
- ***Regulation on the Governance of the Energy Union and Climate Action***[130].
- *Regulation on the Internal Market for Electricity*[137].
- *Electricity Directive*[138].
- ***Regulation on Risk-Preparedness in the Electricity Sector***[139] – lays down the rules for cooperation in preventing, preparing for and managing electricity crises at the national and regional levels. Among other points, it stipulates in which circumstances loads are to be shed and which electricity users are protected against disconnection[140].
- *Regulation establishing a European Union Agency for the Cooperation of Energy Regulators*[141] (ACER).

Furthermore, the European Commission has presented the ***REPowerEU plan***[142] that proposes to increase from 9% to 13% the binding energy efficiency target and, under the ***Fit for 55*** package[136,143] – the EU's plan for a green transition – an increase of the 2030 target for renewables from 40% to 45%. This has also opened the way for other initiatives such as a dedicated ***EU Solar Energy Strategy***[144] to accelerate the deployment of solar energy systems, a EU Solar PV Industry Alliance (similar to the European Battery Alliance established in 2018[145]) to prepare the power grid and secure a resilient supply chain in Europe, but also to accelerate the deployment of heat pumps, the 2030 target for domestic renewable hydrogen production of 10 million tonnes, in addition to another 10 million tonnes of imported hydrogen, and the 2030 target for biomethane production of 35 bcm.

Regarding the management of climate risk and the resilience of CEI, the ***European Critical Infrastructure Directive***[146] (ECI Directive) requires EU Member States to protect infrastructure "of vital societal functions" against all hazards and threats. It aims at identifying and designating European critical infrastructure from specific sectors (e.g., energy), using casualties, economic and public effects as criteria. It also aims at establishing and reviewing (every two years) operator security plans, based on risk assessments that include prioritised security measures and procedures (permanent or activated by varying risk and threat levels). However, due to increasing connectivity, interdependency and cross-border operation of critical infrastructure, the protection of assets alone was considered insufficient to prevent disruption and cascading effects. To account for these new conditions, the ***Critical Entities Resilience Directive***[147] (CER Directive) entered into force in early 2023 to replace the ECI Directive. This new directive aims at protecting vital societal functions in the EU by strengthening the resilience of critical entities that provide essential services. A broader set of economic sectors is now considered as well.

The ***Environmental Impact Assessment Directive***[148] aims to ensure that consent for public and private projects that may have significant environmental effects is only given after an assessment of the likely effects is carried out. Annex I of this directive lists the projects that are within its scope. Among others, CEI such as refineries, power plants, nuclear waste processing, fossil fuel extraction, dams, pipelines, mines, power lines, petroleum, petrochemical or chemical storage, carbon capture and storage (CCS) are included. Annex II of the directive lists the project categories for which EU Member States may provide an assessment, where CEI not listed in Annex I are listed. **It should be noted, however, that when a project has defence or the response to civil emergencies as their sole purpose, EU Member States can decide to not apply this directive**.

The ***European Union Civil Protection Mechanism***[149] is the key instrument for cooperation in disaster risk management, within which EU Member States are required to prepare national risk assessments that account for disaster risk and can include scenarios for critical infrastructure disruption.

On the other hand, EU Member States and the European Network of Transmission System Operators for Electricity (ENTSO-E) action on risk management and the security of energy supply, including ownership concerns, is prompted by the ***Regulation on Risk-Preparedness in the Electricity Sector***[139]. It is also prompted by the ***Regulation Establishing a Network Code on Electricity Emergency and Restoration***[150] – laying down the requirements for the management of emergency, blackout and restoration states, the coordination across EU Member States, simulations and tests, and the tools and facilities needed. Also relevant in the same context is the ***System Operation Guideline***[51].

The ***Council Decision on Minimum Stocks of Crude Oil and/or Petroleum Products***[151], lays down the rules to ensure security of oil supply (e.g., at least 90 days of average daily net imports or 61 days of average daily inland consumption, whichever is greater) and puts in place procedures to deal with serious shortages.

The ***Regulation Concerning Measures to Safeguard the Security of Gas Supply***[152], lays down the rules to ensure security of gas supply, including measures of last resort, and definition and responsibility of preventive action and reaction to gas supply disruptions. In this scope, the European Network of Transmission System Operators for Gas (ENTSO-G) is tasked with carrying out risk assessments. There is also a European Commission proposal for a regulation on gas storage aiming at ensuring that storage capacities in the EU are not underused and can be shared in a spirit of solidarity[153].

The ***Nuclear Safety Directive***[154] establishes a framework for the safety of nuclear installations accounting for multiple hazards, particularly in stress testing.

Finally, the prevention of major industrial accidents involving dangerous substances and the mitigation of their consequences is handled by the ***Seveso-III Directive***[155] that requires operators of, for example, refineries or terminals, to implement safety and risk reduction measures and to consider natural hazards as triggers of such accidents.

6.2.2. Research, innovation and technology

The armed forces can greatly benefit from sustainable energy solutions (e.g., energy efficiency, renewable energy), particularly in terms of energy security and resilience. If they reduce the use of fossil fuels (e.g., heating), and thus the dependency on fuel imports, they produce cost savings, help in diversifying energy supply and secure self-sufficiency, provide flexibility and facilitate new optimisations (modular distributed generation), as well as reduce the potential for technological accidents (including Natech accidents) and for targeted attacks. Although sustainable energy solutions may create new dependencies (e.g., supply of rare earth metals), their one-off installation, low maintenance, and recycling potential also means that resupply may happen over longer timeframes (i.e., for spare parts or when new upgrades are programmed).

These benefits become particularly evident during periods of destabilising fuel prices and fuel shortages. However, there is not a one-size-fits-all solution. EU MoDs must identify which are the most appropriate technologies, and energy system architecture, for each site that deliver on the desired goals, while ensuring the continuity of critical missions. Each solution may have its own merits for a given application (i.e., tactical, prime or utility energy; Tavares da Costa and Krausmann, 2021), location and time (i.e., during a specific severe weather event or an energy crisis), and budget. It is important to note that renewable energy technologies are weather dependent and may create undesirable fluctuations in generation if these are not accounted for and mitigated (e.g., via storage). Thus, R&D should continue to focus on a wide range of technologies that can potentially increase energy security, resilience and environmental sustainability.

Energy and climate issues are of high importance to EU MoDs, as they are often large owners of infrastructure that must be energy secure, and some of which are energy intensive. On the other hand, EU MoDs have the potential to provide a significant contribution to climate change mitigation. Furthermore, military testbeds and proving grounds[156] facilitate the transition of R&D to operational implementation, which make the military a key first user and early customer of pre-commercial technology.

To provide a concrete example, nested energy systems and smart microgrids[157,158] are introduced in the following paragraphs.

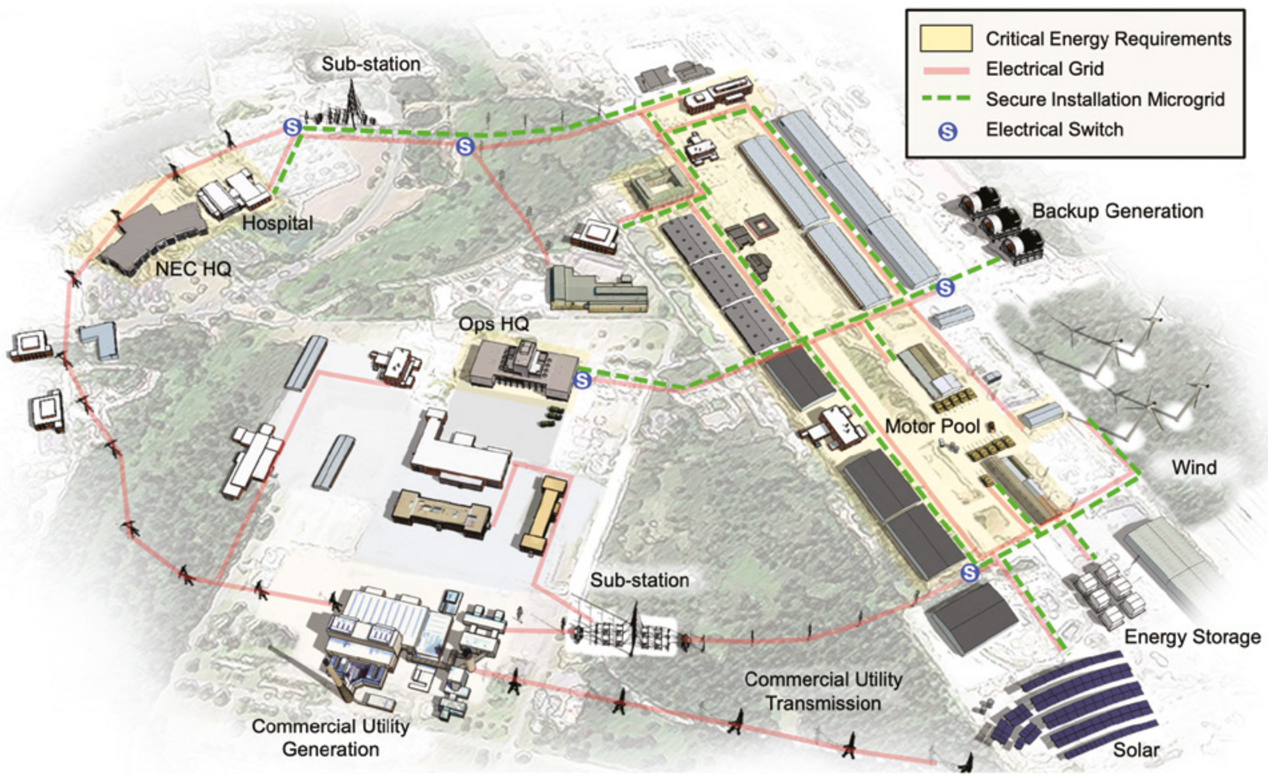


Figure 12. Notional picture of an army microgrid (DoA, 2015). NEC HQ means network enterprise center headquarters and Ops HQ means operations headquarters.

Nested energy systems and smart microgrids

When it comes to electricity supply, military installations are often connected to the civilian power grid and have traditionally used individual backup power generators, uninterruptable power supply (UPS) units, and redundancy as protection from electric power disruptions. An alternative to this approach is the use of smart microgrids that can interconnect distributed energy resources acting as a single controllable unit, and operate in islanded mode (i.e., off-the-grid), within defined electric boundaries (see Figure 12).

Smart microgrids provide independence from the civilian power grid, when needed, and may improve reliability and quality of service through automatic functions such as grid balancing, network reconfiguration, fault detection, isolation and restoration. They also allow a greater control over the choice of energy sources (technological diversity), facilitating the local integration of renewable energy for example, and control of energy performance and maintenance needs using sensors, data acquisition, analytics and algorithms. Together, these characteristics help to:

1) reduce the impacts of climate change, particularly cascading failures associated with the civilian power grid;
2) facilitate the introduction of renewable energy technologies and distributed energy resources;
3) reduce the use of traditional backup power systems[118], on-site fuel reserves and refuelling needs, by allowing operation in islanded mode and integrating different electricity generation and storage technologies;
4) improve energy performance by having a more granular and integrated monitoring and control of energy systems, including building energy management[159] (e.g., HVAC, lighting). This may ultimately result in higher energy security by ensuring both a continuous and optimal use of energy, cost savings (e.g., energy efficiency, off-peak electricity use, peak shaving), and a significant reduction of GHG emissions, particularly if heating is electrified.

When operating in grid-tied mode (i.e., connected to the civilian power grid), smart microgrids may facilitate the energy transition by providing flexibility and ancillary services on request to civilian power grid operators (e.g., curtailing non-critical loads to alleviate power grid congestions). It also allows the participation in new electricity markets, which may generate revenue, the joint operation with oil and gas pipeline systems and district heating grids for further optimisation, and the integration of vehicle-to-grid technology, for example.

To strengthen the resilience of military installations, smart microgrids may also be combined with individual nanogrids (e.g., individual buildings and data centres) that, during normal operation, share their highly localised energy generation and storage, and during a disruption of the microgrid may operate in islanded mode serving specific critical loads.

Often, the largest economic benefit of smart microgrids is realised when they are installed to serve critical loads and interconnect already existing systems (e.g., energy generation and storage, emergency power, energy management, metering). On the other hand, because smart microgrids are intrinsically linked to electrification, digitalisation, connectivity and automation, **cybersecurity is generally a major concern associated with smart microgrids** and should be accounted for.

Finally, **smart microgrids have been recognised (e.g., DoA, 2022) as important solutions for risk reduction, resilience and sustainability, and military installations are uniquely positioned to help demonstrate and validate this technology under real-world conditions.**

6.2.3. Data sharing and knowledge exchange for strategic foresight

Strategic foresight[160] is used by the European Commission for anticipatory governance. It informs work programmes, such as the *Horizon Europe Framework Programme for Research and Innovation 2021-2027*[161], which focus on key challenges, particularly through specific EU mission areas. A mission area example is adaptation to climate change that aims at supporting European regions and communities to become climate resilient[162]. In 2021, the European Commission *Strategic Foresight Report*[163] identified four megatrends:

1) climate change and environmental challenges;
2) hyperconnectivity and digital transformation;
3) pressure on democracy and European values;
4) global order and demographic shifts.

These are in line with the **security trends identified in 2017 by NATO in its *Strategic Foresight Analysis*** (NATO, 2017): political (e.g., **power transitions, non-state actors**), human (e.g., ageing population, unemployment and low education), technology (e.g., **interconnectivity, technological dependence**), economic (e.g., inequality) and environmental (e.g., **climate change, natural hazards**).

To address megatrends, **the European Commission has put forward ten strategic areas of action**, of which five are highly relevant to this study, namely:

1) decarbonised and affordable energy;
2) data, artificial intelligence and cutting-edge technology;
3) supply of critical raw materials;
4) security, defence and space;
5) resilient institutions.

At the level of EU MoDs, strategic foresight could be used for through-life capability management. In this context, data sharing and knowledge exchange[164] is fundamental to address key challenges by strengthening R&D and innovation, setting new standards, accelerating transformations, including energy improvements and climate-proofing of infrastructure, accelerating the energy transition, and to feedback on strategic foresight itself.

Knowledge (and intelligence) exchange also has the potential for improved situational awareness, risk preparedness (e.g., effective planning, early warning, training, or CMCoord – civilian-military coordination for response and recovery), future-proofing, improved energy security, strengthening the resilience of critical entities and critical infrastructure protection (e.g., Bocse, 2020). Data sharing and knowledge exchange is something that is actively pursued by EDA, for example in the scope of the CF SEDSS, but is also envisioned in NATO's *Green Defence framework*[101].

6.2.4. Through-life capability management

It is critical that the right military capability can be deployed swiftly when needed. However, the process of procuring and managing military capability is complex and expensive. Through-life capability management (TLCM) is an agile, integrated (development, procurement, operation, servicing, upgrading and disposal) and whole-system approach to manage military capability that aims at making systems more cost-effective, affordable through their whole lifecycle, and responsive to rapidly changing threats (Urwin et al., 2010).

Given the potential of climate change to multiply threats, the effectiveness and lifecycle cost of procured goods, services (electricity, oil and gas) and works by the armed forces should be founded on climate and energy foresight. This implies allocating sufficient resources at an early stage of the investment cycle to understand climate risk in defence.

EU MoDs should increasingly consider the significantly different, and potentially adverse, future operating conditions in their acquisition and capability management processes. Incorporating climate risk and energy security trends in planning for future requirements[165] may help to avoid malfunctioning, early deterioration, unavailability, obsolescence and cost overruns, and overall climate change maladaptation.

Procurement should take a holistic view of capabilities and components during their entire lifecycle, ensuring that the trade-off between replacing and upgrading is well understood. In addition, it should ensure that adequate maintainability, upgradability and flexibility is built-in to accommodate changes in operating conditions, energy systems[166] (ENTSO-E, 2019b), and an increase in unexpected burdens due to climate change (this can be potentially addressed by dual-use technology).

At the same time, the acquisition of goods, services and works should not hinder the efforts of EU Member States to reduce GHG emissions. As already seen, it is also in the EU MoDs' own interest to pursue resource-efficiency and security, where sustainable energy requirements are key. Some of these concerns are loosely addressed by the *Defence Procurement Directive*[167], for example regarding technical specifications (Art. 18), conditions for performance of contracts (Art. 20), obligations (Art. 24) and environmental management standards (Art. 44).

On the other hand, as EU MoDs look into civilian technological advances, diversification of energy sources, eco-design, reducing energy and carbon footprints, energy efficiency, renewable energy and the use of alternative fuels, NATO's single fuel policy may not be fit for purpose anymore. To drive the energy transition and reduction of GHG emissions, energy could be treated as a military capability in its own right (*Ministère des Armées*, 2020).

In this scope, it is also relevant to **consider developing a green joint procurement framework**[168] **for defence** – one that does not compromise on having all the necessary military capability when needed and which accounts for the technological maturity of each solution[169], as well as the incorporation of material traceability and circular economy principles, essential for the recovery of critical components and critical materials.

As concluded in the CF SEDSS study "Green Public Procurement (GPP) Options in the EU Defence Sector"[170], **GPP is about risk management** (considering the climate-security nexus and the need to ensure supply chain resilience) and **the opportunity to influence the market to ensure that green products and services meet the specific needs of defence organisations**. Hence, there is a need to promote a more pro-active implementation of GPP in the defence sector, reflecting energy and climate commitments, and its integration with sustainability, climate and energy policies. **Building on the possibility of a joint procurement framework, the establishment of an EU Defence Helpdesk would be of immense value** in assisting procurers in greening their purchasing decisions with the application of GPP, considering climate-proofing, capability and infrastructure requirements.

6.2.5. Multi-national and multi-stakeholder collaboration

Multi-national and multi-stakeholder collaboration provides a unique opportunity to discuss and share knowledge on the impacts of climate change on CEI, possible solutions (from risk reduction to resilience and low GHG emissions), situational awareness and foresight on environmental issues, including climate change, the energy transition and energy security. It allows to deliver training (e.g., crisis gaming), iteratively develop or refine action plans (e.g., risk preparedness), monitor implementation, facilitate decision-making, and to identify relevant points of contact to establish partnerships and priority relations with key stakeholders (e.g., CMCoord and joint rapid response teams, data collection and exchange).

Sectors are increasingly interconnected and interdependent and often CEI operators know very little about infrastructure they do not operate, but depend upon (e.g., water and wastewater, telecommunications), exerting little to no control over them, but also about the needs of their critical customers such as defence. In this context, **a multi-stakeholder forum on climate change and CEI in the defence context could help strengthen civilian-military cooperation and provide the right platform for dialogue, learning, decision-making and the effective implementation of measures**. It could serve purposes such as:

1) raising awareness of climate change impacts, with particular focus on infrastructure interdependency and lessons learned;
2) coordinating actions to reduce risk and strengthen resilience between different CEI stakeholders, and between them and defence decision-makers;
3) promoting the integration of measures that may benefit multiple stakeholders at the same time (e.g., cross-border infrastructure, tree-trimming, targeted undergrounding of pipelines and electric power lines) and finding appropriate funding mechanisms;
4) sharing knowledge and identifying best practices, challenges and opportunities, for cross-fertilisation and technology transfer.

Key stakeholders (non-exhaustive) in this context could include:

- European Commission (e.g., Directorate-General for Energy, Directorate-General for Climate Action, Directorate-General Joint Research Centre, Directorate-General for Defence Industry and Space)
- European External Action Service (EEAS)/ European Union Military Staff (EUMS)
- European Defence Agency (EDA)
- European Climate, Infrastructure and Environment Executive Agency (CINEA)
- Organization for Security and Cooperation in Europe (OSCE)
- International Energy Agency (IEA)
- International Atomic Energy Agency (IAEA)
- NATO (see page 17 of NATO *Strategic Concept*; NATO, 2010b)
- Representatives of the European energy sector (e.g., ACER, ENTSO-E, ENTSO-G)

Supporting EU climate **neutrality and GHG targets**

07

For many years and for different reasons (e.g., limited awareness, no readily available solutions, size and complexity of the problem) all sectors of society, including the armed forces, have put just enough emphasis on environmental issues. However, as the impacts of climate change and environmental degradation become increasingly damaging and a pressing concern for society, it has become more urgent to transition to activities that are compatible with the preservation of the livelihoods of today's and of future generations.

Defence, as any other sector, has already experienced numerous times the impacts of climate change on military installations and operations (e.g., Tavares da Costa and Krausmann, 2021), and the tendency is for these to increase. In this context, defence will increasingly be asked to contribute to climate change mitigation, by reducing GHG emissions and increasing their environmental sustainability.

From the use of electricity, oil and gas, to the use of OME, resource consumption and waste production, military activities have a non-negligible impact on the environment. On the other hand, MoDs are often large owners of public land and infrastructure (most buildings being energy inefficient[171]), have a high number of staff (on duty stations or deployed), move a large quantity of products using vast supply-chains and logistics, and acquire a large number of services representing a relevant share of public expense (defence budgets). These characteristics are often reflected in their carbon footprint, but at the same time confer on them the enormous opportunity to help counter global warming and to speed up the transition to a greener and more sustainable economy, in line with the *Paris Agreement*[15] and the *European Green Deal*[28], without losing their operational effectiveness and readiness and in some cases even improving them.

7.1. Reducing the carbon footprint of the defence sector

The armed forces are among the largest consumers of fossil fuels[171,172] and GHG emitters. For example, in 2019, the French MoD reported a consumption of 835 000 m^3 of petroleum products, more than 2.6 TWh of energy (electricity, gas and other sources) consumed by its infrastructure, and a building contribution to GHG emissions of 455 000 tCO_2eq (metric tons of CO_2 equivalent)[173]. Most of their energy use was due to transport[174], which depends on the level of military activities, and 27% due to infrastructure (similar to the numbers reported by the US DoD for the fiscal year of 2011; Nuttall et al., 2019). Excluding fuels, electricity represented 44% of their energy mix, gas represented 41%, and the remaining 15% was associated with fuel oil (6%) and other energy sources (*Ministère des Armées*, 2020).

EDA's defence energy data, provided in its 2019 factsheet[172], shows that defence electricity and heating for the EU27+UK accounted for 49% and 48% of total energy consumption for the years 2016 and 2017, respectively, with transportation accounting for the remaining shares. In this section, electricity and fuel consumption statistics for heating, from EDA's factsheet, are used to estimate GHG emissions of military installations.

Emissions associated with **defence electricity consumption** reported by EDA, i.e., net electricity imports (in MWh) and on-site generation by conventional power plants (in MWh) were summed for each reported year (2016 and 2017). On-site generation by renewable energy sources was assumed to have zero emissions and was disregarded. The resulting values were multiplied by the corresponding EU27+UK average GHG intensity factor for the EU electricity sector (in gCO_2eq/kWh, converted to tCO_2eq/MWh) – reported annually since 1990 by the European Environmental Agency[175] – for the years of 2016 (301 gCO_2eq/kWh) and 2017 (297 gCO_2eq/kWh). The GHG intensity factor excludes emissions from heat production, renewables, nuclear energy (no lifecycle emissions assumed) and biomass. It disregards transmission and distribution losses, but includes emissions from autoproducers[176].

Emissions associated with **defence fuel consumption for heating** reported by EDA, i.e., total consumption for heating by armed forces of 22 EU Member States (in MWh) was multiplied by each fuel type share, to obtain an EU defence figure of fuel consumption per fuel type. Reported fuel consumption for district heating imported (indirect emissions, no information on fuel type), fuel-based electricity generators (no information on fuel type) and electric heating (indirect emissions, unclear if accounted for in electricity consumption) were disregarded, since insufficient information was provided. Fuel consumption for heating per fuel type was mapped/aggregated into natural gas, crude oil (light, medium and heavy fuel oils), anthracite (coal, manufactured ovoids), gas/diesel oil (gasoil/marked diesel), liquefied petroleum gas (LPG), wood/wood waste (wood pellets, wood chips, wood briquettes), gas biomass (biogas), other kerosene (kerosene, other than aviation) and residual fuel oil (RME – marine residual fuel). Default emission factors for stationary combustion in the commercial/institutional category (in kgGHG/TJ on a net calorific basis) were obtained for each new fuel group and for the GHGs CO_2, CH_4 and N_2O from IPCC (2006, Volume 2 Energy, Chapter 2 Stationary Combustion). The emission factors were converted to kgGHG/MWh and multiplied by each newly mapped/aggregated fuel consumption for heating per fuel type, and per year, to obtain the corresponding emissions of CO_2, CH_4 and N_2O. The estimated emissions of CH_4 and N_2O were converted to $kgCO_2eq$, using their corresponding global warming potential (IPCC, 2021), before being added to the total estimated GHG emissions associated with defence fuel consumption for heating (i.e., sum of CO_2, CH_4 and N_2O emissions of all fuel types per year) for the years of 2016 and 2017.

Using these data, GHG emission estimates for military installations in the EU27+UK correspond to ca. 4 755 315 and 4 431 412 tCO_2eq for the years 2016 and 2017, respectively (see Table 2). These estimates are comparable to those of an EU Member State with a small area.

The exclusion of some EU Member States from EDA reporting (six excluded out of EU27+UK), of lifecycle emissions and transmission and distribution losses, result in the underestimation of GHG emissions for the EU27+UK defence. Moreover, for electricity consumption, a EU27+UK average GHG intensity factor, that is also applied to onsite generation using conventional power plants, does not provide the refined estimate that per country/technology figures would. For fuel consumption for heating, the exclusion of three reported fuel types due to a lack of information, and the potential mismatch between fuel types reported by EDA and by the IPCC may be influencing the final emissions estimation.

Nevertheless, the numbers presented in Table 2 show that from 2016 to 2017 a decrease of almost 7% of GHG emissions associated with electricity and heating for the EU27+UK defence was observed. For electricity (higher GHG emissions decrease than heating), the decrease is mostly due to an improvement of the average GHG intensity factor for the electricity sector from 2016 to 2017, but also due to less electricity being consumed by EU27+UK defence from the power grid, more renewable energy use and less conventional power plants use onsite. For heating, the decrease is mostly due to a decrease in the use of crude oil, followed by biogas, LPG and kerosene, and this despite an increase in natural gas, coal and gas/diesel oil use.

Although the observed decrease in GHG emissions associated with electricity and heating for EU27+UK defence is significant, a higher reduction can certainly be achieved. In this context, some **EU MoDs have committed already to GHG emissions reduction**. For example, France has committed to achieve a 40% reduction of GHG emissions by 2030, compared to 1990 levels, and 40% reduction in fossil fuel consumption by 2030, compared to 2012 (van Schaik et al., 2020). Germany has committed to achieve 40% reduction of GHG emissions of buildings by 2030, military ones included (BMVg, 2020). The Netherlands has committed to achieve 50% energy self-production in all military installations by 2030, self-sufficiency by 2050, and a 20% reduction of GHG emissions by 2030 and a 70% reduction by 2050, compared to 2010 levels (van Schaik et al., 2020). Finland has committed to

Table 2. Military installation's estimated 2016 and 2017 GHG emissions for the 27 EU Member States and the United Kingdom.

	2016	2017	Δ2016-2017
Electricity (tCO_2eq)	2 093 660	1 914 521	-179 139 (-8.6%)
Heating (tCO_2eq)	2 661 655	2 516 891	-144 764 (-5.4%)
Electricity + Heating (tCO_2eq)	4 755 315	4 431 412	-323 903 (-6.8%)

heat all buildings without the use of fossil fuels by 2025, to achieve 20% energy savings in buildings, and to reduce by 30% GHG emissions by 2020, compared with 2010 levels (van Schaik et al., 2020). Sweden has committed to achieve a 100% reduction in fossil fuel consumption by 2045 (van Schaik et al., 2020).

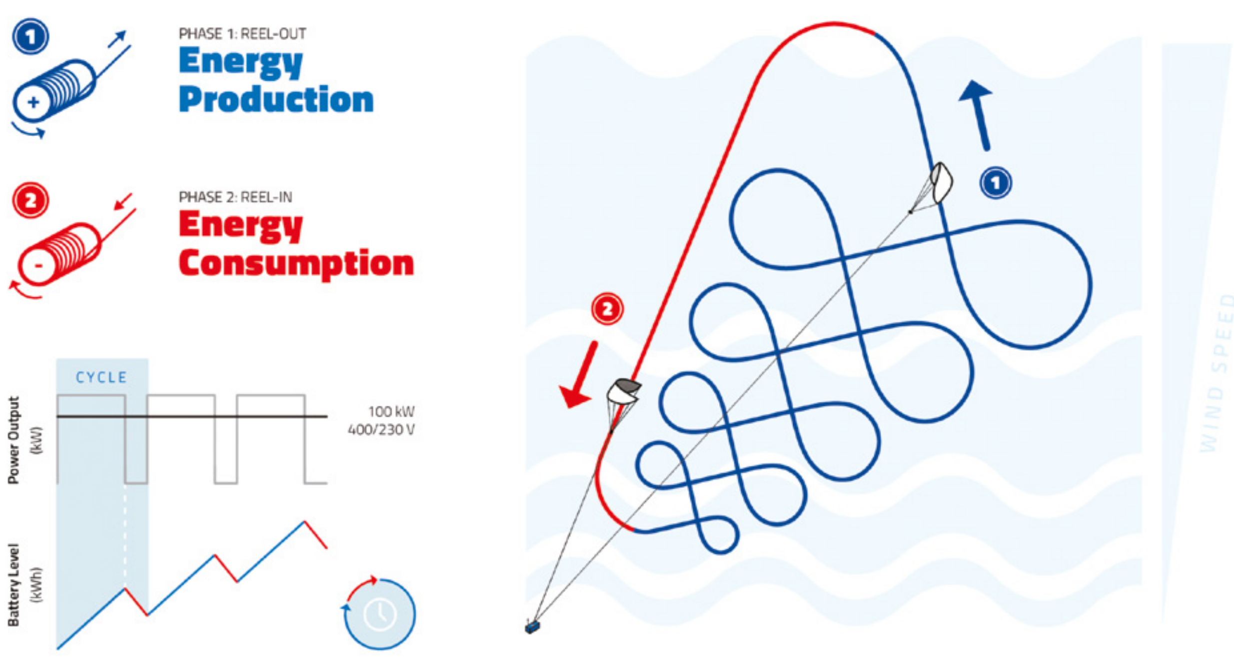
It should be further noted that electricity and heat generation based on fossil fuels not only releases GHG emissions to the atmosphere, but also other substances harmful to human health and the environment (e.g., sulphur and nitrogen oxides). Thus, **monitoring, evaluation** (e.g., using an emission inventory) (EEA, 2019b) **and reduction of air pollutants under the *UNECE Convention on Long-range Transboundary Air Pollution*[177] is desirable.**

Although military installations represent a smaller fraction of the energy use compared to military transport, GHG emissions are perhaps more straightforward to reduce in military installations due to already existing competitive sustainable energy technologies. Facilities and equipment that military installations house can be made more energy efficient[178] (one of the most cost-effective options to reduce GHG emissions; DoE, 2017). Also, energy systems can be modernised (e.g., distributed generation and trigeneration, renewable energy use, wide bandgap semiconductors [e.g., gallium-nitrite-based inverters], multi-fuel variable speed emergency power generators, hybrid generators [e.g., NATO ENSEC CoE, 2018], fuel cells, solid-state and hybrid transformers, electrolysers, energy storage, superconducting electric power lines and dynamic line rating).

Similarly, energy systems can be optimised (e.g., generation closer to loads to reduce losses, secure smart microgrids), with the same applying to Heating, Ventilation and Air Conditioning (HVAC) systems (e.g., heat pumps, use of solar thermal energy, geothermal energy, free cooling and natural ventilation, integrated solar PV and air conditioning, thermal energy storage). Energy and materials can be recovered from waste[179], and building roofs and military land can be used to deploy renewable energy or for ecosystem services[180] (e.g., green roofs, afforestation). Fugitive emissions of greenhouse gases (e.g., methane) can be strictly monitored and controlled and refrigerants (e.g., SF6, a fluorinated GHG that is present in electrical equipment such as switchgear and transformers[181]) can be replaced with environmentally friendly variants. Non-tactical vehicles can be electrified or made more fuel efficient, traditional engines can be adapted to multifuel, and synthetic non-food feedstock fuels can be used directly or blended[182]. Procurement can be made green and sustainable[183] by including criteria such as low lifecycle GHG emissions, energy efficiency, or dual-use to avoid equipment duplication for military and civilian applications (e.g., civil protection). In terms of training, the use of simulators reduces fuel consumption and the use of OME.

Examples such as those in the previous paragraphs will help EU MoDs attain a higher reduction of GHG emissions, with significant co-benefits[184], but will also stimulate R&D and support the energy transition in society (Boehm et al., 2021). Furthermore, several of these solutions may be combined with measures for risk reduction and resilience building, which not only makes implementation easier, but will also maximise benefits and improve cost-efficiency (e.g., reducing payback periods).

Figure 13. Schematic representation of Kitepower cycle. Source: Jeltje van der Meulen/Dutch MoD; Gerben Seevinck/Dutch MoD



7.2. Case study: Kitepower NTP project, Dutch MoD

Within the National Technology Program (NTP) of the Dutch MoD, the award-winning Kitepower Project was born in 2019 by building on a collaboration with Kitepower[185] (also known as Enevate B.V.). Since 2004, R&D on kite power systems at Delft University of Technology (TU Delft) resulted in a 100 kW pre-commercial prototype. The aim of the project was to continue developing the kite power system making it more robust and suitable for use in defence applications (high technological maturity, i.e., TRL 7, and semi-autonomous operation). The system generates electricity by flying a kite tethered to a generator (*Dyneema tether*[186]). A scheme of how the system works is presented in Figure 13.

Kite power systems are lightweight, mobile[187], need 90% less material compared to normal wind turbines, are easy to maintain, repair or replace, easy to operate (semi-autonomous system), make use of wind at high altitudes (from 100 to 450 m) and at variable wind speeds, produce energy during the day or night (contrary to PVs), and present a high-capacity factor. Energy produced by these systems is expected to compete with conventional sources and is more economical than diesel generators (more than 120 000 L/year of diesel can be potentially saved[188]).

As part of the EU-funded REACH project[189], the functionality of the kite power system was demonstrated during a real-life military exercise in Aruba during a two-week period (Figure 14). Valuable results were achieved in terms of system

Figure 14. The Kitepower National Technology Program project of the Dutch MoD in Aruba. Source: Jeltje van der Meulen/Dutch MoD; Gerben Seevinck/Dutch MoD

mobility, flexibility, rapid deployment and operation of a ca. 22 h flight.

EU defence can make use of these systems to increase the supply of renewable energy, e.g., by integrating them in military microgrids, which will help to reduce fuel consumption (e.g., from diesel generators) and dependency on fossil fuels, producing cost savings. This type of innovation may help EU MoDs to achieve their expressed ambition regarding the reduction of GHG emissions, resilience and energy security, and help bring the defence sector in line with EU targets on energy and climate neutrality by 2050. On the other hand, defence-related projects such as this have the co-benefit of accelerating the development of new technologies that may be useful for civilian use and for the energy transition.

08 Recommendations for a **climate-proof future**

To reduce climate risk, strengthen resilience, enhance energy security, and bring the defence sector in line with the EU targets on energy and climate neutrality by 2050, EU defence should be proactive in:

- improving its green credentials by applying the "energy efficiency first principle"[190] and systematically reducing GHG emissions;
- ensuring energy diversification, both onsite and in procurement;
- modernising and future-proofing infrastructure, particularly energy systems;
- streamlining and updating its procedures and applications;
- investing in R&D, innovation and training;
- strengthening multilateral cooperation.

These actions should be tackled while at the same time ensuring operational effectiveness and readiness. It is essential to recognise that the impacts from a disaster or a crisis, on top of response and recovery efforts, may prove to be significantly more expensive than preventive action, and with unknown consequences on EU security. On the other hand, if infrastructure development and investments are not carefully planned for, accounting for climate change, vulnerabilities may become locked-in due to high capital investment, and the long lifespan of infrastructures.

This challenging task requires both innovation and decisive action to address existing gaps, push forward new plans and follow through with the implementation of risk reduction and resilience measures, including increased energy resilience.

To reduce climate risk, strengthen resilience and promote sustainability, this study proposes a number of actions in five dimensions (operational, capability planning and development, governance, multi-stakeholder engagement and R&D) and **at different stakeholder levels** (EU, MoDs).

1) Operational dimension – MoD level

a) Implement energy efficiency and energy diversification measures onsite (e.g., generation, storage and use of renewable energy, electrification), which will benefit resilience, but also sustainability and climate change mitigation.

b) Implement secure digitalisation, integration and optimisation of energy systems (e.g., smart microgrids, emergency power, SCADA).

c) Ensure that climate risk preparedness plans for military installations exist and are up to date. Plans should be specific for each military installation, consistent with risk assessments, focused on optimising response and recovery on- and off-site (e.g., CMCoord) and on mission continuity under different crisis scenarios.

d) Integrate weather and climate data in energy management (e.g., for preparedness planning, operational decisions, early warning, emergency response and recovery, inventory management and pre-positioning of emergency assets and supplies).

e) Collect data on climate change impacts on military installations to produce insights and learn lessons. This includes data on direct damage and the triggering of technological accidents by climate-related hazards, but also the tracking of energy disturbances (e.g., location, assets, components, cause, date and time, duration, unserved critical loads, backup power use, load shedding required, mission impacts, fatalities, costs, response, repair and recovery times). **Data collection and reporting should be standardised.**

f) Routinely assess the performance of installations' energy systems, collect energy data and estimate GHG emissions (e.g., energy usage, energy quality, thermal performance, energy-saving potential[191]). Collecting data is a key step to achieve the expressed ambition of EU MoDs regarding the reduction of GHG emissions and energy security.

g) Review, and if necessary, adapt, the inspection and testing schedule of military installations' energy systems, including emergency power systems, to ensure they function as expected, to identify MRO needs and potential improvements[192] (e.g., by islanding, partial or total shutdown, load tests, including full load testing, stress tests[193] and black start exercises[194]).

h) Review and test crisis scenarios to improve response and recovery and share best practices by identifying gaps and training needs, vulnerabilities, and developing relevant capabilities[195] (Kopustinskas et al., 2019; Nave et al., 2021). Scenarios may be developed based on past events and expert knowledge, existing risk assessments, or by using scenario discovery techniques. They should account for all climate-related hazards, particularly high-impact low-probability events[196], be comprehensive in identifying vulnerabilities, including single points of failure and CEI interdependencies.

i) Incorporate climate, energy and sustainability considerations in military training and evaluation testing. This should include improving response to and recovery from severe weather events and energy crises (e.g., CMCoord, disaster relief, humanitarian aid, search and rescue), operating in adverse conditions, servicing energy systems, risk, energy and environmental management, auditing and certification, circular economy principles, nature-based solutions, and raising awareness and changing behaviour regarding energy use, GHG emissions and environmental degradation.

2) Capability planning and development – MoD level

a) Review risk management plans to identify gaps in the integration of climate considerations in defence capability planning. Plans should follow guidelines for principles, frameworks and processes[197], to acquire the capacity to resist and recover faster from climate impacts (e.g., survivability, energy autonomy) and operate efficiently.

b) Develop specific guidelines for the assessment of climate risk in defence. These should include guidance on measuring and assessing the vulnerability of assets, particularly installations' energy systems, and of CEI, accounting for both direct and indirect impacts of climate-related hazards and changing operating conditions. They should be based on existing best practices for risk assessment of critical infrastructures[198] (e.g., Theocharidou and Giannopoulos, 2015; Miller et al., 2015).

c) Define a CEI strategic framework (such as policies, plans, programmes and investments) for EU defence to ensure protection, continuity and resilience (e.g., *the European Energy Security Strategy*; EC, 2014).

d) Review risk criteria[199] **for each military location, asset, and function or process focusing on mission assurance**. Typically, civil protection focuses on human impacts (fatalities) or economic impacts (costs), but criteria for military installations should instead reflect mission impacts (partial or total interruption) from sustained direct damage or unserved loads[200].

e) Define autonomy requirements for the continuous sustainment of critical loads (e.g., minimum number of days to operate in autonomy, redundancy and flexibility of energy systems, diversity of energy supply sources, trained personnel).

f) Prioritise site-specific measures to reduce risk and strengthen resilience based on climate risk assessments, including hardening and physical protection of infrastructure, fault tolerance, modernisation, resource security, optimised response and recovery, and environmental sustainability. Concrete examples are provided for each climate-related hazard in Tavares da Costa and Krausmann (2021).

g) Prioritise energy performance improvements based on energy performance assessments (e.g., MRO optimisation, energy efficiency and energy performance contracting, renewable energy and power purchasing agreements, awareness and behavioural changes). Improvements reduce the dependency on fossil fuels, increase energy security, strengthen the resilience of military installations and improve the green credentials of EU MoDs.

h) Incorporate climate considerations in military planning, investment lifecycles, procurement criteria and R&D, including the outcomes of climate risk assessments and climate and energy foresights.

i) Implement energy diversification measures in procurement (e.g., contracting with different energy suppliers, purchase of electricity from renewable sources, purchase of alternative fuels). Not only will this benefit resilience, sustainability and help reduce GHG emissions, but it also has the potential to drive market changes, with defence a large-volume end-user of energy.

j) Bring new and existing infrastructure, including energy, up to design and building standards, where necessary, considering site-specific climate risks, resilience and new energy requirements.

3) Governance – EU and MoD level

a) EU level

i) Establish an **EU-led *Competence Centre for Defence, Energy and Climate***. This Centre would support MoDs in addressing the defence, energy and climate nexus, as well as underpin policy and decision-making in climate change mitigation and adaptation. It would ensure coherence in implementing the EU's energy and climate objectives and accelerate cross-border cooperation, including civilian and military, with the potential to generate significant economic savings that enable additional means to be allocated to military priorities.

ii) Develop an ***EU Defence Strategy on Climate Change***[201] to complement national defence strategies on climate change, applicable across different military departments.

b) MoD level

i) Adopt measures to reduce GHG emissions, and to strengthen resilience to the impacts of climate change. This can be achieved by applying resilient and sustainable energy models, and implementing mechanisms for progress monitoring (e.g., DoA, 2022; Ministère des Armées, 2021), while promoting climate-proofing.

ii) Clarify if legal instruments at the national level are sufficient to protect and strengthen the resilience of military installations and CEI to climate-related hazards or if EU-level support would be beneficial. An inadequate level of protection and resilience against climate-related hazards entails potential impacts on military operational effectiveness and readiness, supply disruptions, and the triggering of technological accidents and cascading effects.

4) Multi-stakeholder engagement – EU level

a) Strengthen civil-military cooperation at the EU level for sustainable energy (e.g., risk preparedness, CMCoord agreements, including solidarity clauses[202], irrespective of on-site emergency power systems[203] being perceived as sufficient, equipment and component stockpiling[204], demand side management of non-critical loads[205] for flexibility, training, cybersecurity, R&D).

b) Identify points of contact and establish priority relations with civilian critical entities (e.g., to facilitate data exchange, training, definition of critical supply rates, firm energy contracts and force majeure clauses[206], demand forecast, early warning, situational awareness and emergency communications).

c) Set up an *EU Multi-stakeholder Forum* for defence, energy and climate to address risk reduction and resilience building to climate change and the energy transition in defence. This forum should serve the following purposes:

i) raise awareness of climate change impacts, with particular focus on infrastructure interdependency and lessons learned;

ii) coordinate actions to reduce risk and strengthen resilience between different CEI stakeholders, and between them and military stakeholders;

iii) promote the integration of measures that may benefit multiple stakeholders at the same time (e.g., tree-trimming, targeted undergrounding of pipelines and electric power lines) and find appropriate funding mechanisms;

iv) share knowledge, identify best practices, challenges and opportunities for cross-fertilisation and technology transfer. CEI operators often know little about the infrastructure they do not operate but depend upon (e.g., water and wastewater, telecommunications), exerting little to no control over them, but also about the needs of their critical customers such as defence.

d) Establish civilian-military joint rapid response teams and doctrine for effective response and recovery on- and off-site at the onset of a disaster or crisis.

e) Provide real-time situational awareness and systematically collect post-event data to produce analyses and lessons learned.

5) Research and development – EU level

a) Establish an EU permanent programme to advance R&D and innovation on the various dimensions of climate change and defence, from strengthening resilience and managing risks associated with climate-related hazards, to climate neutrality and sustainability. Consider setting up military testbeds and proving grounds[156] to facilitate the transition of R&D to operational implementation, which make the military a key first user and early customer of pre-commercial technology.

b) Further utilise existing EU instruments for R&D addressing climate change, e.g., *the EU Innovation Fund*[207], *the European Defence Fund*[208], EDA's Energy and Environment capability technology group[209], the Consultation Forum for Sustainable Energy in the Defence and Security Sector, and the *Permanent Structured Cooperation*[210].

c) Review design and building standards, and define benchmarks for new EU defence infrastructure to incorporate climate-proofing, energy efficiency and sustainability (e.g., the *European Defence Standards Reference System*[211]);

d) Support the development of decision-making tools to compare the cost-effectiveness of climate risk reduction and resilience measures, by estimating lifecycle costs, reliability (e.g., expected unserved critical loads, oil or gas, expected downtime and avoided mission impacts) of different architectures and technologies, considering technological maturity[212], co-benefits and trade-offs (e.g., Wallace et al., 2019).

e) Encourage the development of a methodology to analyse the resilience of interdependent civilian energy systems (e.g., using easy-to-interpret indicators of system robustness, fault tolerance, resourcefulness, response and recovery, Vamanu et al., 2021; or computer-based modelling of energy systems and components[213]) to quantify reliability (and possibly sustainability), monitor its evolution, identify vulnerabilities and test scenarios.

Conclusion

09

The EU faces various defence and security threats, which will be exacerbated by climate change. By analysing the vulnerabilities of military installations and CEI, on which they depend for critical energy services, this study shows how EU defence can be impacted by climate change via multiple pathways. It identifies existing gaps in countering the associated risk effectively and shows that significant efforts are still needed to prepare for and to withstand the impacts of climate change and mitigate it.

To this end, the study provides concrete recommendations, at the EU and MoD levels, to strengthen resilience and contribute to the EU's approach to climate change mitigation from a politico-strategic and physical assets perspective. Potentially significant steps forward might be taken in EU defence as a result of the following suggestions:

- establishing guidelines for the assessment of climate risk in defence;
- defining a CEI strategic framework in the defence context;
- incorporating climate considerations in military planning, investment lifecycles, procurement criteria and R&D;
- modernising infrastructure and investing in reskilling and upskilling;
- establishing an *EU Multi-stakeholder Forum for defence*, energy and climate to better address climate change and energy challenges in defence;
- establishing an EU-led *Competence Centre for Defence*, *Energy and Climate* for coordination and long-term support in implementing actions, such as the ones above, in a comprehensive, systematic and structured way, ensuring alignment with the EU's efforts towards climate neutrality by 2050;
- developing an *EU Defence Strategy on Climate Change;*
- promoting an EU programme to advance R&D on climate change and defence.

This study concludes that it is difficult for the military to implement measures to fight climate change because the armed forces are often large owners of public land and infrastructure, have a large number of staff, move large quantities of products, acquire a large number of services, and have rigorous embedded procedures. However, decisions must be taken, and actions must be expedited in the next few years if EU defence is to be climate-resilient and sustainable. Delayed action increases the risk of loss of military capability, higher costs, and potentially severe consequences for EU security.

At the same time, the armed forces have an enormous opportunity to help in countering global warming and to speed up the transition to a greener and more sustainable economy. As the EDA Chief Executive underlined, "the green transition will only be successful if we bring fully on board the defence sector, which is an energy-intensive and large consumer of fossil fuel"[214].

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Annex

Table A 1. Example of impacts of climate change on military installations and military capabilities, more specifically on facilities, equipment and personnel (Tavares da Costa and Krausmann, 2021; permafrost impacts based on Hjort et al., 2022).

	Facilities	Equipment	Personnel
High temperatures and heatwaves	Damage to structures due to thermal stress (e.g., rails, tarmac melting), loss of load-bearing capacity and ground failure from permafrost thaw (e.g., subsidence, thaw settlement, decrease in adfreeze strength, taliks and thermokarst formation, thermal erosion, mass wasting), with possible structural failure and collapse (e.g., buildings, bridges).	Damage due to thermal stress, lubricant deterioration (e.g., gearboxes, pumps), malfunctioning (e.g., electronics, sensors, control systems, engines affected by less oxygen, ship turbines affected by high water temperatures and high salinity), derating and failure.	Health effects (e.g., heat stroke, exhaustion, cardiovascular, respiratory and infectious diseases).
	Increase in ventilation, cooling, refrigeration and energy consumption.		Decrease in air quality (e.g., smog).
	Increase in water use, water shortages and water restrictions.		Increase in fire and water management operations.
	Increase in evaporation losses (e.g., water, fuel, chemicals) and higher potential for Natech accidents (e.g., fire, explosion of aboveground OME storage).		Decrease in manoeuvrability (e.g., decrease in aircraft lift and break power, turbulence increase) and lower visibility (haze).
	Increase in (bio-)fouling (e.g., piers, vessel hull), fuel and water contamination and corrosion.		
Drought	Water shortages and water restrictions.		Increase in fire and water management operations
	Loss of natural cover, concealment and camouflage.		
	Damage to structures due to ground failure and soil dry-out, with possible structural failure and collapse.		
	Increase in desalinisation and energy use.		

	Facilities	Equipment	Personnel
Extreme cold	Damage due to thermal stress, frost heave and frost jacking (e.g., pavement cracks), snow, rain-on-snow, ice build-up (e.g., roof collapse), and impact loads such as avalanche, with possible structural failure and collapse (e.g., buildings, bridges).	Damage due to thermal stress (e.g., icing of wings, vessel topside, carburettors), malfunctioning (e.g., stoppage and slow start of generators, snow covered antennas, decreased output of batteries, altimeters), derating and failure.	Health effects (e.g., hypothermia, frostbite, injuries, electrocution, carbon monoxide poisoning).
	Frozen water systems (e.g., water pipes, pumps), with resulting water shortages and water restrictions, frozen life-safety and security systems (e.g., fire sprinklers), drainage clogging with ice or snow.	Frozen and clogged equipment, decreased machinery performance due to higher viscosity of lubricants and fuels, wax formation, increased adhesion (e.g., seized engine) and drag due to cold air.	
	Condensation and water damage (e.g., buildings, furnishings, fuel contamination, OME drenching and corrosion).		Increase in anti-icing, de-icing, snow clearing, spill management, evacuation and search and rescue operations.
	Increase in losses (e.g., water, fuel, chemicals) due to leaks and higher potential for Natech accidents (e.g., environmental contamination).		
	Increase in heating, backup power and energy use, and higher potential for the disruption of electricity and fuel supply.		
		Decrease in manoeuvrability (e.g., slippery surfaces, brake oxidation due to de-icing and brake failure, drifting ice) and visibility (e.g., snowfall).	
Floods and heavy rainfall	Damage and malfunctions due to water action on structures and equipment in flood-prone areas at ground level, including uplift and displacement (e.g., vehicle and aircraft rollover, vessels swept ashore), impact loads from drifting debris, rainfall-triggered landslides, erosion and abrasion, internal flooding (e.g., aboveground and subsurface OME storage, missile silos), including saltwater intrusion, condensation and water damage (e.g., buildings, furnishings, fuel contamination, OME drenching and corrosion), drainage clogging with sediments and overflow (including wastewater), and possible structural failure and collapse (e.g., buildings, bridges, roofs) due to water action, ponding, impact loads and erosion.		Health effects (e.g., hypothermia, drowning, respiratory and infectious diseases, electrocution, injuries).
	Higher potential for the disruption of electricity, drinking water and fuel supply.		Decrease in air quality (e.g., mould).
	Increase in losses due to leaks (e.g., ruptured vehicle fuel tanks) and higher potential for Natech accidents (e.g., chemical and oil spills, wastewater dispersion, contamination, ignition of flammables by sparks, electric arcs, flames or hot surfaces).		Increase in flood and spill response (e.g., shutdown and purge of pipelines, de-inventorying of storage tanks, deployment of flood barriers or spill booms), unclogging, pumping, evacuation, relocation, security, search and rescue and cleaning operations.
	Increase in ventilation, pumping, backup power and energy use.	Decrease in manoeuvrability (slippery surfaces, standing and moving water, drifting debris such as wood) and visibility (e.g., rainfall).	

	Facilities	Equipment	Personnel
Windstorms and lightning	Damage and malfunctions due to wind, including uplift and displacement (e.g., roofs, vehicle and aircraft rollover), and wave action (e.g., piers, breakwaters, vessels swept ashore) and impact loads from airborne debris and hail, lightning strikes, airborne-particle abrasion and corrosion, drainage clogging with sediments and overflow (including wastewater), and possible structural failure and collapse (e.g., buildings, bridges, roofs) due to wind action, impact loads and erosion.		Health effects (e.g., cardiovascular, respiratory and infectious diseases, electrocution, injuries).
	Increase in losses due to evaporation and leaks (e.g., ruptured vehicle fuel tanks) and higher potential for Natech accidents (e.g., contamination, chemical and oil spills, wastewater dispersion, contamination, ignition of flammables by lightning, sparks, electric arcs, flames or hot surfaces, explosion of above-ground OME storage).		Decrease in air quality (e.g., dust).
	Higher potential for disruption of electricity, drinking water and fuel supply.		Increase in emergency procedures (e.g., removal and securing of equipment, shutdown and purge of pipelines), evacuation, relocation, security, search and rescue and cleaning operations.
	Increase in backup power and energy consumption.	Decrease in manoeuvrability (strong wind, highwaves) and visibility (e.g., dust).	
	Loss of natural cover, concealment and camouflage.		
Wildfires	Damage and malfunctions due to thermal and impact loads (e.g., falling trees, branches), with possible structural failure and collapse (e.g., buildings), corrosion, drainage clogging with sediments and debris.		Health effects (e.g., cardiovascular, respiratory, exhaustion, electrocution, injuries, fatalities).
	Increase in losses (e.g., water, fuel, chemicals) due to evaporation and higher potential for Natech accidents (e.g., fires, explosion of vehicles and aircrafts, aboveground OME storage).		Decrease in air quality (e.g., ash, smoke) and drinking water quality due to ash contamination.
	Loss of natural cover, concealment and camouflage.		Increase in fire management, preventive measures (e.g., shutdown and purge of pipelines, de-inventorying of storage tanks), evacuation, relocation, search and rescue and cleaning operations.
	Increase in backup power and energy consumption.	Decrease in manoeuvrability and visibility (e.g., smoke).	
	Increase in water use (e.g., firefighting).		
	Higher potential for disruption of electricity supply.		

Note. Extreme cold is included here although it is unclear if such events may result from a weakening of the polar vortex due to climate change (Cohen et al., 2021). Floods are generalised to all coastal floods (including the effects of sea level rise and storm surge), riverbank overflows, or ponding.

Table A 2. Examples of possible impacts induced by climate change on CEI, and more specifically on electricity, oil and gas infrastructure.

	Electricity	Oil and Gas
High temperatures and heatwaves	Damage to structures (e.g., access roads, foundations), equipment or components/ network elements (e.g., electricity poles, transmission towers, substations) due to thermal stress (e.g., lubricant deterioration, overheating and cracked solar cells), loss of load-bearing capacity and ground failure from permafrost thaw (e.g., subsidence, thaw settlement, decrease in adfreeze strength, taliks and thermokarst formation, thermal erosion, mass wasting), (bio-)fouling, clogging (e.g., algal or jellyfish bloom) and increased corrosion.	Damage to oil and gas wells, pump/meter stations, tank farms and terminals due to ground failure from permafrost thaw.
	Reduction of electricity generation, e.g., in solar power due to efficiency loss and haze; in wind power due to low wind and decrease in air density, but also derating; in hydropower due to evaporation losses, seasonal flow change from rainfall, ice and snow melt and increase in water demand (e.g., irrigation, residential, commercial, industrial); in thermal power plants due to generation cycle efficiency loss, derating, higher water temperature and decrease in cooling efficiency (including CCS), and restrictions in the discharge of warm water (heat sink); in coal-fired power plants due to coal self-combustion; in biofuel power plants due to biofuel crops yield loss due to heat stress and pests.	Refining process efficiency loss due to warmer air and water temperatures, restrictions in the discharge of warm water, and (bio-)fouling.
	Increase in electricity demand due to an increase in ventilation, cooling, humidity control and refrigeration.	Damage to pipelines and components (e.g., small-bore connections, welds, flanged joints, seals, valves, sensors, concrete anchor blocks, aboveground storage tank foundations) due to ground failure from permafrost thaw, (bio-)fouling, and thermal stress (overheating, overpressure).
	Efficiency reduction of transmission and distribution lines (e.g., power line sag, derating) and of batteries.	Increase in evaporation losses in transport, storage and refuelling, and higher potential for Natech accidents (e.g., fire, explosions).
	Transmission and distribution congestion.	Decrease in pipeline transport capacity, increase in costs and aftercooling, pressure and flow rate fluctuations.
	Energy export restrictions (reduction of electricity interconnector capacity or curtailment of oil and gas exports).	
	Decrease of energy demand for heating and seasonal shift in peak demand for energy.	
	Malfunctioning of equipment (e.g., backup power generators due to less oxygen, PV overheating, electronics, sensors, control systems, life-safety and security systems, such as relief valves), false signals, derating (e.g., transformers) and tripping of circuit breakers.	
		Increase in fuel consumption for electricity generation, including backup power, constraints in fuel supply and lower fuel reserves.

<table>
<tr><th></th><th>Electricity</th><th>Oil and Gas</th></tr>
<tr><td rowspan="5">Drought</td><td>Damage to structures, equipment or components/network elements due to ground failure from soil dry out.</td><td>Damage to oil and gas wells, pump/meter stations, tank farms and terminals due to ground failure from soil dry out.</td></tr>
<tr><td>Reduction of electricity generation, e.g., in hydropower due to low river flows, and restrictions associated with water use and environmental flows; in Concentrated Solar Power (CSP) due to water use restrictions; in thermal power plants due to water use restrictions for cooling and emissions control systems (including CCS), restrictions in the discharge of warm water, and due to limited inland water transport of fuels (e.g., coal transport); in biofuel power plants due to biofuel crops yield loss.</td><td>Damage to pipelines and components (small-bore connections, welds, flanged joints, concrete anchor blocks, aboveground storage tank foundations) due to ground failure from soil dry-out.</td></tr>
<tr><td colspan="2">Energy export restrictions (reduction of electricity interconnector capacity or curtailment of oil and gas exports).</td></tr>
<tr><td>Reduction of transmission and distribution efficiency of subsurface electric power lines and effectiveness of earth wires.</td><td rowspan="2">Releases of dangerous substances from damaged components.</td></tr>
<tr><td>Increase in electricity demand due to an increase in water use (e.g., pumping, irrigation, desalinisation).</td></tr>
<tr><td rowspan="9">Extreme cold</td><td>Damage to structures, equipment or components/network elements due to ice, snow and rain-on-snow loads (e.g., roofs), frost heave (e.g., access roads, foundations), thermal stress (e.g., cracked solar cells), glazing and wind-on-ice loads (e.g., power lines, transmission towers), impact loads from drifting ice (e.g., hydroelectric power plants, offshore wind turbines, bridges and access roads) and falling debris (e.g., trees and branches), clogging (e.g., power plant water intake) and corrosion (e.g., condensation, internal flooding).</td><td>Damage to pipelines and components (e.g., small-bore connections, welds, flanged joints, concrete anchor blocks) due to thermal stress, freeze-thaw, frost heave, impact loads from drifting ice (e.g., pipeline suspension bridges) and falling debris (e.g., trees and branches), clogging (e.g., hydrate formation) and corrosion (e.g., condensation).</td></tr>
<tr><td>Reduction of electricity generation, e.g., in all power plants due to sustained damage; in thermal power plants due to fuel shortage; in hydropower and thermal power plants due to frozen water bodies; in wind power due to wind turbine blade icing and excessive vibration; in solar power due to cloudiness, fog and snow or ice deposition; in biofuel power plants due to biofuel crops yield loss from frost; in coal power plants due to frozen coal.</td><td>Damage to aboveground storage tanks due to ice, snow and rain-on-snow loads (e.g., roofs), thermal stress, freeze-thaw, frost heave (e.g., aboveground storage tank foundations) and corrosion.</td></tr>
<tr><td>Increase in electricity demand due to an increase in heating.</td><td>Damage to oil and gas wells, pump/meter stations, tank farms and terminals due to thermal stress, freeze-thaw, frost heave, clogging and corrosion.</td></tr>
<tr><td>Transmission and distribution congestion.</td><td>Pressure and flow rate fluctuations in pipelines, malfunctioning of process equipment not prepared to handle multiphase fluids (e.g., meters, sensors, pressure relief valves).</td></tr>
<tr><td colspan="2">Ice accumulation on insulators and flashover, malfunctioning of equipment (e.g., stoppage and slow start of backup power generators, transformers, inverters, electronics, sensors, control systems, life-safety and security systems, water systems), false signals, derating (e.g., transformers) and tripping of circuit breakers.</td></tr>
<tr><td colspan="2">Energy export restrictions (reduction of electricity interconnector capacity or curtailment of oil and gas exports).</td></tr>
<tr><td rowspan="2"></td><td>Increase in fuel consumption for electricity generation, including for backup power generators, constraints in fuel supply and lower fuel reserves.</td></tr>
<tr><td>Increase in losses due to leaks and higher potential for Natech accidents (e.g., environmental contamination).</td></tr>
<tr><td rowspan="7">Floods and heavy rainfall</td><td>Damage to structures, equipment or components/network elements sitting in flood-prone areas at ground-level due to water action (e.g., power plants, transmission towers, substations, electricity poles), impact loads from drifting debris (e.g., hydroelectric power plants, substations, bridges and access roads, levees), ground failure (including swamping and rainfall-triggered landslides), condensation, erosion (e.g., wind turbine and transmission tower foundations, PVs), sediment accumulation, clogging, abrasion (e.g., gates, dams, hydroelectric power plant turbines, water intakes), internal flooding and increased corrosion (including sediments, seawater and salt deposits in the case of coastal floods).</td><td>Damage to pipelines and components (small-bore connections, welds, flanged joints, concrete anchor blocks) due to water action, impact loads from drifting debris, ground failure (including swamping and rainfall-triggered landslides), and corrosion damage, exposure and damage of subsurface pipelines due to erosion, damage to pipeline suspension bridges and riparian infrastructure due to water action, impact loads from drifting debris and rainfall-triggered landslides.</td></tr>
<tr><td>Reduction of electricity generation, e.g., in all power plants due to sustained damage; in thermal power plants due to fuel shortage; in hydroelectric power plants due to the forced use of floodways and loss of output, and increased silting of reservoirs and water intakes; in coal-fired power plants due to coal drenching and coal transport disruption; in solar power due to cloudiness increase or fog; in biofuel power plants due to biofuel crops yield loss due to water damage and salinisation (coastal).</td><td>Displacement, deformation and fracture of aboveground storage tanks (e.g., flotation, roof collapse) due to water action, impact loads from drifting debris and rainfall-triggered landslides, corrosion, exposure and damage of subsurface storage tanks due to erosion.</td></tr>
<tr><td colspan="2">Potential increase in releases of dangerous substances (e.g., spent fuel dry casks, coal stockpiles, open cast mines, tailing dams, pipelines, fuel storage tanks) and higher potential for Natech accidents (e.g., chemical and oil spills, wastewater, toxic or radioactive contamination, ignition of flammables by sparks, electric arcs, flames or hot surfaces).</td></tr>
<tr><td colspan="2">Malfunctioning of equipment (e.g., transformers and inverters, electronics, sensors, backup power generators, control systems, life-safety and security systems, water systems) and tripping of circuit breakers.</td></tr>
<tr><td rowspan="3"></td><td>Damage to oil and gas wells, pump/meter stations, tank farms and terminals due to water action, impact loads from drifting debris and corrosion, flooding of open mines.</td></tr>
<tr><td>Malfunction of sump pumps and drainage (including clogging with debris) and overflow of sump tanks.</td></tr>
<tr><td>Constraints in fuel supply and lower fuel reserves.</td></tr>
</table>

	Electricity	Oil and Gas
Windstorms and lightning	Damage to structures, equipment or components/network elements due to wind action, abrasion, impact loads from airborne debris and hail (e.g., PVs, wind turbines, roofs, transmission towers, substations, electricity poles, electric power lines) and lightning (e.g., wind turbine blades, solar inverters). Strong wind and wave action damage to structures, equipment or components located offshore or in low-lying coastal areas, damage due to sediment accumulation, abrasion (e.g., wind turbines, PVs), clogging (debris and dirt), erosion (e.g., wind turbine and transmission tower foundations, PVs, subsurface equipment) and corrosion from moisture and salt sprays (if coastal) and lightning.	Damage to pipelines and components (small-bore connections, welds, flanged joints, valves) due to strong winds, wave action as a result of windstorms (e.g., tanker loading/unloading, submarine pipeline damage due to anchor dragging), impact loads from airborne debris and hail, underwater landslides, and corrosion damage (salt sprays and lightning), damage to pipeline suspension bridges due to wind action and impact loads.
	Reduction of electricity generation, e.g., in all power plants due to sustained damage; in thermal power plants due to fuel shortage; in solar power due to cloudiness increase, fog, or dust and dirt deposition; in wind power due to increase in turbulence and excessive vibration; in wave power due to excessive wave heights; in biofuel power plants due to biofuel crops yield loss from wind damage.	Uplift and displacement, deformation and fracture of aboveground storage tanks (including roofs) due to wind action, impact loads from airborne debris and hail, corrosion damage (salt sprays and lightning), and pipeline depressurisation and purge.
	Potential increase in releases of dangerous substances (e.g., spent fuel dry casks, coal stockpiles, tailing dams, pipelines, fuel storage tanks) and higher potential for Natech accidents (e.g., chemical and oil spills, wastewater, toxic or radioactive contamination, ignition of flammables by sparks, electric arcs, flames or hot surfaces).	
	Malfunctioning of equipment (e.g., transformers and inverters, electronics, sensors, backup power generators, control systems, life-safety and security systems, water systems), false signals (e.g., lightning, debris, salt deposits) and tripping of circuit breakers.	
		Damage to oil and gas wells, offshore oil platforms, pump/meter stations, refineries, tank farms and terminals due to wind action, impact loads from airborne debris and hail, lightning puncturing and corrosion (salt sprays and lightning).
		Constraints in fuel supply and lower fuel reserves.
Wildfires	Damage to structures, equipment or components/network elements due to thermal stress, impact loads from airborne debris (e.g., electricity poles, PVs, wind turbines, substations), ash and sediment accumulation, clogging and corrosion.	Damage to oil and gas wells, pump/meter stations, tank farms and terminals, aboveground pipelines and storage tanks due to thermal stress, impact loads from airborne debris and corrosion.
	Reduction of electricity generation, e.g., all power plants due to sustained damage; solar power due to ash deposition on solar cells; biofuel power plants due to biofuel crops yield loss from fire.	Failure of aboveground storage tanks and pipelines, pipeline depressurisation and purge.
	Malfunctioning of equipment (e.g., transformers, inverters, electronics, sensors, backup power generators, control systems, life-safety and security systems, water systems, plastic tubing), false signals (e.g., fire and smoke) and tripping of circuit breakers.	
	Efficiency reduction of transmission and distribution lines (e.g., power line sag, derating).	Higher potential for Natech accidents (e.g., oil spills, fire and explosion).

Note. Extreme cold is included here although it is unclear if such events may result from a weakening of the polar vortex due to climate change (Cohen et al., 2021). Floods are generalised to all coastal floods (including the effects of sea level rise and storm surge), riverbank overflows, or ponding. Natech accidents may take place in all stages of an energy supply chain, particularly those associated with nuclear and fossil fuels, from production such as extraction or mining, processing such as milling, refining or enrichment, transport and storage, electricity generation, to waste disposal. CCS decreases the efficiency of power plants, and increases their water requirements and overall costs (EEA, 2019a).

List of Acronyms

ACER	European Union Agency for the Cooperation of Energy Regulators
AR6	IPCC Sixth Assessment Report
CCS	Carbon Capture and Storage
CEI	Critical Energy Infrastructure
CMCoord	Civilian-Military Coordination for Response and Recovery
CSDP	Common Security and Defence Policy
CSP	Concentrated Solar Power
CF SEDSS	Consultation Forum for Sustainable Energy in the Defence and Security Sector
DoD	United States Department of Defence
EDA	European Defence Agency
EEAS	European External Action Service
EGIG	European Gas Pipeline Incident Data Group
EMAS	European Commission Eco Management and Audit Scheme
ENSEC COE	Energy Security Centre of Excellence
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
ERCOT	Electric Reliability Council of Texas
ESR	Energy Storage Resources
EU	European Union
GHG	Greenhouse Gas
GPP	Green Public Procurement
HLV	Highly Volatile Liquid
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
IF CEED	Incubation Forum for Circular Economy in European Defence
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LPG	Liquefied Petroleum Gas
MoD	Ministry of Defence
MRO	Maintenance, Repair and Overhaul
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NBS	Nature-Based Solution
NZEB	Nearly Zero Energy Building
OME	Ordnance, Munitions and Explosives
OECD	Organisation for Economic Co-operation and Development
OSCE	Organization for Security and Cooperation in Europe
PHMSA	Pipeline and Hazardous Material Safety Administration
POL	Petroleum, Oil and Lubricants
PPA	Power Purchase Agreements
PV	Solar Photovoltaic Technology
RCP	Representative Concentration Pathway
R&D	Research and Development
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control And Data Acquisition
TLCM	Through-Life Capability Management
TNCEIP	Thematic Network on Critical Energy Infrastructure Protection
TRL	Technology Readiness Level
TTX	Table-top Exercise
UN	United Nations
UPS	Uninterruptible Power Supply
V2G	Vehicle-to-grid

Terminology

Adequacy problem	Electricity generation unable to match demand.
Adfreeze	The process by which two objects are bonded together by ice formed between them.
Ancillary services	Functions that help grid operators maintain a secure and reliable electricity system or recover from a disruption.
Anthropogenic	Originating in human activity.
Asset	Any resource owned and controlled by an entity for operational purposes (e.g., personnel, infrastructure, facilities, equipment, systems, aircrafts, vehicles, vessels, supply chains).
Autoproducer	Entity that generates electricity and/or heat for its own use in support of its primary activity.
Black start exercise	Restoring power systems using on-site generation.
Carbon capture and storage	Technology to capture (and store) carbon dioxide from the atmosphere.
Climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods.
Climate change adaptation	Actions to prepare for and adjust to current and future effects of climate change, making entities and sectors more resilient.
Climate change maladaptation	Policy or measures meant to reduce vulnerability to climate change that may not have the desired effect. For example, undergrounding pipelines or power lines to protect them from wind action, but then observing an erosion of the soil due to floods. Includes under- and over-adaptation.
Climate change mitigation	Actions to reduce the concentration of greenhouse gases in the atmosphere, making entities and sectors more environmentally sound.
Climate extremes	The occurrence of a value of a weather or climate variable above (or below) a threshold near the upper (or lower) end of the range of the observed variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes.'
CMCoord agreements	Mechanism to coordinate civilian-military support, including engineering, and sharing of experts, specialised equipment and materials for efficient response and recovery.
Co-benefit	Any additional gain from a policy or measure that was not the main objective.
Compound event	A combination of two or more natural hazards or physical processes, occurring simultaneously or successively, possibly interacting.
Critical entity	A public or private entity which provides one or more essential services, which operates, and its critical infrastructure is located, on the territory of a EU Member State, and for which an incident would have significant disruptive effects on the provision by the entity of one or more essential services.
Critical infrastructure	An asset, a facility, equipment, a network or a system, or a part of an asset, a facility, equipment, a network or a system, which is necessary for the provision of an essential service.
Critical load	An energy load that if disrupted will directly affect mission assurance.
Dangerous substances	A substance (or a mixture of substances), constituting a physical, health, or environmental hazard.
Disaster	A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.
Distributed energy resources	Decentralised electricity generation and storage connected to the electrical power grid at the distribution level.
Dual-use technology	Technology that can be used both for civilian and military applications.
Energy performance contracting	A contract where an external entity implements an energy efficiency or renewable energy project and uses the cost savings or the renewable energy produced, to repay the project, including the capital costs.
Energy resilience	Reliable and continuous energy supply, and the existence of contingency measures and resources in the event of a power outage.
Energy security	Uninterrupted availability of energy sources at an affordable price.
Energy transition	Transformation of the energy sector towards the use of clean sustainable energy, which can be achieved through different technological pathways.
Environmental sustainability	Meeting the needs of the present without compromising the ability of future generations to meet their own needs.
Equipment	Set of physical resources used for a particular activity or purpose.
Explosive	A substance (or a mixture of substances), which is capable by chemical reaction of producing gas at such a temperature and pressure and at such speed as to cause damage to the surroundings. It includes all solid and liquid materials variously known as high explosives and propellants, together with igniter, primer, initiatory and pyrotechnic (e.g., illuminants, smoke, delay, decoy, flare and incendiary) compositions.
Exposure	People, property, systems, or other elements present in hazard zones that are thereby subject to potential harm, damage and loss.
Facility	Any property consisting of one or more of the following: building, structure, utility system, pavement and underlying land.

Fault tolerance	Ability to continue operation in a degraded state.
Flood-prone areas	Floodplains, low-lying coastal areas, or impervious areas with limited drainage.
Force structure	The operational availability and organisation of military personnel, weapons and equipment. It can be characterised by in-place forces, deployable forces at different levels of readiness and low-readiness forces used for large-scale defence.
Frost heave	Upward displacement of the ground surface caused by frost action.
Frost jacking	Cumulative upward displacement of objects embedded in the ground, caused by frost action.
Grid balancing	The matching of energy supply to demand in an electrical power grid.
Insolation	Amount of solar radiation per unit area measured at the Earth's surface over a time period.
Islanding	Forced or voluntary disconnection from the main electrical power grid, often the civilian electrical power grid.
Life-safety and security systems	Building elements designed to protect and evacuate persons during emergencies.
Load shedding	Deliberate disconnection of specific consumers or consumer loads to prevent the failure of an entire energy system.
Megatrend	Long-term driving forces that are observable now and will most likely have a global impact.
Microgrid	An isolated electrical power grid that can operate connected to the civilian electrical power grid or autonomously using distributed energy resources under a single controllable unit.
Military capability	The ability to deter, defend, support and ensure stability and peace effectively under specific conditions. It can be sub-divided into force structure, modernisation, operational readiness and sustainment.
Military installation	Military base or location from which operations are projected and/or supported.
Mission assurance	Process to protect or ensure the continued function and resilience of capabilities and assets critical to the execution of defence essential functions.
Munitions	A complete device, (e.g., missile, shell, mine, demolition store, etc.) charged with explosives, propellants, pyrotechnics, initiating compositions or nuclear, biological or chemical material, for use in connection with offence, defence, training, or non-operational purposes, including those parts of a weapons system containing explosives.
Mass wasting	Downslope movement of soil or rock on, or near, the earth's surface under the influence of gravity.
Natech accident	Technological accident triggered by a natural hazard and involving the release of dangerous substances, fires or explosions.

Natural hazard	Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage.
Nature-Based Solution (NBS)	Solution inspired and supported by nature, which is cost-effective, simultaneously provides environmental, social and economic benefits and helps to strengthen resilience. Such solutions bring nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.
Nearly Zero Energy Building (NZEB)	A building that has very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources.
Network reconfiguration	Change in the topology of the electrical power grid by opening and closing switches to relieve overloading, reduce disruptions and improve performance.
N-1 criterion	Criterion that states that the elements remaining in operation within an electricity transmission system operator's control area, after the occurrence of a contingency, are able to accommodate the new operational situation without violating operational security limits.
N-1 formula	Criterion that states that the gas system is able to satisfy demand even if the single largest gas infrastructure is disrupted.
Operational effectiveness	Ability to accomplish missions and operations efficiently.
Operational readiness	Capability of a unit/formation, weapons system, or equipment to perform at a precise moment a mission or function, for which it was organised or designed.
Ordnance	A weapons system with its associated munitions and auxiliary material needed to fire the munition.
Permafrost	Ground with a temperature remaining at or below 0 °C for at least two consecutive years.
Power Purchase Agreements (PPA)	Contract for civilian owned, maintained and operated energy projects on military lands, or on private property, and the purchase of generated energy.
Reliability	Ability to perform satisfactorily during a given time and for the highest number of operating conditions.
Resilience	Ability to absorb impacts, maintain adequate functioning and minimise disruptions, in support of critical missions and operation continuity.
Resourcefulness	Ability to manage disturbances.
Response and recovery	Ability to swiftly restore functions or missions and transition to a normal state.
Risk	The combination of the probability of an event and its consequences.
Robustness	Ability to resist disruption.

Scenario	Plausible description of how the future might develop based on a coherent and internally consistent set of assumptions ('scenario logic') about the key relationships and driving forces (e.g., rate of technology change or prices).
Smart grid	Electrical power grid that can automatically respond to disruptions, improve reliability and quality of service. This is done via automated functions such as grid balancing or network reconfiguration that make use of data acquisition, analytics and algorithms.
Stranded asset	An asset that is not economically viable to operate.
Supervisory Control And Data Acquisition (SCADA) system	A digital system used for gathering data on industrial processes, and for controlling them remotely in real-time.
Sustainment	Provision of logistics and personnel services required to maintain and prolong operations until successful mission accomplishment.
System of systems	Independent systems that when integrated deliver unique capabilities, but also potentially emergent behaviour arising from their interaction.
Talik	A layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrological, hydrogeological or hydrochemical conditions.
Technological pathway	Describes how the energy transition may unfold over time depending on the type of technologies adopted.
Thermal erosion	The erosion of ice-bearing permafrost by the combined thermal and mechanical action of moving water.
Technology Readiness Level (TRL)	A scale for measuring the progress or maturity level of technologies.
Thermokarst	The process by which characteristic landforms result from the thawing of ice-rich permafrost or the melting of massive ice.
Through-Life Capability Management (TLCM)	Approach to manage military capability that aims at making systems more cost-effective, affordable through their life, and responsive to threats.
Uninterruptible Power Supply (UPS)	An electric device that provides short-term instantaneous protection of an asset from electric power disruptions.
Vehicle-to-grid (V2G) technology	A technology that allows the use of electric vehicles as energy storage for the electrical power grid.
Vulnerability	The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.
Weapons system	A combination of one or more weapons with all related equipment, materials, services, personnel and means of delivery and deployment required for self-sufficiency.

List of Figures

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Endnotes

1 The most comprehensive up-to-date understanding of climate change.
2 For example, heatwaves and extreme cold, heavy precipitation and drought.
3 United Nations. Secretary-General calls latest IPCC climate report 'Code Red for Humanity', stressing 'irrefutable' evidence of human influence. https://www.un.org/press/en/2021/sgsm20847.doc.htm
4 Drought is a prolonged deficit of rainfall, soil moisture and/or surface and groundwater in a given region compared to each respective long-term average. Drought is exacerbated by high temperatures (heatwaves), low relative humidity, intense water use and poor water management (Tavares da Costa and Krausmann, 2021).
5 Rainfall-induced floods occur because excessive rainfall surpasses soil infiltration capacity, soil is excessively saturated (high soil moisture or thick snow cover), or because it surpasses urban drainage capacity (Tavares da Costa and Krausmann, 2021).
6 The conditions on which wildfires depend, such as high temperature, strong wind, low humidity and rainfall (EC, 2020; Feyen et al., 2020; Tavares da Costa and Krausmann, 2021).
7 Further warming may lead to an increase in the duration, intensity and frequency of heatwaves in all land regions (i.e., several days of excessively high temperature) (Christidis et al., 2015; Tavares da Costa and Krausmann, 2021).
8 Costal floods are caused by the combination of and interaction between high tides, storm surge (i.e., temporary sea level rise due to low atmospheric pressure and high winds), waves, mean sea level rise (i.e., due to global warming and the resulting expansion of seawater, melting ice sheets and glaciers), river flows into estuaries, and coastal subsidence (i.e., the lowering of ground due to, for example, groundwater loss outpacing recharge) (Tavares da Costa and Krausmann, 2021).
9 Permafrost is ground that remains at or below 0 °C for two or more consecutive years. Its thawing may lead to a loss of bearing capacity, irregular pitted terrain (i.e., thermokarst), and the release of methane, a powerful greenhouse gas (Tavares da Costa and Krausmann, 2021).
10 While cold extremes are expected to decrease in intensity, frequency and duration in a warming climate, phenomena related to cold weather will continue to remain a threat at least until mid-century (EC, 2020; IPCC, 2021; Tavares da Costa and Krausmann, 2021).
11 Windstorms, including cyclones and convective storms, are a weather phenomenon characterised by gusts and strong sustained winds that may be accompanied by precipitation (e.g., rainfall, hail), lightning, suspended particulate matter (e.g., dust), waves and storm surge – the last two only if large water bodies are involved. A cyclone is a large-scale rotating storm with low atmospheric pressure in its centre that forms along the boundaries separating air masses of different temperatures (extratropical cyclone) or over warm waters (tropical cyclone), while convective storms are severe, relatively short-lived, localised storms that form due to convection (Poljanšek et al., 2017; Tavares da Costa and Krausmann, 2021).
12 European Environmental Agency. Economic losses and fatalities from weather- and climate-related events in Europe https://www.eea.europa.eu/publications/economic-losses-and-fatalities-from/economic-losses-and-fatalities-from
13 Physical climate system conditions (e.g., normals, extremes) that affect an element of society or ecosystems (IPCC, 2021). For the purpose of this study, impacts refer to negative impacts only.
14 Above pre-industrial levels, i.e., the reference period 1850-1900.
15 Council Decision (EU) 2016/1841 of 5 October 2016 on the conclusion, on behalf of the European Union, of the Paris Agreement adopted under the United Nations Framework Convention on Climate Change. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32016D1841
16 Prioritising and implementing site-specific measures, enhancing preparedness, response and recovery.
17 For the purpose of this study, climate resilience is to be understood as the ability to absorb climate impacts, maintain adequate functioning and minimise disruptions.
18 For the purpose of this study, energy security is defined as the uninterrupted availability of energy at an affordable price.
19 Ritchie, H., Roser, M. and Rosado, P. (2020). CO_2 and greenhouse gas emissions. https://ourworldindata.org/co2-and-greenhouse-gas-emissions
20 For the purpose of this study, CEI is to be understood as any physical asset or system on- or off-site that produces, stores, converts or transports electricity, or fuel, essential for the functioning of a military installation. Any reference to CEI in this study is in respect only to those physical assests or systems that are defence-related.
21 Grubliauskas, J. and Rühle, M. (2018). Energy security: a critical concern for Allies and partners. https://www.nato.int/docu/review/articles/2018/07/26/energy-security-a-critical-concern-for-allies-and-partners/index.html
22 Council of the European Union. Council Conclusions on Security and Defence in the context of the EU Global Strategy – Council Conclusions, 17 June 2019, 10048/19 https://www.consilium.europa.eu/media/39786/st10048-en19.pdf
23 Council of the European Union. Council Conclusions on Security and Defence, 17 June 2020, 8910/20. https://www.consilium.europa.eu/media/44521/st08910-en20.pdf
24 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Commission contribution to European defence, COM/2022/60 final. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52022DC0060
25 Council of the European Union. A Strategic Compass for Security and Defence – For a European Union that protects its citizens, values and interests and contributes to international peace and security, 21 March 2022, 7371/22. https://data.consilium.europa.eu/doc/document/ST-7371-2022-INIT/en/pdf
26 European Commission. The Megatrends Hub. https://ec.europa.eu/knowledge4policy/foresight/tool/megatrends-hub_en
27 Communication from the Commission to the European Parliament and the Council 2020, Strategic Foresight Report, Strategic Foresight – Charting the course towards a more resilient Europe, COM/2020/493 final. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0493&from=EN
28 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal, COM/2019/640 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640
29 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Stepping up Europe's 2030 climate ambition investing in a climate-neutral future for the benefit of our people, COM/2020/562 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0562
30 Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), PE/27/2021/REV/1. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R1119
31 For example, recovery and recycling of rare-earth metals from discarded electric and electronic equipment (urban mining).
32 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, Tackling rising energy prices: a toolbox for action and support, COM/2021/660 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A660%3AFIN&qid=1634215984101
33 Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC
34 For the purpose of this study, the references to the defence sector include predominately the EU ministries of defence (MoDs) and armed forces, but also EU entities and relevant EU defence stakeholders (including industry, think tanks, etc.).
35 In other words, the armed forces becoming both consumers and producers of electricity.
36 European Commission initiative managed by EDA to assist EU MoDs to move towards green, resilient and efficient energy models. https://eda.europa.eu/what-we-do/eu-policies/consultation-forum
37 A systematic analysis of threats, vulnerabilities and opportunities.
38 European Defence Agency. EDA Factsheet: Consultation Forum for Sustainable Energy in the Defence and Security Sector (CFSEDSS) – Phase III, Working Group 3 – Protection of Critical Energy Infrastructure. https://eda.europa.eu/docs/default-source/events/eden/phase-iii/factsheets/wg3-factsheet.pdf
39 A substance (or a mixture of substances), constituting a physical, health, or environmental hazard.

Dangerous substances are covered in multiple EU Directives that aim to improve safety (e.g., European critical infrastructure, Seveso-III, nuclear safety, spent fuel and radioactive waste, safety of offshore oil and gas operations, and transport of dangerous goods). Note, however, that military installations, pipelines and intermediate temporary storage are excluded from these legal acts.

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41 Irregular pitted terrain resulting from permafrost thawing.

42 Including climate extremes.

43 Alternatively, more rotating shifts.

44 Including military training and testing, inspection and MRO.

45 A combination of two or more natural hazards or physical processes, that occur simultaneously or successively, possibly interacting. For example, rain after a wildfire may lead to flood due to loss of vegetation and soil infiltration capacity, but also to erosion and landslides (Tavares da Costa and Krausmann, 2021).

46 Thermal (e.g., salt tanks, ceramic bricks), chemical (e.g., lithium-ion, synthetic fuel production such as hydrogen and methanol), mechanical (e.g., compressed air, flywheels, hydropower) or electric (e.g., supercapacitors, superconducting magnetic energy storage).

47 When an electric fault condition is detected a circuit will shut itself off to prevent damage.

48 European Commission. Blackout of November 2006: important lessons to be drawn. https://ec.europa.eu/commission/presscorner/detail/en/IP_07_110

49 Lee, H. and Birol, F. (2020). Energy is at the heart of the solution to the climate challenge. https://www.ipcc.ch/2020/07/31/energy-climatechallenge/

50 As a basis for Table A2 we used the following studies. For the impacts on electricity infrastructure: Ebinger and Vergara, 2011; EEA, 2019a; Forzieri et al., 2015, 2018; Hjort et al., 2022; IAEA, 2019; IEA, 2020, 2021b; Karagiannis et al., 2017, 2019a, b; NATO, 2010a; Necci et al., 2018; Solauna and Cerdá, 2019; Tavares da Costa and Krausmann, 2021; and Urban and Mitchell, 2011. For the impacts on oil and gas: Cruz and Krausmann, 2013; Girgin and Krausmann, 2015; Hjort et al., 2022; Katopodis and Sfetsos, 2019; Kern and Krausmann, 2020; NATO, 2010a; Necci et al., 2018; Piccinelli and Krausmann, 2013; and Tavares da Costa and Krausmann, 2021.

51 Including those defined in Article 24(1) of Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R1485

52 Assets that may not be economically viable to operate as a result of changing operating conditions due to climate change.

53 In other words, forced islanding (i.e., disconnection from the civilian electrical power grid) and reconfiguration.

54 The N-1 criterion states that the elements remaining in operation within a transmission system operator's control area, after the occurrence of a contingency, are capable of accommodating the new operational situation without violating operational security limits. Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation, C/2017/5310. https://eur-lex.europa.eu/eli/reg/2017/1485/oj

55 Including for safety reasons, which may lead to multiple shutdowns of similarly designed power plants.

56 The adequacy problem refers to electricity generation unable to match demand.

57 Load-disconnection from the synchronous electric system to control the system frequency in emergencies (ENTSO-E, 2004). To reduce impacts, disconnections may roll from one customer to another.

58 For example, voltage fluctuations.

59 Blackouts (i.e., total loss of electric power) and brownouts (i.e., an intentional or unintentional reduction in voltage in the electrical power grid).

60 Sheperd, D. (2022). Climate disasters threaten U.S. grids, risking billions in losses. Bloomberg. https://www.bloomberg.com/news/articles/2022-01-05/climate-disasters-threaten-u-s-grids-risking-billions-in-losses#xj4y7vzkg

61 The N-1 formula states that the gas system is able to satisfy demand even if the single largest gas infrastructure is disrupted. Regulation (EU) No 994/2010 of the European Parliament and of the Council of 20 October 2010 concerning measures to safeguard security of gas supply and repealing Council Directive 2004/67/EC. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32010R0994

62 Shutdown or loss of throughput in oil and gas pipelines.

63 Extended period with high amount of clouds, and thus low insolation, and low wind speeds.

64 In other words, considering that plants grow better under higher CO_2 concentrations in the atmosphere (e.g., Zhu et al., 2016).

65 Power outages can be either planned (e.g., maintenance) or unplanned (e.g., failure of network element). The latter may occur as a result of a failure in production, conversion or transmission and distribution due to natural hazard impacts, external interference, equipment failures, operational failures, malicious attacks (e.g., terrorist, cyber, vandalism), but also a result of demand exceeding generation capacity (i.e., supply shortage).

66 For more information on reliability, indices and their formula see CEER (2016).

67 The concept of exceptional event accounts for the characteristics of each EU Member State electricity sector and the impact of severe weather in each EU Member State. For more information, see CEER (2008).

68 The 27 EU Member States and the United Kingdom.

69 Caution must be exercised when interpreting incident statistics in the electricity sector due to several factors: 1) inadequate categorisation of indirect impacts and aggregation rules (CEER, 2016, 2018). For example, natural hazards can be the root cause of several effects such as fire/explosion, corrosion, erosion, but are considered in a separate category (e.g., technical equipment; ENTSO-E, 2021b). This is particularly important for cascading effects (e.g., heatwaves and the sudden increase in electricity demand for air conditioning leading to adequacy problems); 2) important methodological and conceptual differences in reporting among EU Member States exist (e.g., definition of "exceptional event", distinction between short and long interruptions, formulas used for calculating reliability); 3) specific reporting criteria and rules have been updated over the years, making trend analysis challenging (ENTSO-E, 2019a). Furthermore, the impacts of climate change should not be limited to power outages, they may also result in efficiency loss and increasing costs for example; 4) coverage (e.g., ENTSO-E only collects data on disruption at the transmission level and for facilities with net generation capacity larger than 100 MW).

70 Defined in the study as long disruptions during which consumers are out of power.

71 For more information on reliability, indices and their formulae see CEER (2016).

72 Crude oil, non-HLV (highly volatile liquid), refined and/or petroleum products which are liquid at ambient conditions, HLV or other flammable and toxic liquids which are gas in ambient conditions, or carbon dioxide.

73 Lindsey, R. (2021). Climate variability: Arctic oscillation. https://www.climate.gov/news-features/understanding-climate/climate-variability-arctic-oscillation

74 National Oceanic and Atmospheric Administration. February 2021 synoptic discussion. https://www.ncei.noaa.gov/access/monitoring/monthly-report/synoptic/202102

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77 Defense Visual Information Distribution Service. Army hospital powers through record-breaking winter storms. https://www.dvidshub.net/news/389379/army-hospital-powers-through-record-breaking-winter-storms

78 National Oceanic and Atmospheric Administration. February 2021: Historic winter storm and Arctic outbreak. https://www.weather.gov/fwd/Feb-2021-WinterEvent

79 National Oceanic and Atmospheric Administration. National Climate Report – February 2021. https://www.ncdc.noaa.gov/sotc/national/202102

80 Everhart, K. and Molnar, G. (2021). Severe power cuts in Texas highlight energy security risks related to extreme weather events. https://www.iea.org/commentaries/severe-power-cuts-in-texas-highlight-energy-security-risks-related-to-extreme-weather-events

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83 Electric Reliability Council of Texas. Review of February 2021 extreme cold weather event. http://www.ercot.com/content/wcm/key_documents_lists/225373/2.2_REVISED_ERCOT_Presentation.pdf
84 Entergy Corporation. Entergy Texas winter storm update – 2/15/21 @ 5 p.m. https://www.entergynewsroom.com/storm-center/article/entergy-texas-storm-update-2-15-21-5-p-m/?utm_source=twitter&utm_medium=social&utm_term=entergytx-&utm_content=4494908302&utm_campaign=power_outages%2Frestoration
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104 Ministère des Armées. Stratégie Défense Durable. https://www.defense.gouv.fr/sga/au-service-nation-du-public/developpement-durable/strategie-defense-durable
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110 European Defence Agency. New Energy Consultation Forum project to promote low carbon military camps. https://eda.europa.eu/news-and-events/news/2022/02/17/new-energy-consultation-forum-project-to-promote-low-carbon-military-camps
111 Ability to continue operation in a degraded state (e.g., network topology optimisation, redundancy of components, functions or mission capabilities, backup power, fuel reserves and energy storage, fault detection, isolation and restoration, safeguard devices, ancillary services).
112 Ability to resist disruption (e.g., transmission towers and electricity poles reinforcement, targeted undergrounding of pipelines and electric power cables, enhanced insulation, asset monitoring and inspection, digital twins and predictive MRO, improved design and building standards, construction or reinforcement of flood defences, asset relocation).
113 Ability to manage disturbances (e.g., forecast, early-warning, expert staff, spare parts and equipment availability).
114 Ability to restore functions, missions and operations swiftly and transition to a normal state (e.g., emergency plans and procedures, emergency communications, agreements and contracts, readiness).
115 For example, natural hazards can trigger technological accidents in petroleum, oil and lubricants (POL) storage tanks and pipelines used to supply the fuel needed for operations, heating and emergency power.
116 A policy conceived to simplify military logistics by focusing on the supply and use of a single type of fuel (F-34), even if a system was not designed for its use.
117 A common response to a disruption is the dispatch of expensive and high-intensity GHG emission generation or backup power systems.
118 Backup power generators are often oversized and serve individual facilities. This characteristic makes emergency power systems difficult to refuel, operate and systematically maintain, may entail higher failure rates, and lead to a rapid depletion of fuel reserves (also needed for other purposes). An example of a possible optimisation is to place emergency generators at the substation.
119 Data is often considered sensitive and its exchange problematic, including during a disaster or a crisis.
120 For example, the purchase of renewable energy, alternative fuels, but also of equipment with characteristics that confer greater reliability under adverse operating conditions, or that meet certain energy efficiency, environmental, or resource security requirements (e.g., supply diversification). Procurement criteria may also apply to bidders (e.g., compliance with EU standards, technical and financial soundness). If the lowest bid is the only criterion, there may be no incentive to deliver on resilience or sustainability.
121 For example, the dependency on foreign entities for the supply of fossil fuels is a liability, as it may be used as a means for economic pressure, political leverage or to gain strategic advantage.
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128 Council of the European Union, Council Conclusions on Security and Defence, 10 May 2021, 8396/21. https://data.consilium.europa.eu/doc/document/ST-8396-2021-INIT/en/pdf
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132 United Nations Framework Convention on Climate Change. Long-term low greenhouse gas emission development strategy of the European Union and its Member States. https://unfccc.int/documents/210328
133 Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0075.01.ENG
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136 European Council. 'Fit for 55': Council agrees on stricter rules for energy performance of buildings. https://www.consilium.europa.eu/en/press/press-releases/2022/10/25/fit-for-55-council-agrees-on-stricter-rules-for-energy-performance-of-buildings/
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150 Commission Regulation (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R2196
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156 As an example of a military testbed available to accelerate R&D, the Portuguese Navy Operational Experimentation Center was recognized as a Technological Free Zone (regulatory sandbox), with the mission to facilitate and accelerate innovation focused on the development of dual-use application solutions for the ocean. Portaria n.o 189/2022, de 25 de julho. Diário da República n.o 142/2022, Série I de 2022-07-25, páginas 6 – 32. https://dre.pt/dre/detalhe/portaria/189-2022-186577200
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158 ENTSO-E. ENTSO-E Technopedia, Microgrid for Reliability of Supply. https://www.entsoe.eu/Technopedia/techsheets/microgrid-for-reliability-of-supply
159 United Nations Climate Technology Centre & Network. Building Energy Management Systems (BEMS). United Nations Framework Convention on Climate Change Technology Mechanism. https://www.ctc-n.org/technologies/building-energy-management-systems-bems
160 Strategic foresight explores descriptions of the future to guide decisions. It is often based on scenario development (scenario discovery, past and present trends, drivers of change, emerging issues and visions of the future), analysis (crisis gaming) and the identification of challenges and opportunities.
161 European Commission. Horizon Europe. https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en
162 European Commission. EU mission: Adaptation to climate change. https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/

horizon-europe/eu-missions-horizon-europe/adaptation-climate-change-including-societal-transformation_en

163 Communication from the Commission to the European Parliament and the Council 2021, Strategic Foresight Report on the EU's capacity and freedom to act, COM/2021/750 final. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM%3A2021%3A750%3AFIN

164 For example, energy and environmental performance, low-carbon and resilient technologies, best practices, lessons learned.

165 To be integrated in the technical specifications set out in the contract documentation.

166 Determined by a chosen energy transition pathway.

167 Directive 2009/81/EC of the European Parliament and of the Council of 13 July 2009 on the coordination of procedures for the award of certain works contracts, supply contracts and service contracts by contracting authorities or entities in the fields of defence and security, and amending Directives 2004/17/EC and 2004/18/EC. https://eur-lex.europa.eu/eli/dir/2009/81/oj/eng?cookies=disabled

168 With the potential to drive market changes and help EU Member States in achieving their climate and environmental goals.

169 For example, using Technology Readiness Levels (TRLs).

170 Study conducted by Greenville Procurement Partners in the context of the third phase of the CF SEDSS and is expected to be published in 2023 on the CF SEDSS webpage.

171 European Defence Agency. 1st High-level Joint Defence and Energy Meeting in the context of the CF SEDSS. https://eda.europa.eu/docs/default-source/events/eda-chief-executive-speech.pdf

172 European Defence Agency. EDA Factsheet: Defence Energy Data 2016 & 2017. https://eda.europa.eu/publications-and-data/latest-publications/factsheet-defence-energy-data-2016-2017

173 CO_2eq is a metric for total GHG emissions, providing the same reference for various GHG to be summed up based on their comparable global-warming potentials.

174 Unclear if it includes non-tactical vehicles.

175 European Environmental Agency. Greenhouse gas emission intensity of electricity generation in Europe. https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1

176 Entity that generates electricity and/or heat for its own use in support of their primary activity. For example, on-site generation by conventional power plants.

177 United Nations Economic Commission for Europe. Convention on Long-range Transboundary Air Pollution. https://unece.org/environment-policy/air

178 For example, towards zero emissions facilities that have optimised design, energy efficient building envelopes that retain heating and cooling for longer periods, including the use of high albedo building materials, HVAC and lighting systems, appliances, reducing energy consumption and increasing the share of renewable energy (self-produced or procured renewable energy from civilian entities).

179 For example, biodiesel from used oils, biogas from anaerobic digestion of organic matter, pellets from forest management biomass, heat recovered from power generation, components salvaged and materials recovered from equipment at the end of its lifecycle.

180 Any benefit that an ecosystem provides (e.g., clean air and water).

181 Report from the Commission assessing the availability of alternatives to fluorinated greenhouse gases in switchgear and related equipment, including medium-voltage secondary switchgear, C(2020) 6635 final. https://ec.europa.eu/clima/system/files/2020-09/c_2020_6635_en.pdf; and the F-Gas Regulation.

182 For example, blended diesel, containing up to 50% HRF-76 (Hydrogenated Renewable Fuel) was successfully tested by the Italian Navy in ships and submarines. https://www.marina.difesa.it/EN/Conosciamoci/notizie/Pagine/20160608_green_fleet.aspx; also see Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32014L0094

183 European Commission. Green and Sustainable Public Procurement. https://ec.europa.eu/environment/gpp/versus_en.htm

184 Any additional gain from a policy or measure that was not the main objective. For example, energy efficiency that often aims at reducing use, bills and GHG emissions, may also improve comfort, air quality, productivity and property value, decrease the dependency on external suppliers, the exposure to supply chain risks and price volatility, and the risk of technological accidents due to less fuel stored onsite.

185 Kitepower. Kitepower in Aruba. https://thekitepower.com/kitepower-in-aruba/

186 A high-performance (high-strength, low-weight) synthetic non-woven composite fibre particularly adapted for use in traction ropes.

187 The whole system fits in a standard 20 ft. container and does not require a tower, nor a foundation.

188 Estimation based on a 100 kW diesel generator.

189 European Commission. High-altitude wind power reaches new milestone. https://cordis.europa.eu/article/id/435387-high-altitude-wind-power-reaches-new-milestone; European Commission. Resource Efficient Automatic Conversion of High-Altitude Wind. https://cordis.europa.eu/project/id/691173; and European Commission. Story: EIC-funded Kitepower is taking its clean wind energy to the Caribbean Island. https://eic.ec.europa.eu/projects/kitepower-taking-its-clean-wind-energy-caribbean-island_en

190 European Commission. Energy efficiency first principle. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-first-principle_en

191 ISO 50002:2014. Energy audits – Requirements with guidance for use. https://www.iso.org/standard/60088.html

192 Often, generators are single fuel (which is frequently not considered in strategic fuel stocks), inadequately sized, in large numbers, operated at low efficiency (low load), or used for non-critical loads, leading to inefficient energy use, quick depletion of fuel reserves, increases in operation and MRO costs and in GHG emissions.

193 Germany, for example, has recently conducted stress tests to its power system.

194 Performed with electronic equipment switched off to avoid problems associated with inrush currents.

195 Using cross-sector table-top exercises (TTX), or in other words scenario-based games where stakeholders share unique expert knowledge and interact to identify challenges, threats and opportunities at each stage of response and recovery.

196 Such as large-scale disasters, or catastrophic power outages.

197 ISO 31000:2018. Risk management – Guidelines. International Organization for Standardization, Geneva, Switzerland. https://www.iso.org/standard/65694.html; Commission Notice Reporting Guidelines on Disaster Risk Management, Art. 6(1)d of Decision No 1313/2013/EU 2019/C 428/07. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019XC1220(01)

198 IEC 31010:2019. Risk management – Risk assessment techniques. https://www.iso.org/standard/72140.html

199 Risk criteria define acceptable risk threshold and risk profiles.

200 Energy demand subtracted from available energy supply. Unserved critical loads can also serve as a resilience measure.

201 Taking into account the core principles and targets outlined in: Forging a Climate-Resilient Europe – the new EU Strategy on Adaptation to Climate Change, COM/2021/82 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN

202 Article 222 of the Treaty on the Functioning of the European Union (TFEU). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A12012E%2FTXT

203 Traditional backup power generators depend on fuel reserves, which limits their use in time, subjects them to fuel price fluctuations and supply disruptions, and increases the potential for technological accidents and targeted attacks. Backup power generators may also fail and present quality and efficiency issues (e.g., higher operating costs and higher GHG emissions).

204 For example, mobile transformers, substations and power generators may operate under severe weather and are ready for deployment in a short time frame. They allow service to continue by temporarily replacing assets, helping power restoration efforts, upgrades, MRO, or serve remote locations.

205 For example, defining the rules for load shedding of non-critical loads as an ancillary service. It requires prior identification of critical locations, assets, functions and processes, and the estimation of maximum load required for mission assurance.

206 Clause that may void contracts of guaranteed delivery in the event of a disaster or a crisis.

207 European Commission. Innovation Fund. https://climate.ec.europa.eu/eu-action/funding-climate-action/innovation-fund_en

208 Factsheet on EDF calls 2022. https://defence-industry-space.ec.europa.eu/factsheet-edf-calls-2022_en

209 European Defence Agency. CapTech Energy and Environment. https://defence-industry-space.ec.europa.eu/factsheet-edf-calls-2022_en

210 Permanent Structured Cooperation (PESCO). Energy Operational Function (EOF). https://www.pesco.

europa.eu/project/energy-operational-function/

211 European Defence Agency. European Defence Standards Reference System (EDSTAR). https://edstar.eda.europa.eu

212 For example, through TRLs.

213 Also known as digital twins.

214 European Defence Agency. Consultation Forum concludes first round of defence energy deliverables. https://eda.europa.eu/news-and-events/news/2022/06/29/consultation-forum-concludes-first-round-of-defence-energy-deliverables

Impacts of **climate change** on defence-related critical energy infrastructure

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