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European Defence Energy Network

CF SEDSS III
Consultation Forum for Sustainable Energy in the Defence and Security Sector

SHAPING THE FUTURE

Energy Transition in the Defence Sector

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This publication is the result of collective effort and shared commitment to advancing the energy transition within the defence sector. We acknowledge the hard work of all authors, researchers, and industry experts who have contributed to this important endeavour.

Preface

In an era marked by profound environmental challenges and geopolitical complexities, the intersection of climate change, energy, and defence has emerged as a critical area of inquiry. As the European Union advances towards its ambitious goal of carbon neutrality by 2050, the defence sector must navigate this transformative landscape, balancing operational effectiveness with energy transition and climate change adaptation. This book is essential, presenting the future of the defence sector in the energy transition through comprehensive and forward-thinking research.

Developed within the framework of the third phase of the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS), this book is based on extensive research conducted by the Consultation Forum's members with substantial support from external contractors. It thoroughly considers the defence sector's priorities and requirements. It is a testament to our collective efforts to align the Forum's work on improving defence energy efficiency and enhancing building performance by integrating renewable energy sources and cutting-edge clean technologies.

The ministries of defence will find this book invaluable. It provides a comprehensive and actionable guide for the defence sector to enhance its sustainability and energy transition efforts. The content begins with an overview of current and future trends in energy efficiency and building performance within the EU framework, emphasising the defence sector's role and perspectives. It then explores green public procurement options specific to the EU defence sector, examining obstacles and proposing solutions for implementing energy efficiency measures in defence buildings and sites. Additionally, the book defines the key requirements for an energy storage selection decision support tool tailored for homeland defence installations.

The defence sector can also benefit from analysing the impact of defence activities on offshore renewable energy developments, assessing the constraints, and considering the recommendations for improving coexistence. Another area of defence interest is innovative disciplines that increase defence energy efficiency and output through life cycle assessment and material flow analysis.

Ministries of defence are encouraged to leverage the tools and insights provided in this research to address their military energy needs effectively. The strategies and insights detailed in this book are designed to help the defence sector achieve a sustainable and resilient future aligned with the European Green Deal.

In conclusion, I extend our heartfelt gratitude to all the members of the Consultation Forum, defence experts, and representatives from industry, research and technology organisations and academia for their valuable insights and support. I also want to thank the European Commission for its unwavering support in facilitating this research. Additionally, I acknowledge the dedicated efforts of the authors, whose hard work and commitment have culminated in this pivotal report, and especially the CF SEDSS management team for their overall direction and coordination.

Together, we stand at the threshold of a sustainable future for the defence sector and invite all stakeholders to join us in this transformative effort.

Nathalie Guichard
EDA Research Technology and Innovation Director

Content

Executive summary

This publication investigates the intersection of the European Union's (EU) sustainability imperatives, particularly embodied in the "European Green Deal" and the strategic considerations of the defence sector, focusing on energy efficiency, building performance, and the defence role within this framework.

It scrutinises current and future trends in the EU and endeavours to establish a comprehensive understanding of the potential ramifications of energy-related policies emanating from the broader "European Green Deal" initiative, aspiring to render Europe climate-neutral by 2050. The analysis provides an intricate mapping of the extant conditions within EU ministries of defence, assessing the implementation status of action programmes derived from the overarching framework policy and legislative actions and directives. It identifies gaps, delineates causative factors for their existence, and draws upon data from the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS III) and bespoke inquiries to substantiate its findings.

Furthermore, this analysis examines the implementation landscape of green public procurement (GPP) within European defence sector organisations. Grounded in research conducted under the auspices of the CF SEDSS, it identifies challenges and opportunities and underscores the risks associated with non-action. Strategic, operational, and tactical recommendations align with both EU and national emission reduction targets.

A distinct facet of the study addresses barriers impeding the successful implementation of energy efficiency measures within the defence sector. Utilising insights from member states and contractors involved in supporting energy management systems, the report proposes nuanced solutions to surmount these impediments, emphasising the urgency of achieving emission reduction targets.

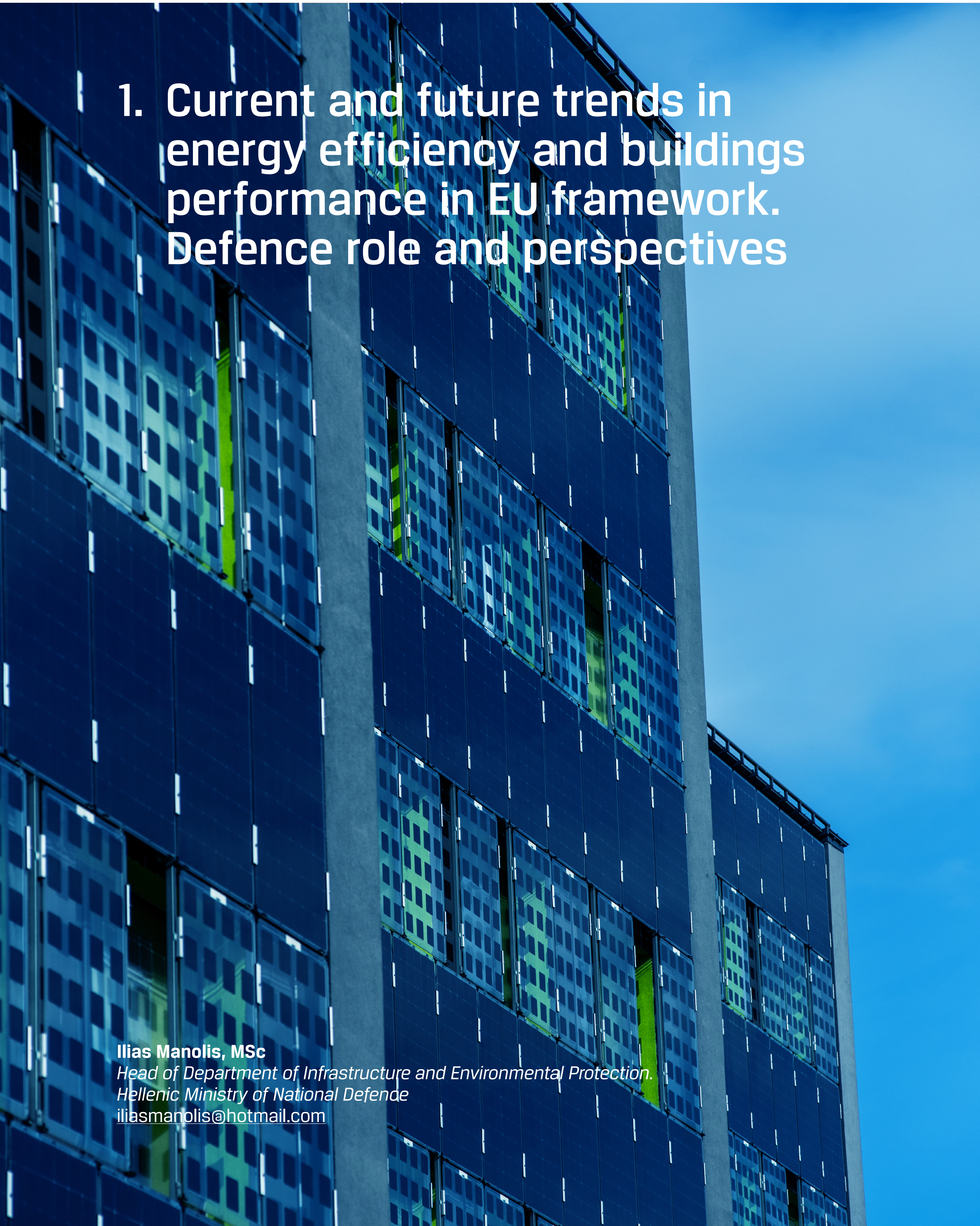
Shifting its focus to the global commitment to achieve zero greenhouse gas emissions by 2050 and beyond, this publication delves into the challenges confronting the renewable energy generation market. Specifically, it scrutinises the variable nature of renewable sources and underscores the critical need for effective energy storage systems. It delineates key requirements for an energy storage selection decision support tool, proposing future developments and initiatives tailored to ministry of defence (MoD) environments.

The strategic deployment of offshore wind, as outlined in the EU's offshore renewables sector strategy, is examined with a keen eye on its implications for the defence sector. As offshore wind farms evolve into critical infrastructure, the study elucidates concerns related to defence activities and recommends regulatory reviews, stakeholder engagement, and actions for ensuring the harmonious coexistence of offshore renewables and military operations.

The report also addresses the substantial environmental impact of the defence sector, encompassing areas such as greenhouse gas emissions, waste management, hazardous waste, noise pollution, and habitat destruction. Advocating for a proactive stance in minimising these impacts underscores the importance of life cycle assessment and material flow analysis to monitor and mitigate the sector's contribution to environmental degradation. This exhaustive compendium navigates the intricate terrain of sustainability imperatives, defence operations, and environmental considerations, offering not only a panoramic view of the current landscape but also strategic insights and tangible recommendations for a more sustainable and environmentally conscious future in the defence sector.

The publication concludes by highlighting the significant strides made during Phase III of the CF SEDSS. It underscores the crucial role of the defence sector in advancing the EU's climate neutrality goals by 2050. In this context, it introduces key initiatives such as the establishment of an EU-led Competence Centre on Climate Change, Security, and Defence, and the development of the European Defence Sustainable Energy Profiles (EDESEP) platform, both aimed at driving the defence energy transition in a structured and long-term manner. These initiatives are expected to enhance energy efficiency, resilience, and collaboration between the defence sector and civilian communities.

The publication also calls for continued support and cooperation among the European Defence Agency, the European Commission, Member States, and relevant stakeholders to ensure that the defence sector leads in the transition to sustainable energy, fully aligning with the objectives of the European Green Deal.



1. Current and future trends in energy efficiency and buildings performance in EU framework. Defence role and perspectives

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Abstract

The study aims at identifying the current and future trends in energy efficiency and buildings performance in EU Framework, whilst it also aims at defining the defence role and perspectives. More specifically, it focuses on analysing the potential impact of a series of energy related policies has on the defence domain. These policies are stemming from a number of legislative, technological and human factor framework plans, which are imposed by the wider "umbrella" initiative called "European Green Deal", aiming to render Europe the first carbon-neutral continent by 2050.

It also provides a complete mapping of the existing conditions in the EU ministries of defence (MoDs), concerning the already implemented (or not) action programmes which are deriving from the aforementioned framework plans. The next issue addressed is the consequent identification of the current gaps and shortfalls as well as the main reasons of their creation. This process is supported by a series of data and information gathered by either the previous phases of the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS III) or specific inquiries posed for the purpose of this study.

Finally, the study is proposing a list of concrete steps (in terms of specific milestones of an Energy Efficiency and Buildings Performance Roadmap), to enhance the practical and effective involvement of the defence sector in the wider (EU or nationally) endeavours which are relevant to the necessity of decarbonising the EU building stock.

Executive summary

Reducing energy consumption and increasing energy efficiency is essential for the armed forces, first to ensure a high level of readiness and sustainability and second to contribute to each EU Member State (MS) specific energy and climate goals, as these are defined within the National Energy and Climate Plans (NECPs). Furthermore, improving energy efficiency of the defence building stock could save human and finance resources, which defence can respectively allocate or invest in other essential needs.

While there are several actions and ongoing initiatives at national and EU level to achieve the aforementioned goals, efforts are scattered and occasionally duplicated or overlapped. It is also evident that a Member State itself cannot always ensure the effective implementation of the Energy Efficiency and Buildings Performance legislative provisions, due to a number of potential obstacles (organisational lack of awareness and commitment; lack of knowledge and expertise; budget and constraints to access funding; lack of building stock and energy consumption data; etc.).

Based on the main aspects of the problem, as they have been described above, some specific challenges and necessities emerge which assist in defining the major aim of the study. These challenges and necessities are related to the following elements:

- The need to define and establish the role of the defence sector in the EU energy efficiency framework, with specific focus on the energy performance of the defence building stock.
- The need to foster collaboration among EU MoDs, to share best practices and knowledge, to coordinate activities and join forces. To this end, there is the need to lay the foundations to formulate an effective energy efficiency policy and strategy and explore current and future trends in this area.
- To further analyse this shortcoming, there is a need to identify and map existing conditions **in terms of (1) policies and legislation, (2) technological solutions, and (3) the importance of having the human factor (MoD's personnel) actively involved in this endeavour.** Exploring adequately these 3 pillars will be an essential and required leap to underpin policy and decision-making processes of the MoDs to increase energy efficiency and ensure the coherence of activities in the implementation of the EU's energy and climate targets.

In this perspective, the findings and the outcome of the study should help the EU (EDA, DG ENER[1], and CINEA[2]) energy constitutional cells and the MoDs to:

a. Evaluate the current and future trends of the EU energy efficiency and building performance policies and legislation framework, assess their impact on the defence sector and define potential role in this framework.
b. Investigate and analyse current and future technological trends in the aforementioned domains, in order to facilitate the definition of the defence role in contributing to achieving energy efficiency and building energy consumption reduction goals. This would be processed both through their EU MS NECPs, as well as through collaborative efforts to reduce energy consumption while contributing to the implementation of the EU's climate and energy targets.
c. Propose effective ways to foster and to enhance the participation of the human factor to this endeavour, in terms of active involvement of the EU MoD's personnel in all levels of hierarchy, with specific focus on the higher-level/ decision-making levels, where crucial resolutions are made (e.g., funding energy related projects, prioritisation of tasks, human resources allocation).

To achieve the aforementioned objectives, the study has followed the methodology analysed below:

- The creation of a complete mapping framework, assessment and definition of the current and future trends of the EU energy efficiency and buildings performance matrix, as well as the defence's role in the present and prospective dimensions**.**
- The conduct of a specific focus on the strategic context (the role that defence plays in the energy domain), the problem analysis (assumptions and arguments for the assessment of the trends in policy-legislation / technology / human factor aspects), the proposed solutions (steps, milestones and deliverables), in order to ensure the active and concrete contribution of the defence sector in achieving the Energy and Climate goals, both at national and EU level, etc.

Based on the findings of the study in overall terms, it is evident that the limited involvement of the defence sector in national legislative, managerial and technological energy efficiency and building performance tools, enhanced consequently by a limited access to national and EU funding opportunities, has led to the conclusion that such existing relative framework schemes (notably speaking about Energy Efficiency Directive -EED, Energy Performance Building Directive -EPBD, Green Public Procurement -GPP, NECPs, Long-Term Revision Strategies -LTRS and Energy Performance Contracting -EPCs) have low or average impact in defence. The ongoing adoption of revised energy efficiency targets stemming from the implementation of the Renovation Wave (with the strategic aim to double the rate of the annual renovation rate of public buildings) would inevitably affect vastly also the defence community, setting a more intense need to allocate increased budgeting resources to energy efficiency upgrade of existing military infrastructure.

Therefore, the adoption of a defence tailor-made Roadmap for addressing this challenge, should be a top national priority of the defence domain in every EU MS. Main milestones of this roadmap are referring to the active involvement of the MoDs in achieving NECP goals, the establishment of effective Long-Term Renovation Strategies, the promotion of existing and emerging technological solutions in these strategies and the assessment of related risks (cyber-attacks and data breach), etc, the adoption of GPP principles and guidelines to their acquisition procedures, the conduct of suitable supporting evidence for applying E-mobility programmes of the defence conventional (combustion) fleet, the establishment of permanent mechanisms which ensure effective access of the MoDs to national and EU funding schemes, the application of suitable energy efficiency policy instruments such as Energy Performance Contracting (EPC) and Energy Performance Certificates (EPCs), and the continuing application of adequate training and educative programmes of the Armed Forces' personnel.

1. Directorate General for Energy.
2. Climate, Infrastructure and Environment Executive Agency (CINEA).

1.1. Introduction

1.1.1. Background information and Introduction to the problem

On 1 October 2019, the third phase of the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS III) was launched. The project is funded by the EU's Horizon 2020 research and innovation programme. During phase III, the Forum will continue pursuing the implementation of the EU legal framework on energy and will facilitate sharing information and best practices on improving energy efficiency and buildings performance, utilising renewable energy sources in the defence sector and increasing the resilience of defence-related critical energy infrastructure. The project will also address crosscutting thematic areas on energy management and policy, energy innovative technologies and will identify the applicable funding or financing instruments for defence energy-related topics.

The thematic area of this study falls under the remit of **CF SEDSS III Energy Efficiency and Buildings Performance Working Group (WG1)**. The WG1 aims at helping the European Union ministries of defence (MoDs) and other defence-related stakeholders in establishing policies, strategies, roadmaps, methodologies and tools to improve the energy efficiency of the military building stock.

1.1.2. Aim of the study

Based on the main aspects of the problem, as they have been described above, some specific challenges and necessities emerge which assist in defining the major aim of the study. These challenges and necessities are related to the following elements:

- The need to define and establish the role of the defence sector in the EU energy efficiency framework, with specific focus on the energy performance of the defence building stock.
- The need to foster collaboration among EU MoDs, to share best practices and knowledge, to coordinate activities and join forces. To this end, there is the need to lay the foundations to formulate an effective energy efficiency policy and strategy and explore current and future trends in this area.
- To further analyse this shortcoming, there is a need to identify and map existing conditions **in terms of (1) policies and legislation, (2) technological solutions,** and **(3) the importance of having the human factor (MoD's personnel) actively involved in this endeavour**. Exploring adequately these 3 pillars, will be an essential and required leap to underpin policy and decision-making processes of the MoDs to increase energy efficiency and ensure the coherence of activities in the implementation of the EU's energy and climate targets.

By addressing the aforementioned needs, this study essentially aims at assisting MoDs to implement a consolidated roadmap of policies, measures and actions with regards to energy efficiency, with special focus on the energy efficiency of buildings.

1.1.3. Objectives of the study

To better define and analyse the objectives of this study, there is the compulsory need to follow the content of the Terms of Reference (ToRs), as they have been introduced in the WG1 of the Consultation Forum, accepted by the participants and later validated by the CF SEDSS Management Team. In this perspective, the findings and the outcome of the study should help the EU (EDA, DG ENER and CINEA) energy constitutional cells and the MoD's representatives/ delegates to:

a. Evaluate the current and future trends (in terms of assessment and orientation of the focus areas which pose the biggest challenges with regards to the EU energy efficiency and building performance policies and legislation framework), assess their impact on the defence sector and define potential role in this framework.

b. Investigate and analyse current and future technological trends and risks in the aforementioned domains, in order to facilitate the definition of the role of the defence sector in contributing to achieving energy efficiency and building energy consumption reduction goals. This would be processed both through their EU MS NECPs, as well as through collaborative efforts to reduce energy consumption while contributing to the implementation of the EU's climate and energy targets.

c. Propose effective ways to foster and to enhance the participation of the human factor to this endeavour, in terms of active involvement of the EU MoD's personnel in all levels of hierarchy, with specific focus on the higher-level/ decision making levels, where crucial resolutions are made (e.g. funding energy related projects).

1.1.4. Conceptual approach of the study to address the problem

In accordance with the aforementioned ToRs and given the fact that, due to the lack of identified nominated experts, the CF SEDSS Management Team identified WG-1 Team Leader, as the suitable contractor of this study, the following approach has been followed:

- The study provides a holistic presentation of the energy efficiency and buildings performance status quo, an assessment and definition of the current and future trends of the EU energy efficiency and buildings performance fundamental elements (policies, technology, human behaviour), as well as the defence role in the present and prospective dimensions.
- It is also offering particular focus on the strategic context (the role that defence plays in the energy domain), the problem analysis (assumptions and arguments for the assessment of the trends in policy-legislation / technology / human factor aspects), the proposed solutions (steps, milestones and deliverables), in order to ensure the active and concrete contribution of the defence sector in achieving the Energy and Climate goals, both at national and EU level, etc.

1.2. Methodology

1.2.1. Approaches to address the study's objectives and identified gaps

The study is trying to cover the necessary mapping and analysing activities to address the proposed sections, with particular focus on the strategic context (the role that defence plays in the energy domain), the problem analysis (assumptions and arguments for the assessment of the trends in policy-legislation / technology / human factor aspects), the proposed solutions (steps, milestones and deliverables, in order to ensure the active and concrete contribution of the defence sector in achieving the Energy and Climate goals, both at national and EU level).

It is also based on a series of inputs, which were provided by the EDA CF SEDSS III Management Team and EDA participating Member States (pMS), in order to be utilised in the assessment process. These sources of inputs[3] refer to the following elements:

- Energy related data provided by the EU MS, in the framework of the Energy Data Collection Analysis and Sharing Support Frame (EDCAS-SF) Project (ran by the EDA Energy and Environment Working Group- EnE WG).
- EU MS answers and statistical analysis stemming from questionnaires, distributed and analysed during the previous 2 Phases of the CF SEDSS.
- EU MS answers and statistical analysis stemming from questionnaires which are going to be distributed and analysed during the 3rd Phase of the CF SEDSS.
- EU MS answers and statistical analysis stemming from questionnaires which will be developed and further processed to the EU MS (through the NCPs and WG1 delegates), for the purpose of this study.
- Inquiries, which will be made to relevant/energy related academia and industry institutes.

1.2.2. Study's position and proposed solutions

From the mapping and analysing process, as it has been described above, the study aims at exploiting all available information and data (from the sources mentioned), so that a concrete and consolidated picture of the interface between the defence and the energy efficiency and energy performance of buildings sectors is produced and provided.

This mapping is being put into actions, focusing in the three main areas of consideration (policies, technology and human factor). The deliverables of the study are going a step further, to more concrete and practical paths, aiming to indicate and demonstrate tangible solutions, on how the aforementioned interface can become mutually productive, focusing, of course, on the defence side.

It is offering a series of proposed actions/measures, not only in terms of dedicated defence energy efficiency policies and in terms of strategies, but also in terms of a well-defined Roadmap for Energy Efficiency & Buildings (REEB), which essentially deals with all mandatory aspects: strategy, policy axes, measures and addressed socio-economic and environmental impact of such enrolments. Therefore, it is considered that the study is covering all the way from the conceptual to the practical implementation of the relevant spectrum.

3. The CF SEDSS III management team agreed on sharing these information and data to the contractor for the purposes of this study. The contractor cannot use them in other publications or fora.

1.3. Energy efficiency landscape and trends for EU defence sector

1.3.1. The energy union and the clean energy for all European package

The energy union strategy (COM/2015/080)[4] published on 25 February 2015, as a key priority of the Juncker Commission (2014-2019), aims at building an energy union that gives EU consumers – households and businesses – secure, sustainable, competitive and affordable energy. Since its launch in 2015, the European Commission has published several packages of measures and regular progress reports, which monitor the implementation of this key priority, to ensure that the energy union strategy is achieved. The energy union builds five closely related and mutually reinforcing dimensions:

- **Security, solidarity and trust** – diversifying Europe's sources of energy and ensuring energy security through solidarity and cooperation between EU countries.
- **A fully integrated** internal energy market – enabling the free flow of energy through the EU through adequate infrastructure and without technical or regulatory barriers.
- **Energy efficiency** – improved energy efficiency will reduce dependence on energy imports, lower emissions, and drive jobs and growth.
- **Climate action, decarbonising the economy** – the EU is committed to a quick ratification of the Paris Agreement and to retaining its leadership in the area of renewable energy.
- **Research, innovation and competitiveness** – supporting breakthroughs in low-carbon and clean energy technologies by prioritising research and innovation to drive the energy transition and improve competitiveness.

The EU has agreed a comprehensive update of its energy policy framework to facilitate the transition away from fossil fuels towards cleaner energy and to deliver on the EU's Paris Agreement commitments for reducing greenhouse gas emissions. The completion of this new energy rulebook – called the Fit for 55 package, which aims at reducing greenhouse gass (GHG) emissions of 55% by 2030 – marks a significant step towards the implementation of the energy union strategy. The changes will bring considerable benefits from a consumer perspective, from an environmental perspective, and from an economic perspective. It also underlines EU leadership in tackling global warming and provides an important contribution to the EU's long-term strategy of achieving carbon neutrality by 2050[5].

1.3.2. The regulation on the governance of the energy union and climate action

The new regulation on the governance of the energy union and climate action establishes a unique framework for cooperation between Member States and the EU to[6]:

- Ensure that national and EU trajectories are best aligned with a view to meeting the objectives and targets of the energy union, consistent with the Paris Agreement goal and in particular the EU's 2030 targets for energy and climate.
- Cover all dimensions of the energy union, including energy security, the internal market; inter connections and research, innovation and competitiveness.

4. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2015:80:FIN.
5. https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans.
6. Fact sheet on the EU Regulation on the governance of the energy union and climate action, available at: https://ec.europa.eu/energy/sites/ener/files/documents/governance_regulation_factsheet.pdf.

- Ensure a transparent and coordinated planning, reporting and monitoring process, and promote closer cooperation between EU countries in these areas.
- Offer more clarity and predictability to unlock clean energy investments, across the EU.
- Ensure consistent reporting to the EU and its member countries, under the United Nations (UN) Framework Convention on Climate Change and the Paris Agreement.

This governance regulation is part of the framework strategy for a 'Resilient energy union with a forward-looking climate change policy' and was finalised as part of the **Clean Energy for All Europeans package, which was completed in 2019.**

1.3.3. Energy efficiency directive

Putting energy efficiency first is a key objective in the Clean Energy for all Europeans package, as energy savings are the easiest way of saving money for consumers and for reducing greenhouse gas emissions. In 2012, under the Energy Efficiency Directive 2012/27/EU[7], the EU set a 20% energy savings target by 2020 (when compared to the projected use of energy in 2020) – this is roughly equivalent to turning off 400 power stations. In December 2018, the revised Energy Efficiency Directive entered into force (amending Directive EU (2018/2002) updating some specific provisions and introducing some new elements. Above all, it establishes a headline EU energy efficiency target for 2030 of at least 32.5% (compared to projections) with a clause for a possible upwards revision by 2023. Under the new Governance rules, Member States were required to draft by the end of 2018 their 10-year integrated National Energy & Climate Plans (NECPs) for 2021-2030, outlining how Member States will meet the 2030 targets for energy efficiency and for renewable energy.

Finally, the recast Energy Efficiency Directive EED (2023/1791/EU)[8] – replacing old EED 2012/27/EU and its amending Directive 2018/2002 – was published in on 20 September 2023, significantly raising the EU's ambition on energy efficiency and establishing 'energy efficiency first' as a fundamental principle of EU energy policy, giving it legal-standing for the first time. In practical terms, this means that energy efficiency must be considered by EU countries in all relevant policy and major investment decisions taken in the energy and non-energy sectors.

In addition to requirements already established by the old EED of[9]: (1) an annual reduction of 1.5% in national energy sales, (2) the 3% annual renovation rate for buildings owned and occupied by central governments per year, (3) the mandatory energy efficiency certificates accompanying the sale and rental of buildings, (4) the minimum energy efficiency standards and labelling (eco-design) for a variety of products (such as boilers, household appliances, lighting and televisions), (5) the preparation of National Energy Efficiency Action Plans every three years by EU countries or (6) the planned rollout of approximately 200 million smart meters for electricity and 45 million for gas by 2020, among others, the 2023 revised directive[10] raises the EU energy efficiency target, making it binding for EU countries to collectively ensure an additional 11.7% reduction in energy consumption by 2030, compared to the 2020 reference scenario projections. As a result, overall EU energy consumption by 2030 should not exceed 992.5 million tonnes of oil equivalent (Mtoe) for primary energy and 763 Mtoe for final energy.

Under the updated rules, EU countries have agreed to help achieve the EU target by setting indicative national contributions using a combination of objective criteria which reflect national circumstances (energy intensity, GDP per capita, energy savings potential and fixed energy consumption reduction). The directive also includes an enhanced "gap-filling mechanism" that will be triggered if countries fall behind in delivering their national contributions.

7. These Directives are available at: https://www.eda.europa.eu/european-defence-energy-network/policy-legislation.
8. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.
9. https://ec.europa.eu/energy/en/topics/energy-efficiency.
10. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.

A number of key articles of EED with special interest to the defence sector were reviewed, during the second and third phases of CF SEDSS. In particular, discussion among MoDs was on:

- **Article 4 (from old EED) – Building Renovation** (this Article has, actually, been eliminated from the recast EED and moved to the forthcoming recast EPBD): requiring MS to define long-term strategies for stimulating renovations (in particular, cost-effective deep renovations) in their building sector, in order to increase with immediate effect the historically low renovation rates, and ultimately reduce significantly the energy consumption of the building stock by 2050.
- **Article 5 – Public sector leading on energy efficiency:** requiring that total final energy consumption of all public bodies combined, which together accounts for about 30% of energy consumption of all services across the EU, or 5% of EU final energy consumption, be reduced by at least 1,9 % each year, when compared to 2021 (with option for MS to exclude the armed forces).
- **Article 6 – Exemplary role of public bodies' buildings:** requiring that at least 3 % of the total floor area of heated and/or cooled buildings with a total useful floor area over 250 m2 that are owned by public bodies (at all levels of the public administration) and that, on 1 January 2024, are not nearly zero-energy buildings, be renovated each year to be transformed into at least nearly zero-energy buildings or zero-emission buildings in accordance with Article 9 of the EPBD (with option for MS to apply requirements that are less stringent for buildings owned by the armed forces and serving national defence purposes and historical buildings, among others).
- **Article 7 – Public procurement:** requiring contracting authorities and contracting entities to purchase only products, services buildings and works with high energy-efficiency performance in accordance with the requirements of the Directive when exceeding a value equal to or greater than established thresholds, and apply the energy efficiency first principle, unless it is not technically feasible (applicable to the contracts of the armed forces only to the extent that their application does not cause any conflict with the nature and primary aim of the activities of the armed forces, and not applicable to contracts for the supply of military equipment).
- **Article 12 – Data centres:** introducing an obligation for the monitoring of the energy performance of data centres, and the creation of an EU-level database to collect and publish data relevant for the energy performance and water footprint of data centres with power capacity over 500kW (not applicable to data centres used for defence).
- **Article 29 – Energy services:** promoting the Energy Performance Contracting for renovations of large buildings that are owned by public bodies, with the aim to mobilise the private sector to provide finance, performance guarantees and share risks.

1.3.4. Energy performance of buildings directive

The EPBD is, together with the EED, the main legislative instrument to promote the energy performance of buildings and to boost renovation within the EU. Buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU, making them the single largest energy consumer in Europe. By improving energy performance in buildings, the EU can more readily achieve its energy and climate goals. The EPBD outlines specific measures for the building sector to tackle challenges; the **main EPBD (2010/31/EU)** has been in force since 2010 and helps consumers to make informed choices allowing them to save both energy and money.

The revised EPBD (2018/844/EU)[11], which amends small parts of the 2010 EPBD and introduces new elements, is an important part of the implementation of the EU priorities to build a resilient Energy Union and a forward-looking climate change policy. EU countries had a deadline until 10 March 2020 to write the new and revised provisions into national law. The main articles (of the main and revised Directives) which have been examined in the framework of the CF SEDSS II, and expected to have an impact for the defence sector are explained below. It should be also stated (as in the case of EED), that EPBD is under review/ revision process, in the framework of the "Fit for 55" Package. The Commission's proposal was published on December 15th, 2021:

11. https://www.eda.europa.eu/european-defence-energy-network/policy-legislation.

- Establishment of stronger **long-term renovation strategies** (Article 2a of the revised EPBD), aiming at decarbonising the national building stocks by 2050, with indicative milestones for 2030, 2040 and 2050, measurable progress indicators and with a solid financial component. The strategy should clearly contribute to achieving the energy efficiency targets, as outlined in the National Energy & Climate Plan. As mentioned, the EU public domain (MoDS having the lion's share of the building stocks, in the majority of the MS) has to play an exemplary role in this renovation campaign.
- Introduction of a common European scheme **for rating the smart readiness of buildings,** optional for EU countries (Article 8 of the revised EPBD). In the revised Draft of the EPBD, the establishment of the SRI is expected to be mandatory.
- Further promotion of smart technologies, for instance through requirements on the installation of **building automation and control systems** and on devices that regulate temperature at room level (Article 8 of the revised EPBD). In case of defence infrastructure, it should be cited that while promoting these smart technologies, there is a potential risk associated with cyber attacks, data breach/capture, etc.
- Support of the **e-mobility,** by introducing minimum requirements for car parks over a certain size and other minimum infrastructure for smaller buildings (Article 8 of the revised EPBD).
- Promotion of a **homogenised processes of setting emerge performance requirements,** so that cross-national comparisons could be allowed. These processes must be reviewed every five years and, if necessary, updated (Article 10 of the revised EPBD).
- Promotion of **health and well-being of building users,** for instance through an increased consideration of air quality and ventilation. This specific provision is expected to be additionally promoted over the next year, in the light of the Covid-19 crisis (Article 7 of the revised EPBD).
- All new or deeply renovated buildings must be **nearly zero-energy buildings** (NZEB) from 31 December 2020. Since 31 December 2018, all new public buildings already need to be NZEB (Article 9 of the main EPBD).
- Establishment of **cost-optimal minimum energy performance requirements** for new buildings, for the major renovation of existing buildings, and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls and so on Article 5 of the main EPBD).

Although the EPBD does not provide any general exemption/derogation for buildings owned by the armed forces, it should be cited that there is an increased concern with regards to Article 4/sub paragraph 2c, which grants a potential exemption for temporary non-operational buildings (office or similar non-operational facilities) that can be normally used in military installations for "temporary" (re)locations of military personnel while building a new, or deep renovating an existing non-operational building (office or similar non-operational facilities), and the fact that these "temporary" (re)locations tend to extend in time and go beyond the 2 years' time expressed in the said article of the EPBD. The proposal for the recast of the EPBD is still analysis at the time of this study, and expected to be approved and adopted by February or March 2024.

1.3.5. Existing policies overall impact assessment for defence

Through the first two Phases of the Consultation Forum, a number of Questionnaires have been sent to the WG1 experts and relevant data were gathered to assess the overall and dedicated (on specific Articles) impact which the two Directives have on the defence sector. The basic conclusions are visible in **Figures 1.1-1.3**[12]:

12. GUIDANCE DOCUMENT. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019, available at: https://eda.europa.eu/docs/default-source/events/eden/phase-ii/guidance-document/cfsedssii-guidance-document.pdf.

Figure 1.1. Overall impact assessment of EPBD on defence

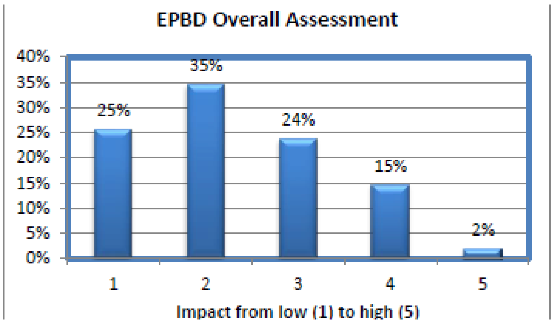


Figure 1.2. Detailed (by article) assessment of EPC on defence

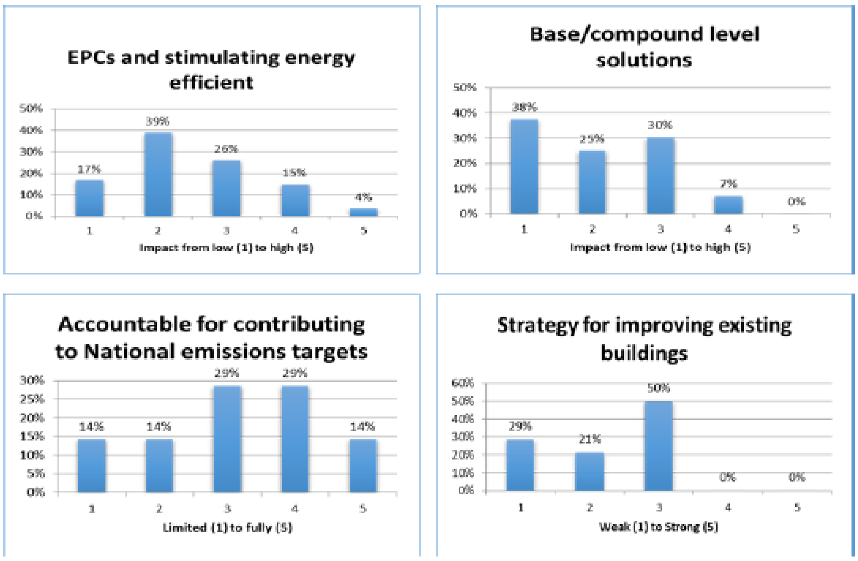
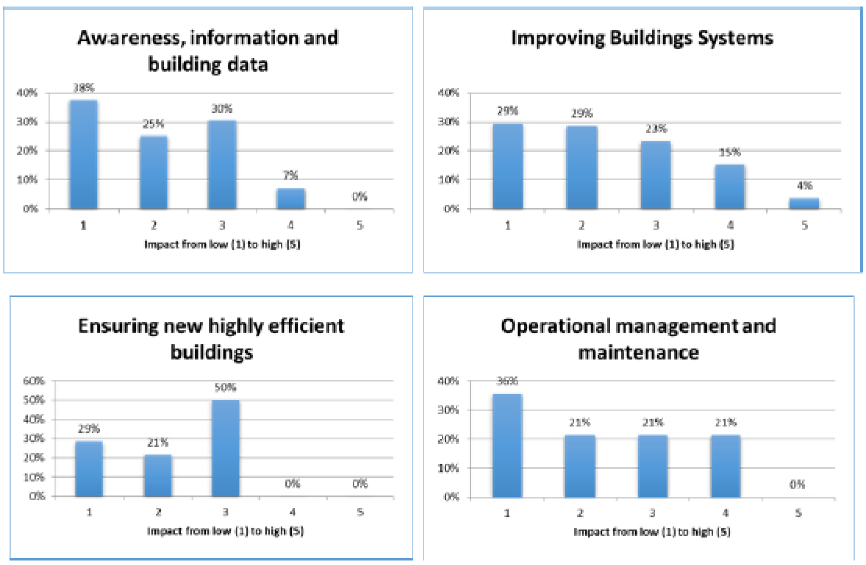


Figure 1.3. Detailed (by article) assessment of EPBD on defence



Apart from the mathematical/ statistical approach of the issue, the general conclusion from the discussions taking place during the CF SEDSS Phase I and II showed that the impact of this Directive has not been uniform across the EU defence sector. Moreover, a majority of EU MoD delegates (60%) observed that the overall impact of the EPBD was small. The reasons attributed to it were common across the EU defence sector, the main reasons among others being:

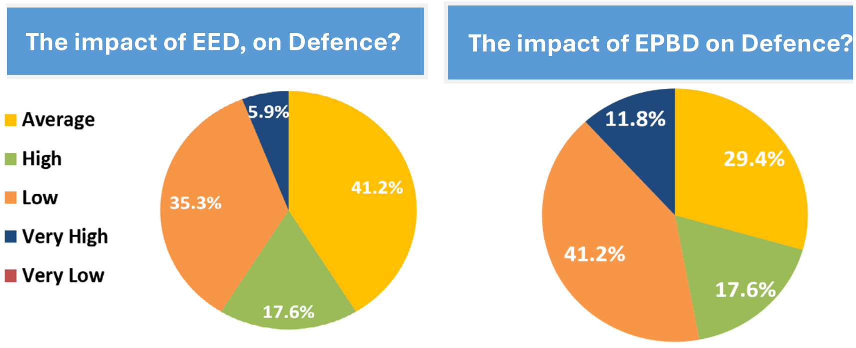
- Energy efficiency interventions and infrastructure maintenance are of lower priority to defence, with the bulk of the budgets being dedicated to armament and other operational purposes.
- Lack of commitment, sensitivity and adequate mentality towards energy sustainability (especially at senior levels).

The new provisions of the revised EPBD are deemed to have, in general terms, a limited impact on the defence sector. In general, the views from the MoDs can be summarised in the following conclusions:

- The expanded definition of "technical building system" in Article 2 of revised EPBD has very limited, but positive nonetheless, impact on the defence sector, as it only adds new trends and systems that are normally installed in buildings nowadays.
- The inclusion of a requirement for temperature self-regulating devices in Article 8 of revised EPBD will have some impact on the defence sector, both positive (related to technology advancement) and negative (related to excessive costs).
- The requirement for installation of recharging points in Article 8 of revised EPBD will have a limited impact on the defence sector, as it applies to new/deep renovated buildings only. As it is mentioned in other cases, it would stimulate positive (related to the sensitisation of the military personnel) and negative effects (regarding mainly major capital investments and extra costs related to the default necessity of securing military related infrastructure against cyber attacks, data breach/capture risks, etc.
- Renovation passports may be very useful to help prioritise cost-effective investments and assist in the decision-making process, depending on the proposed template of such renovation passports. It may be beneficial to establish a building size threshold (m2), as renovation passports may not be relevant for small buildings.
- There is consensus that the defence sector should influence the methodology to calculate the smart readiness indicator (SRI) to account for the defence sector specificities, mainly for operational buildings, where a standard methodology may not be applicable or may impose too many constraints or unrepresentative results particularly for buildings containing numerous and varied (sometimes non-conventional and/or high consuming) equipment.
- There is also consensus that a "cluster" approach to the calculation of the SRI may fit better for the defence sector, as opposed to a "single building" SRI.

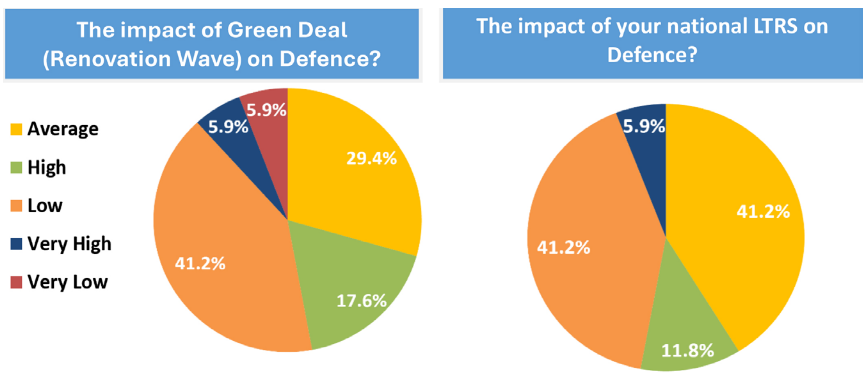
During the third Phase of the Consultation Forum, the management team prepared an overarching-holistic questionnaire, aiming at indicating potential shifts of opinion regarding the basic elements of the EED-EPBD provisional requirements and their impact on the defence domain. Except of the legal framework impact assessment, in this (so-called) "umbrella" questionnaire, novel elements, recently introduced by the revised Directive (e.g., e-mobility) were put in debate. Apart from that aspect, issues dealing with existing and future technological trends were included in the questions, as well as elements regarding recent awareness campaigns, educational and/or training initiatives, attempting to highlight and stress the significance of the human factor and eventually provide tangible evidence that, without the proper endorsement of the Armed Forces personnel, no programme objectives are going to be adequately met. In **Figures 1.4-1.6** presented below, the main conclusions are illustrated:

Figure 1.4. Overall impact assessment of (a) EED & (b) EPBD on defence



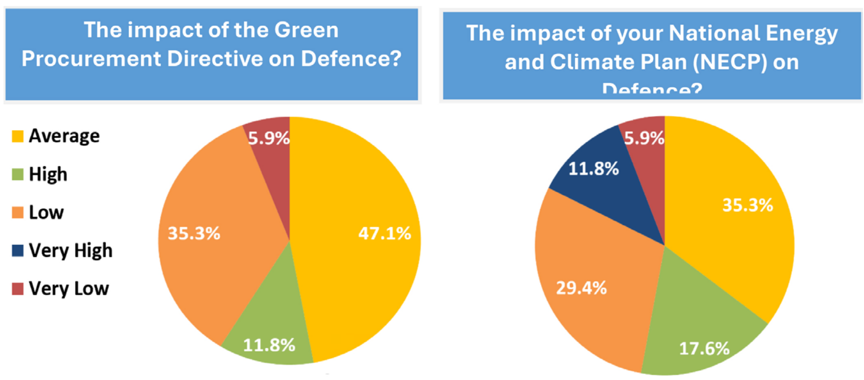
(a) (b)

Figure 1.5. Overall impact assessment of (a) Green Deal (RW) & (b) Long-Term Renovation Strategy (LTRS) on defence



(a) (b)

Figure 1.6. Overall impact assessment of (a) Green Public Procurement (GPP) Directive & (b) National Energy and Climate Plans on Defence



(a) (b)

The three figures presented above are illustrating a small impact assessment, drawn by the ministries of defence representatives of the CF SEDSS project, on how the defence sector approaches and characterises the level of influence that the basic elements of Energy Efficiency and Building Performance have on their activities. These elements are reflecting not only the main legislative framework (Energy Efficiency Directive, Energy Performance of Buildings Directive), but also wider initiatives such as Renovation Wave, Green Procurement, National Energy and Climate Plans, as well as Long-Term Renovation Strategies.

1.3.6. European green deal and renovation wave strategy

The Communication on the European Green Deal[13] stresses the key role of renovation of buildings in order to achieve climate neutrality by 2050 and introduces a new "renovation wave" initiative to boost energy performance of buildings in the EU. The objective of this initiative is to support an important increase (at least doubling) of renovation rates in the EU and to this end, it will include different strands of action to support renovation: an Open Platform for the buildings and construction sector, innovative financing schemes, additional work to lift national regulatory barriers, and a focus on some key segments of the building stock.

The most significant elements, objectives, targets and expectations of this "flagship" initiative were presented to the WG1 participants in the first two Plenary Meetings of CF SEDSS III, both by the European Commission (EC) officials as well as by the Working Group 1 management team. The main conclusions are provided below:

- The renovation wave for Europe integrated strategy, presented by the EC in October 2020, aims to double the current annual renovation rate (1%) by 2030 and increase renovations' depth.
- Mobilising forces at all levels towards these goals will result in renovating 35 million European building units; a reduction of 60% in GHG emissions; a reduction of 14% overall energy consumption, a reduction of 18% of energy for heating and cooling; and the creation of 160.000 green jobs in construction.
- An annual investment gap of 270 billion EUR has been estimated if the EU is to reach the recently proposed more ambitious 2030 targets (55% emissions reduction, 38-40% share of RES and 36-39% energy efficiency increase).
- The CF SEDSS III WG1 participants agreed that the defence public sector should be considered a key target, on account of its high-energy consumption profile.
- The lack of funding and human resources, and regulatory barriers, were identified as main obstacles for renovation measures in the defence public sector.

Apart from the generic publication of the Green Deal, another dedicated Communication was issued by the European Commission (COM-2020-662 of 14.10.2020[14]), the Renovation Wave Strategy. Based on the anticipated main areas of interest to the defence sector, a dedicated questionnaire was circulated to the WG1 participants, referring to the following research domains and seeking to evaluate the qualitative impact on the MoD's performance:

- The Commission revised in 2021 the Energy Efficiency and the Energy Performance of Buildings Directives and proposed to introduce a stronger obligation to have Energy Performance Certificates alongside a phased introduction of mandatory minimum energy performance standards for existing buildings.
- The Commission will also propose to extend the requirements for building renovation to all public administration levels.
- The European Investment Bank (EIB) will step up its support for the aggregation into portfolios of building renovation projects and the provision of tailored financial support through its newly established European Initiative for Building Renovation.
- The 2021 Annual Sustainable Growth Strategy and the Guidance on Resilience and Recovery Plans identified building renovation as a priority for national recovery plans under the European Flagship 'Renovate'. **37% of this recovery fund has been set aside for green transition projects and initiatives.**

Based on the aforementioned research areas, initial feedback was selected by the WG participants. Fundamental elements and conclusions, which are considered mandatory to be demonstrated, are illustrated in the following conclusions:

13. https://ec.europa.eu/info/publications/communication-european-green-deal_en.
14. https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf.

- EPBD consultation and impact assessment due in July 2021.
- EPBD new Directive was published on December 15th 2021, targeting and focusing on renovations by:
  - Reflecting a proper definition for "Deep Renovations".
  - Introducing obligations for minimum energy performance requirements in existing buildings as well as the use of building renovation passports.
  - Updating of the EPC framework and new approaches of EP certificates.
  - Extending the electromobility provisions scope, among other subjects.
  - Extending the targets beyond the NZEB concept (Net zero energy and net emissions) by 2030.
  - Provides for a higher use of smart devices in buildings.
- Revised EED would increase the annual 3% renovation rate for public buildings by:
  - Introducing obligations to perform energy audits and to renovate public buildings.
  - Reinforcing the role of energy performance contracting and public procurement.
  - Enlarging the baseline pool of public buildings, by deleting the potential exemption provided so far not only for the operational defence buildings but also for the buildings used for religious purposes, buildings of special historical interests, etc.

Elaborating on the aforementioned statements, the study presents the following analysis which could support EDA's feedback to the respective EU Climate Change and Defence Roadmap:

- Create incentives that allow a smoother implementation of both EED & EPBD's policy tools and instruments like Energy Saving Contracts, Long-Term Renovation Strategies to NZEB Standards and Renovation Passports, to the wider EU public and (therefore) to the defence sector.
- Identify defence (based on the outcomes of the CF SEDSS related studies and conclusions) as one of the key stakeholders of the EED's provision about NECP periodical strategic amendments to promote the potential contribution that energy efficiency action plans of the military domain can have in order to achieve national energy efficiency and saving goals.
- Although defence-specific operational buildings can be exempted from complying with some provisions of the recast EED (Arts. 6.2, 7.2 and 12), there is consensus in the defence sector that revised versions of the two documents should set an appropriate categorisation of defence operational buildings, along with the definition of appropriate energy related metrics and indicators in order to allow the calculation of their energy performance and exploit opportunities for energy saving.
- Modify accordingly Articles 22, 29 and 30 of the recast EED to facilitate the establishment of suitable monitoring measures of awareness raising and capacity building activities, not only in the military but in the wider EU public sector. Such measures could render compulsory the setting of indicators which correlate, for instance, the number of people participate in training, education or even sensitising programmes with regards to the energy efficiency achieved through these activities.

1.3.7. EU 2030 climate target plan

The Commission's proposal[15] to cut greenhouse gas emissions by at least 55% by 2030 sets Europe on a responsible path to becoming climate neutral by 2050[16]. Based on a comprehensive impact assessment, the Commission has proposed to increase the EU's ambition on reducing greenhouse gases and set this more ambitious path for the next 10 years. The assessment shows how all sectors of the economy and society can contribute, and sets out the policy actions required achieving this goal. The specific objectives of this Target Plan are the following:

15. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.
16. https://ec.europa.eu/clima/policies/strategies/2050_en.

- Set a more ambitious and cost-effective path to achieving climate neutrality by 2050.
- Stimulate the creation of green jobs and continue the EU's track record of cutting greenhouse gas emissions whilst growing its economy.
- Encourage international partners to increase their ambition to limit the rise in global temperature to 1.5°C and avoid the most severe consequences of climate change.

The new proposal delivers on the commitment made in the Communication on the European Green Deal[17] to put forward a comprehensive plan to increase the European Union's target for 2030 towards 55% in a responsible way. It is also in line with the Paris Agreement[18] objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it to 1.5°C.

1.3.8. The new EU circular economy action plan

The European Commission adopted the new circular economy action plan (CEAP)[19] in March 2020. It is one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The new action plan announces initiatives along the entire life cycle of products. It targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible. It also introduces legislative and non-legislative measures targeting areas where action at the EU level brings real added value. The specific measures that will be introduced under the new action plan aim to:

- Make sustainable products the norm in the EU.
- Empower consumers and public buyers.
- Focus on the sectors that use most resources and where the potential for circularity is high such as: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients.
- Ensure less waste.
- Make circularity work for people, regions and cities.
- Lead global efforts on circular economy.

The Commission will implement all 35 actions listed in the action plan. The full list of actions can be found in the implementation-tracking table[20].

1.3.9. EU's "Fit for 55" package

In the European Commission work programme for 2021, the revisions and initiatives linked to the European Green Deal climate action and in particular the climate target plan's net reduction target for 55%, are presented under the "Fit for 55 Package". Within this package, there is also the target of spending 37% of the €750 billion Next Generation EU Recovery and Resilience Plan on the wider EU Green Deal objectives. The following initiatives[21] are linked in the aforementioned Fit for 55 Package, and could (in)directly affect the defence sector:

- Revision of the EU Emissions Trading System (ETS), including maritime, aviation as well as a proposal for ETS as own resource (adopted in April 2023).

17. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.
18. https://unfccc.int/process-and-meetings/the-paris-agreement.
19. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN.
20. https://ec.europa.eu/environment/pdf/circular-economy/implementation_tracking_table.pdf.
21. https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/package-fit-for-55.

- Carbon Border Adjustment Mechanism (CBAM) and proposal for CBAM as own resource.
- Revision of the Energy Tax Directive.
- Amendment of the EED, to implement the ambition of the new 2030 Climate target (adopted in November 2023).
- Amendment of the RED, to implement the ambition of the new 2030 Climate target (adopted in November 2023).
- Revision of the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (adopted in March 2023).
- Revision of the Regulation setting CO_2 emissions performance standards for new passenger cars and for new light commercial vehicles (adopted in March 2023).
- Revision of the EU specifications of both maritime and aviation fuels (adopted in July and October 2023).

1.4. Defence energy efficiency landscape and trends for EU defence sector

1.4.1. EU defence concepts, policies and plans in relation to energy

a) EU climate change and defence roadmap

In its June 2020 Conclusions on Security and Defence the Council invited the High Representative to propose, together with the Commission and the European Defence Agency (EDA), and in close dialogue with Member States, a set of concrete short-, medium-, and long-term actions addressing the links between defence and climate change as 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[22].

These actions have been included in the EU Climate Change and Defence Roadmap[23], where the term "Climate Change" has undertaken a wider concept, incorporating phenomena related to environmental degradation. While constituting an integral part of the EU's overall effort to address climate change, this Climate Change and Defence Roadmap encompasses three different interlinked areas of action:

- The operational dimension.
- Capabilities development.
- Strengthening multilateralism and partnerships.

Specific actions have been identified on a short/medium/long term basis, for all of the aforementioned dimensions of the Roadmap. The actions are correlating various EU Institutions involved in the defence sector (EUMS, EDA, JRC, etc.) as well as concrete contributions by the MS, which are invited to endorse the principles of the Roadmap into their national climate change/defence policies.

With regards to the scope of this study, relevant topics addressed and linked to the context of the Roadmap, whilst being included in the list of required data by the EU Institutes to the EDA are:

22. https://www.consilium.europa.eu/media/44521/st08910-en20.pdf.
23. https://data.consilium.europa.eu/doc/document/ST-12741-2020-INIT/en/pdf.

- Assessment of the impact that EED and EPBD have on defence.
- Analysis of the fundamental elements of the European Green Deal/Renovation Wave (apart from the revision of the 2 aforementioned Directives) and how these elements interact with the respective military activities.

b) The new European Defence Fund

The European Defence Fund[24] incentivises and supports collaborative, cross-border research and development in the area of defence. The Fund will increase the EU's technological edge and develop the capabilities that are key for the strategic autonomy and resilience of the Union and its Member States and the protection of its citizens. The expected advantages and contributions by the effective implementation of the EDF (namely the materialisation of dedicated projects) are the following:

- Enabling a more secure and competitive Europe.
- Providing a collaborative tool to reduce fragmentation and inefficiencies.
- Offering a budget that matches the level of ambition of the involved stakeholders (governments, academia, industry, etc.). Around €8 billion is expected to be allocated to the EDF for the next seven years (2021-2027), of which 5.3 will be dedicated to capability oriented collaborative projects and 2.7 to R&D defence initiatives.

The Fund finances up to 100% of the total eligible costs of awarded projects, in particular through grants, including up to 35% of possible bonuses. Research activities could be funded up to 100% while development activities have different funding rates complementing Member States' or industrial investments, between 20%-80% from prototyping to certification. However, the Fund does not cover the acquisition phase.

Energy resilience and environmental transition are identified amongst the medium priority key areas of the EDF, therefore this fact is regarded as an excellent opportunity for the MS to discuss, to foster and submit collaborative project ideas in this domain.

c) EU's latest conclusions on energy and defence

On June 11th 2021, the Council of the EU[25] approved conclusions on a renovation wave that repairs the economy now, and creates green buildings for the future. The renovation wave strategy aims to intensify renovation efforts throughout the EU, in order to make the necessary contribution by the buildings sector to the 2050 climate neutrality goal and to deliver a fair and just green transition. Member States endorse the strategy's aim to double energy-related renovation rates in the EU by 2030, while tackling energy poverty, creating new jobs and promoting resource efficiency and circular economy. This should go hand in hand with the integration of energy efficient solutions and the use of renewable energy and waste heat or cold. The strategic aim for doubling the annual renovation rate sets up the necessity to revise the EPBD. The respective process started in March 2021, and is focusing on the three following thematic areas[26]:

- Tackling energy poverty and worst performing buildings, ensuring access to healthy housing for all households.
- Meeting the need for renovation of public buildings, e.g., healthcare, educational and administrative facilities, so that public buildings can lead by example.
- Decarbonisation in heating and cooling which are currently responsible for 80% of energy consumed in residential buildings.

24. https://defence-industry-space.ec.europa.eu/document/download/69aa3194-4361-48a5-807b-1a2635b91fe8_en?filename=DEFIS%20_%20EDF%20Factsheet%20_%2030%20June%202021.pdf.
25. https://www.consilium.europa.eu/en/press/press-releases/2021/06/11/council-approves-conclusions-on-an-eu-renovation-wave/?utm_source=dsms-auto&utm_medium=email&utm_campaign=Council+approves+conclusions+on+an+EU+renovation+wave.
26. https://www.rehva.eu/rehva-journal/chapter/the-3rd-revision-of-the-energy-performance-of-buildings-directive-epbd.

On July 14th, 2021, the **European Commission** adopted the Communication **'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality**"[27] to ensure a fair, competitive and green transition by 2030 and beyond. As part of this Adoption Decision, the recasts of both the Energy Efficiency Directive and the Renewables Energy Directive have been adopted, while the recast of the Energy Performance of Buildings Directive is still undergoing. The package includes 12 legislative proposals, which aim at strengthening the EU's action to reach the climate target of at least 55% by 2030 and adopts the recommendation and guidance on the "**Energy Efficiency First principle**".

1.5. Tools and instruments for attainment of energy efficiency targets and implementation status in the defence sector

1.5.1. Policy tools and instruments

The following tools and instruments facilitate and channel the deployment of resources and means necessary to undertake the implementation of the energy related policies and legislation and to achieve the objectives set within these policy and legislative packages. Each Member State and relevant organisation must first analyse and assess its current state in terms of energy efficiency, and then develop and apply these tools and instruments based on the desired objectives to be achieved.

The defence sector in particular, which by its specific nature has, in general, been exempted from complying with some of the energy efficiency provisions so far, should pay special and careful attention to its participation in the relevant inter-ministerial committees or boards to this effect within its Member State, in order to negotiate and establish a staged and realistic contribution to the achievement of the national energy objectives.

a) National Energy and Climate Plans (NECPs)

Integrated NECPs address all five dimensions of the Energy Union (decarbonisation, energy efficiency, energy security, internal energy market, research and innovation and competitiveness) and are one of the main pillars of the Energy Union governance mechanism. Complemented by Member States' long term decarbonisation strategies, they represent a key tool for a more strategic energy and climate policy planning and ensure that energy-related actions at Union, regional, national and local level all contribute to the Energy Union's objectives[28].

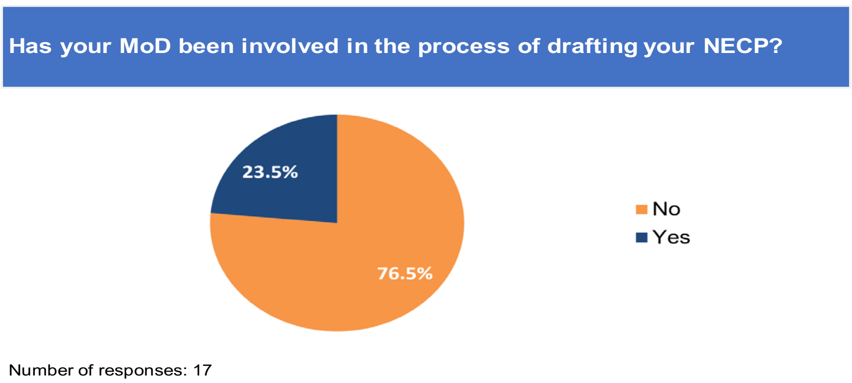
27. https://ec.europa.eu/info/sites/default/files/chapeau_communication.pdf.
28. Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R1999&from=EN.

The integrated national energy and climate plans covering the first period from 2021 to 2030 should pay particular attention to the 2030 targets for GHG emission reductions, renewable energy, energy efficiency and electricity interconnection. In line with the European Green Deal's statement and multiple references to the necessary transition of all sectors to more sustainable and inclusive growth models, the defence sector should have been involved by their national Competent Authorities in the drafting of these NECPs, both in terms of analysis of their current situation and definition of a defence-specific staged introduction to the national efforts, as well as in the definition of achievable objectives which can be realistically accomplished with available means and budget.

Even if not involved, the defence sector should at least be well aware of its current situation and of their assigned objectives at national level, in order to define their own strategies, roadmaps and plans adapted to their own specificities. On the contrary, should the defence sector have not been taken into account as part of their corresponding national efforts, a unique opportunity for the defence sector stems up so as to propose and put forward a new defence sectoral trajectory to their national authorities which will reinforce national potentials and will bring the defence sector into the forefront of the green transition to achieve the ambitious target of reducing greenhouse gas emissions by at least 55% by 2030. This trajectory should be a comprehensive one including not only energy efficiency, but also the installation and utilisation of renewable energy sources and, in many cases, perhaps the utilisation of free land for installation of community wide RES installations.

The role of the defence public sector in green public procurement and energy performance contracting, in public-private partnerships and in energy communities is still scarce at the moment and its potential needs to be fully explored and studied. With regards to the defence involvement in the elaboration of their MS's NECP[29] and in accordance with information collected from questionnaires circulated among the CF SEDSS MoD's in February 2021 (Phase IIII of the CF SEDSS), less than 25% of the MoD declared they had been involved in the preparation and elaboration of their respective NECPs **(Figure 1.7)**.

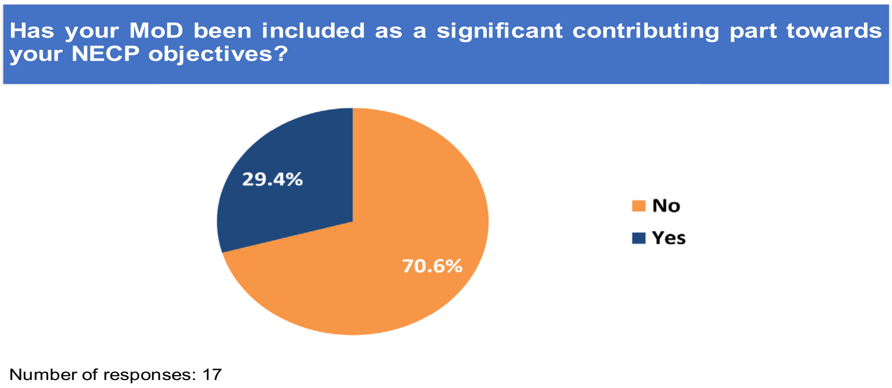
Figure 1.7. Involvement of defence in drafting and setting of objectives in their NECPs



The reasons for not participating were mainly that their competent energy authority did not consider it necessary, lack of communication with other administration bodies or operational restrictions imposed by their MoD hierarchy. Moreover, around 70% of the MoD declared they had not been considered as significant contributors to the objectives set in their NECP, and the main reasons for those MoDs not considered as such important contributors towards their national objectives were that either they had not been involved in the elaboration process or they had not sufficient data to support the case **(Figure 1.8)**.

29. https://eda.europa.eu/docs/default-source/events/eden/phase-ii/guidance-document/cfsedssii-guidance-document.pdf.

Figure 1.8. Consideration of defence as a significant contributing factor towards NECP's objectives

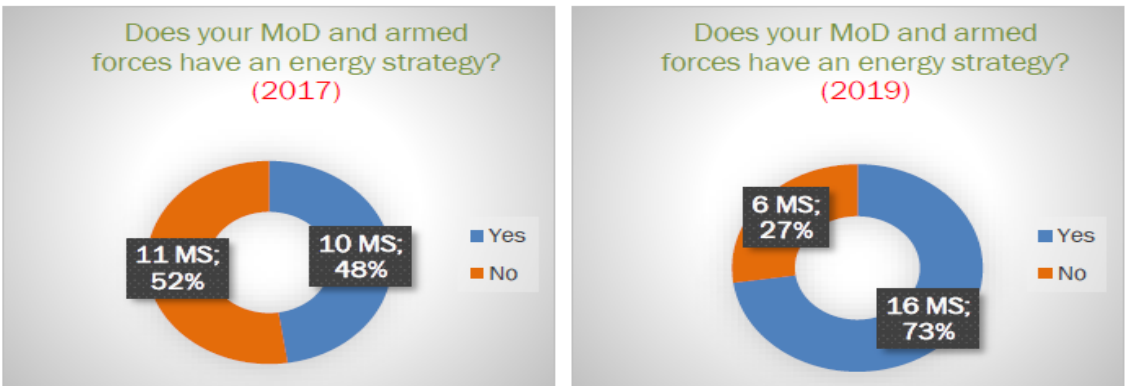


b) Energy efficiency and environmental policies and strategies in defence

Defining and adopting an appropriate policy, a strategy and an action plan, fully in line with national and EU objectives and guidelines and considering all defence-specific needs and constraints are crucial to the attainment of energy efficiency targets through well-planned interventions.

In general terms, a good energy policy should state the vision and general scope of action for the organisation in the short, mid and long-term, whereas a good strategy should clearly state all strings of action and set clear and SMART (Specific–Measurable–Achievable–Relevant–Time-bound) targets and provide for monitoring mechanisms to safeguard its implementation. Given the criticality and impact that these policy tools will have on the success of each one of the interventions, it is of paramount importance that they are defined, developed and endorsed at the highest level within the MoD's organisational hierarchy, and in close collaboration with corresponding Competent National Authorities. With regards to Energy efficiency and environmental policies and strategies implementation status in the defence sector[30] and in accordance with information collected from questionnaires circulated among the CF SEDSS MoD's in May 2017 (Phase I of the CF SEDSS) and May 2019 (Phase II of the CF SEDSS), almost 75% of the MoD did have an energy policy and strategy by 2019, either as a stand-alone energy strategy or as part of their environmental protection or sustainable development strategy, in line with their defence operational capabilities policies and strategies. Moreover, there were plans in 5 MoD's without an energy policy and strategy to implement one in the coming years. However, on a positive note, in 2019 73% (16) of the EU MoDs confirmed that they developed a national defence energy strategy **(Figure 1.9)**.

Figure 1.9. Incorporation of energy strategies in the defence sector (May 2017 & May 2019)



30. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

Adding to the problem is the lower-than-required level of commitment from the hierarchy, which may be due to a lack of visibility within the organisations of energy as one of the most critical operational capabilities' enablers, and inevitably, results in a shortage of resources and means allocated to the endeavour.

Furthermore, and based on the information collected from a questionnaire circulated among the CF SEDSS MoD's in January 2016 (Phase I of the CF SEDSS), less than half of the MoDs do project their future energy needs (in 10 out of the 22 MoDs that replied, 45%), which inevitably leads to their inability to planning for energy saving measures.

c) Long-term buildings renovation strategies, logbooks and renovation passports

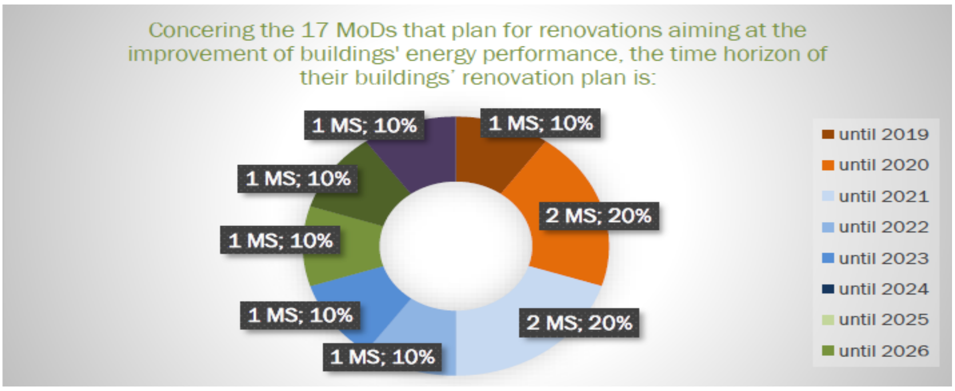
Based on the Council conclusions of 10 June 2011 on the Energy Efficiency Plan 2011 that buildings represent 40 % of the Union's final energy consumption, Article 4 of Directive 2012/27/EU on energy efficiency (EED) demanded that Member States establish a long-term renovation strategy (LTRS) beyond 2020 for mobilising investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock.

Later on, and through the Directive 2018/844/EU amending Directive 2010/31/EU (EPBD) and Directive 2012/27/EU (EED), the provisions on LTRS were moved from the EED to the EPBD and complemented with the introduction of new objectives to decarbonise the building stock by 2050 through the transformation of existing buildings into nearly zero-energy buildings and new provisions to facilitate this transformation, which include the life-cycle analysis of buildings, the introduction of building logbooks and renovation passports, policies and actions to target worst performing buildings in the national building stock and alleviate the energy poverty, as well as all public buildings, and the promotion of smart.

With regards to the LTRS implementation status in the defence sector[31] in accordance with information collected from questionnaires circulated among the CF SEDSS MoD's in February 2019 (Phase II of the CF SEDSS), more than 75% of the MoDs reported that they prepare plans for buildings renovation aimed at improvements of energy performance, although only with a short/medium term horizon, and based on a combination of different energy performance standards, using both single building and "cluster" (multiple building) approaches, and both sole complete one-off and staged renovations.

The main barrier for those MoDs that do not plan for renovations in buildings aiming at the improvement of the energy performance is that energy efficiency is not among their highest priorities and the associated budgets are consequently not significant. Only a bit less than 50% of the MoDs maintain some type of logbook or record keeping on buildings renovations or different aspects of energy use without standardised parameters or methodologies **(Figures 1.10-1.13)**.

Figure 1.10. Time horizon of renovation plans for the defence sector building stocks (February 2019)



31. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

Figure 1.11. Renovation drivers for the building stocks of the defence sector (February 2019)

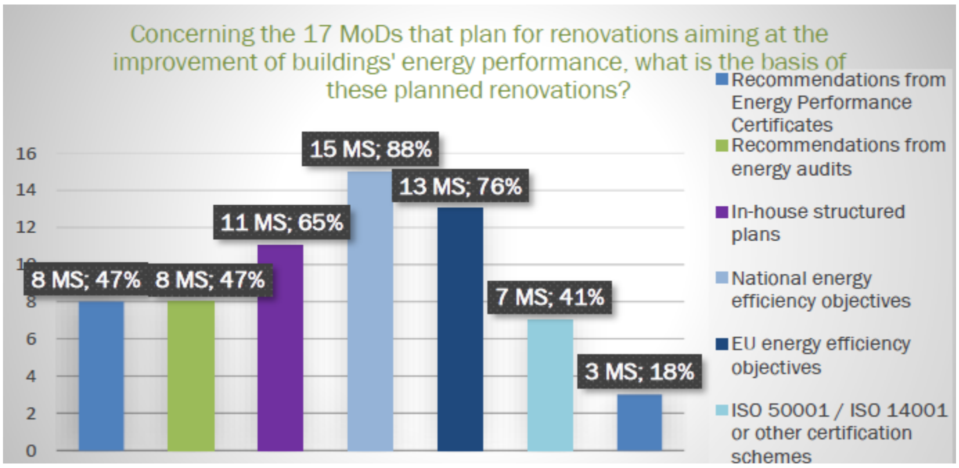


Figure 1.12. Renovation approach for the building stocks of the defence sector (February 2019)

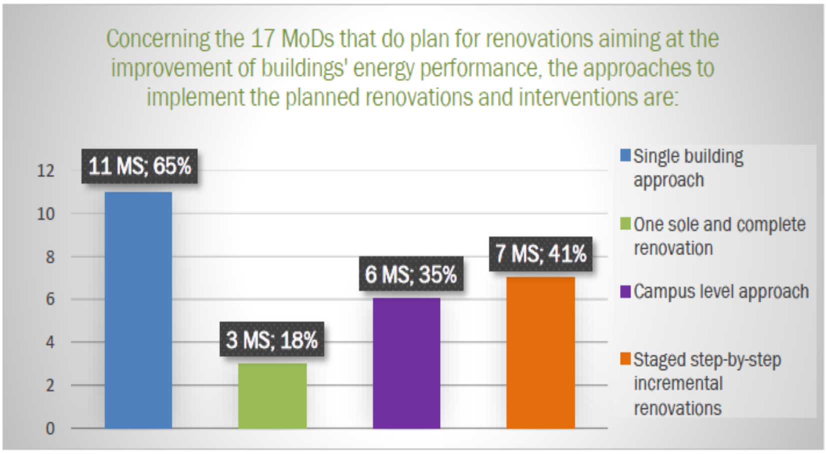
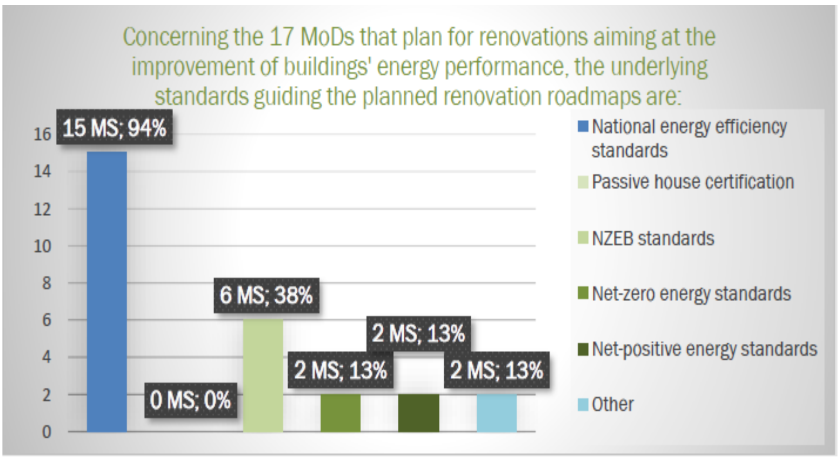


Figure 1.13. Renovation requirements and standards used for the building stocks of the defence sector (February 2019)



d) *Energy Performance Certificates (EPCs)*

Energy performance certificates are legally recognised certificates that indicate the energy performance of a building or building unit, calculated according to a methodology and common general framework adopted in accordance with Article 3 and Annex I of the EPBD. Also, in accordance with the multiple provisions reflected in Articles 11 through to 13 of the EPBD, the energy performance certificate shall include recommendations for the cost-optimal or cost-effective improvement of the energy performance of a building or building unit, unless there is no reasonable potential for such improvement compared to the energy performance requirements in force.

Public authorities should lead by example and should endeavour to implement the recommendations included in the energy performance certificate. Member States should include within their national plans measures to support public authorities to become early adopters of energy efficiency improvements and to implement the recommendations included in the energy performance certificate as soon as feasible.

With regards to the Energy performance certificates implementation status in the defence sector[32]. Different MoDs have different interpretations of the concept of a "public building", resulting in different level of adherence, ranging from full to no adherence at all, to the provisions in the EPBD Articles 11, 12 and 13 regarding the obligation to obtain and display an energy performance certificate on MoDs' buildings. The implementation of energy performance certificate programmes for existing buildings is not uniform across MoDs, and the main obstacles to it are the perception that the defence sector is not obligated to comply with these provisions, the consensus that raising the performance of some buildings may not be cost effective and also that raising the commercial value of a building is of limited impact to the defence sector, the lack of resources and budget, and last but not least, the lack of proper energy consumption benchmarks for defence buildings which, as explained later on in this report, may lead to sub-optimal or even wrong results and conclusions.

Moreover, existing energy performance certificates represent only a single set of information at a specific point in time and do not have into account the full concept of sustainability and circularity of the building throughout its whole life cycle. There is, thus, a need to adopt different approach to modelling energy performance to improve predictions of the real energy performance of the building during its operational life, such as Building Information Modelling (BIM) and artificial intelligence (AI) tools, as presented further in this document in subsection 5.4.1.

e) *Energy Performance Contracting (EPC)*

An energy performance contract is a contractual arrangement between a beneficiary and the provider (energy service companies – ESCOs) of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings[33]. Overall, it comprises a form of financing for energy efficiency improvements where the financial risk is partly or totally transferred from the beneficiary to an ESCO.

Recast EED Article 29 (old EED Article 5) encourages public bodies within EU, under their exemplary role responsibilities, to use, where appropriate, energy service companies, and energy performance contracting to finance renovations and implement plans to maintain or improve energy efficiency in the long term. With regards to the Energy performance contracting implementation status in the defence sector[34], there is a general acknowledgement of the multiple potential benefits of pursuing EPC with ESCOs in terms of energy efficiency upgrading, emissions and costs reductions and transfer or risk through externalisation of services and without the need to commit additional budget and resources from their organisations.

32. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.
33. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=en.
34. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

However, the perception of the difficulties of implementing EPC is seen by the defence sector, almost unanimously, as very challenging, with only a few MoDs (approximately 21%) implementing or in the process of signing EPC and a majority of them facing not only challenging obstacles imposed by their national policies and accounting rules, but also a lack of baseline building stock and energy consumption data and of knowledge on the development of the appropriate indicators to monitor and the practicalities and details of measurement and verification (M&V) to carry out during the contract.

f) New EU level(s) framework and indicators

Level(s) is a relatively new common EU framework of core indicators and metrics for measuring the sustainability of office and residential buildings, comprising not only energy, but also environmental performance, as well as health and comfort, life cycle cost and potential future risks to performance.

As far as the defence sector, as a public body and end-user of buildings, is concerned, the EU Level(s) framework focuses on performance aspects that are of direct ongoing financial interest to occupiers, such as operating and maintenance costs, including headline indicators that measure comfort aspects of a building and its internal environment, such as indoor air quality or thermal comfort. It also provides recommendations on how the performance of an occupied building can be monitored and surveyed[35].

This framework is still unknown within the defence sector and perceived as the potential way ahead in the mid or long-term future. None of the EU MoDs has even considered making the first steps and evolving towards this framework, as they have not even completed fully the implementation of the existing and better known environmental and energy efficiency legislative packages.

g) Green public procurement

The old EED Article 6 required Member States to ensure that central governments purchase only products, services and buildings with high energy-efficiency performance, insofar as that is consistent with cost-effectiveness, economic feasibility, wider sustainability, technical suitability, as well as sufficient competition. This obligation applied to the contracts of the armed forces only to the extent that its application does not cause any conflict with the nature and primary aim of the activities of the armed forces. The obligation shall not apply to contracts for the supply of military equipment including works, supply and service contracts by contracting authorities or entities in the fields of defence and security[36]. Annex III of the old EED provided further guidance on the energy efficiency requirements for purchasing products, services and buildings by the central government, taking into account:

- The Energy Labelling Regulation [Regulation (EU) 2017/1369] as well as the delegated acts on specific products.
- The Eco-design implementing regulations (under Directive 2009/125/EC on Energy labelling, repealed by Regulation (EU) 2017/1369) adopted after the entry into force of the EED.
- The EU-US Energy Star Agreement (expired on 20 February 2018).
- The minimum energy efficiency requirements for buildings and building elements that the EPBD obliges EU Member States to set.
- The Public Procurement Directive (PPD – Directive 2014/18/EC).

35. JRC Science for Policy Report. Level(s) – A common EU framework of core sustainability indicators for office and residential buildings. August 2017, available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC109285.
36. 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 field of defence and security".

Building on this, the recast EED Article 7 requires contracting authorities and contracting entities to purchase only products, services buildings and works with high energy-efficiency performance in accordance with the requirements referred to in the Annex IV to the Directive when exceeding a value equal to or greater than established thresholds, and apply the energy efficiency first principle, unless it is not technically feasible, once again, applicable to the contracts of the armed forces only to the extent that their application does not cause any conflict with the nature and primary aim of the activities of the armed forces, and not applicable to contracts for the supply of military equipment.

Further to this, the European Commission has developed GPP criteria to facilitate the inclusion of green requirements in public tender documents, which provide a good balance between environmental performance, cost considerations, market availability and ease of verification, which public procuring authorities may include partly or fully in accordance with their needs[37]. Moreover, the Commission has published a Handbook on green public procurement[38] to help public authorities successfully plan and implement GPP following the logic and structure of a procurement procedure, that has shown to be widely unknown by the defence community.

GPP implementation status in the defence sector[39]

In accordance with information collected from a questionnaire circulated among the CF SEDSS MoD's in May 2017 (Phase II of the CF SEDSS), the majority (in average, around 75%) of the MoDs/armed forces have incorporated the relevant public procurement specifications concerning energy efficiency into their procedures/requirements for the procurement of various products. However, based on the information collected from a second questionnaire circulated among the CF SEDSS MoD's in February 2021 (Phase III of the CF SEDSS), only a bit more than 50% of the MoDs have a GPP policy as such in place and include specific GPP criteria in their procurement procedures.

The challenges and barriers preventing implementation of GPP criteria from happening include the excessive costs of energy efficient equipment and certified service providers and the predominant criteria within organisations of lower purchase cost against lower life-cycle cost, due to difficulties to justify return of investment (ROI) and payback periods following the existing budgeting procedures and rules. When there are a GGP policy and criteria in place, they are normally more widely applied for the procurement of products rather than for services.

1.5.2. Management tools and instruments

a) *Metering, data collection and analysis*

Data collection and analysis, along with defining and developing appropriate Key Performance Indicators (KPI) are prerequisites for any successful attempt of monitoring energy consumption, of defining and developing any successful energy efficiency strategy, plan and objectives and of implementing any energy management system, as well as for evaluation of and feedback from energy efficiency implemented measures. Energy consumption metering, data collection and analysis solutions become thus key and critical tools at the very basis of any energy management system.

However, the use of smart tools to measure the energy performance of MoDs' buildings can increase the risks of cyber security and data breach/capture and the mischievous use of defence data. Thus, the implementation of such tools should not be made mandatory and should be done with respect to each MoD's choices. As far as data collection and analysis is concerned, no requirements or methodologies are provided in the existing legislation other than providing general main energy consumption indicators in accordance with the common general framework methodology guidelines.

37. https://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm; (consulted on 19.08.2021).
38. Buying green! A handbook on green public procurement 3rd Edition. European Union 2016, https://op.europa.eu/en/publication-detail/-/publication/8c2da441-f63c-11e5-8529-01aa75ed71a1/language-en.
39. GUIDANCE DOCUMENT. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

Energy data, collection and analysis solutions implementation status in the defence sector[40]

In accordance with information collected from questionnaires circulated among the CF SEDSS MoD's in January 2016 (Phase I of the CF SEDSS) an October 2018 (Phase II of the CF SEDSS), all MoDs collect energy data and maintain relevant records to a certain extent. However, the type and granularity of these data, the use of smart meters and the level of record keeping for infrastructure consumptions differs among MoDs, and the energy consumption metering is most of the times done at base level, rather than at building level, which makes it difficult to identify particular energy saving opportunities within the military bases and building complexes (**Figures 1.14-1.15**).

Figure 1.14. Utilisation of smart metering devices for electricity in the defence sector (October 2019)

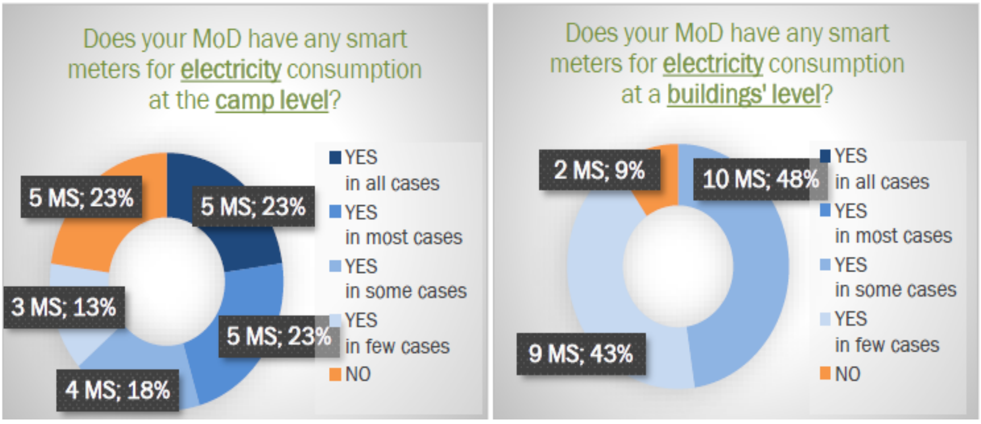
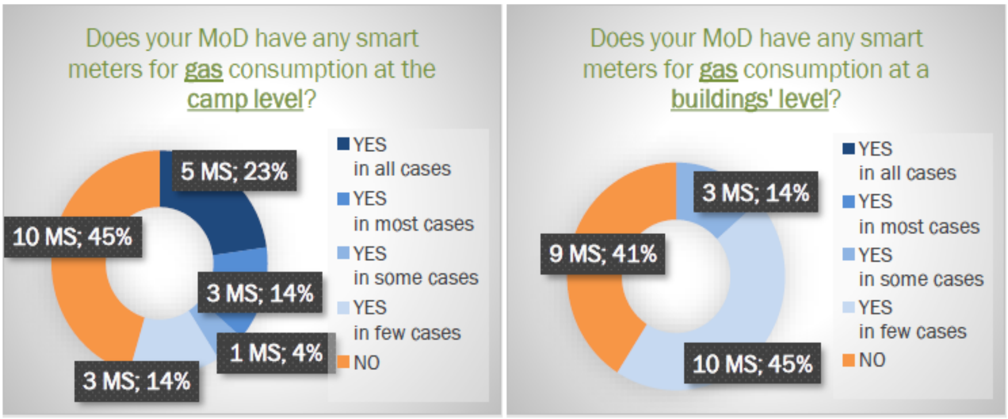


Figure 1.15. Utilisation of smart metering devices for gas in the defence sector (October 2019)



As far as energy performance indicators (EnPIs) are concerned, they have been developed and are being used by only 1/3 of the MoD as simple ratios of consumed energy per metric (m2, number of personnel, distance driven) or emissions that do not take into account weather conditions, building uses or other independent variables for normalisation purposes, which may render them misleading for monitoring energy consumption.

40. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

Last but not least and equally or even more critical than the instruments described above, is the absence of defence-specific energy consumption benchmarks. In general, the assumption has been made across the EU that non-operational defence buildings (offices, living quarters, hospitals, schools, canteens, etc.) have similar consumption profiles to those of their "equivalent buildings" in the civil sector, which means that the nationally defined minimum energy performance requirements, energy benchmarks, energy performance certification programmes and NZEB concepts can be directly applicable and extrapolated to defence non-operational buildings. However, it should be clarified that even in these cases defence energy uses can be very much different from civilian ones : more hot sanitary water consumption (even in very standard offices), due to the amount of sports performed during service, significative variation of energy needs (because of very sudden departures of companies in overseas operations, or to training camps, etc), sensitivity of detailed energy data (even in very standard offices, it can be too much information to disclose to give consumption data that can give details on the presence / absence of people), sensitivity to hacking (control of heating systems for instance, etc).

Furthermore, there is a score of defence operational buildings whose defence-specific characteristics and energy consumption profiles do not fall under the same parameters and metrics of any of the nationally defined reference buildings for the civil sector. Even though defence-specific operational buildings are exempted from complying with some provisions of the current EED (Art. 6.2, 7.2 and 12.2), there is consensus in the defence sector that an appropriate categorisation of defence operational buildings, along with the definition of appropriate energy related metrics and indicators are necessary in order to allow the calculation of their energy performance and exploit opportunities for energy savings. This specific recommendation is included in the list of the main recommendations / suggestions of the study with regards to the expected feedback of EDA to the EU Climate Change and Defence Roadmap, which are thoroughly presented in paragraph 3.6 of the study.

b) Energy and Environmental Management Systems

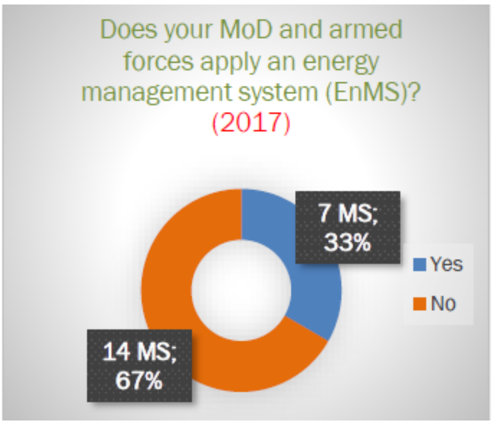
Article 6 of the recast EED (Article 5 of the old EED) requires public bodies to play an exemplary role as far as their energy efficiency and energy consumption of their buildings are concerned. To that end, public bodies are encouraged to adopt specific energy efficiency action plans and, moreover, develop and implement energy management systems (EnMS). These systems are comprehensive tools for promoting continuous improvements in the energy efficiency and environmental performance of organisations. There is an ongoing and intense debate in the defence sector, which is still unfinished, about the scope of EnMS and/or environmental management systems (EMS) such as ISO 50001, ISO 14001, or the EU Eco-Management and Audit Scheme (EMAS) and whether military operational activities should be included or not, as well as the impact of such inclusion would have on operational capabilities. There is no doubt though, as far as defence non-operational building stock is concerned, that the implementation of one of such EnMS/EMS, or even the development of as similar organic one, is critical for a successful energy management in the organisation. Even if the organisation is simply preparing and implementing tools and mechanisms to obtain one of these certifications, the energy saving results should be tangible and considerable if things are done correctly.

Energy and Environmental Management Systems implementation status in the defence sector[41]

In accordance with information collected from questionnaires circulated among the CF SEDSS MoD's in April 2017 (Phase I of the CF SEDSS) an May 2019 (Phase II of the CF SEDSS), the majority of MoDs (around 81%) are applying an EnMS, an EMS or a combined EnMS/EMS in their organisations to a certain extent, however, only 9% of MoDs were applying them in a comprehensive manner reaching the wider scope of their organisations, whereas for the rest of them, the implementation of these management systems were constrained to pilot or small scale cases (**Figures 1.16-1.17**).

41. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

Figure 1.16. Implementation of energy management systems in the defence sector (April 2017 & May 2019)



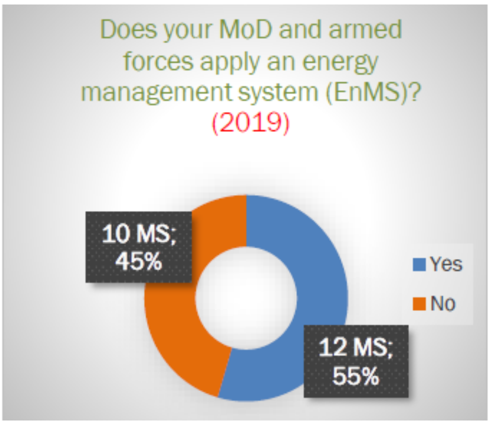
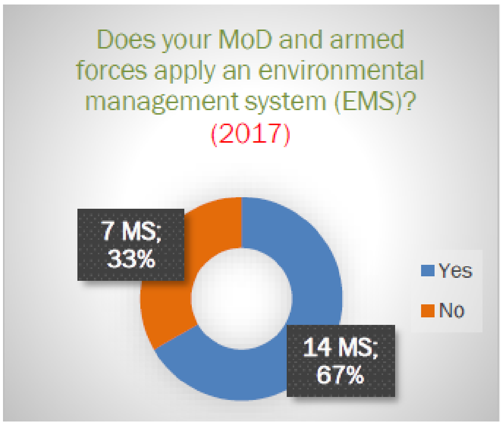
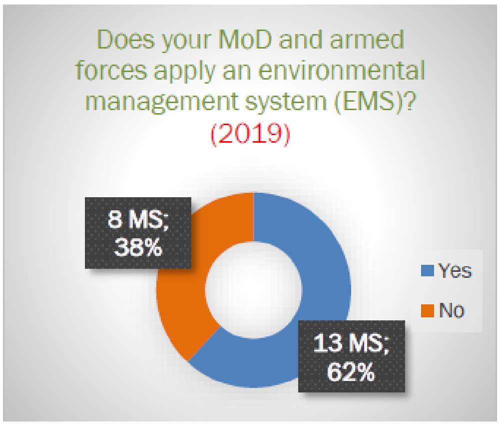


Figure 1.17. Implementation of environmental management systems in the defence sector (April 2017 & May 2019)





1.5.3. Awareness-raising and behavioural change programmes

Awareness-raising campaigns and behavioural change of occupants are one of the possible alternative measures whereby Member States may achieve an amount of energy savings that is, at least, equivalent to that which would result from renovating 3% of the total floor area of heated and/or cooled buildings owned and occupied by its central government on an annual basis, as required by paragraph 1 of the recast EED Article 6.

Moreover, the recast EED Article 10 (old EED Articles 17 and 18) encourage MS to promote the uptake of suitable information, awareness raising, and education/training initiatives and technical assistance with an aim to better inform on the benefits and practicalities of taking energy efficiency improvement measures and building relevant capacities among the public and specific sectors. Organisational cultural change and building users awareness-raising and behavioural change programmes are tools with great potential to achieve reasonable energy savings (around 10-20% in accordance with most literature sources) in the medium or long term without much investment. However, its full potential will best realise when synergies are fully exploited in combination with more efficient equipment upgrades and improvements in technology for monitoring and control of energy consumption.

Awareness-raising campaigns and behavioural change programmes implementation status in the defence sector[42]

In accordance with information collected during Phase I of the CF SEDSS, the defence public sector has embarked, in general (around 90%), on some forms of energy awareness campaigns, but does not yet have a comprehensive behavioural change programme implemented and running and, consequently, there is no information available on the potential impact of such measure except for some qualitative historical records of buildings' occupants' behaviour within their organisations.

The difficulty to monitor and control the variables and then to measure and verify the results of an approximate science such as behavioural change programmes may be working in detriment of their implementation. In turn, the absence of such programmes with a set vision, objectives and procedures results in a lack of awareness and motivation by defence personnel when presented with the right opportunity and means that could, otherwise, lead to energy efficient actions.

1.5.4. Technological tools and instruments

a) Smart tools for design of new and existing buildings renovation projects and more accurate energy performance predictions

The migration from classical Computer Aided Designing (CAD) tools to Building Information Modelling (BIM) models and BIM implementation process is a lengthy and effort demanding one, requiring trained personnel and investment. However, there are multiple advantages in using BIM-based design for more accurate buildings energy performance estimations during the buildings' design phase and energy performance realisations during the buildings' construction, use and dismantling phases.

The capacity of BIM to model and estimate the amount of embedded energy in the building materials and construction/assembly processes, as well as to model all different energy uses in the building (escalators, catering facilities, or server rooms, for example) and different solutions, and then simulate different scenarios, allows not only for a better estimation of energy consumption and CO_2 emissions, but also for the analysis of multiple indicators as those defined by the EU levels framework (climatic, air quality, comfort, etc.) and the estimation of energy overall operational and maintenance costs, throughout the life cycle of the building.

Smart design tools implementation status in the defence sector[43]

BIM tools are perceived by the defence sector as the present and the future of modelling tools in the construction/renovation sector and the migration towards BIM models is seen as a necessary step to keep organisations up to date. Nevertheless, the majority of them have not yet started the transition from classical CAD tools towards BIM tools and capacities. The BIM implementation process is a lengthy and effort demanding one, requiring trained personnel and investment that, in most cases, are not available in the defence organisations. Also, the requirement for storing energy data with buildings maps could create potential cyber security risks.

b) Building automation and control systems and smart technical systems for optimal energy management and consumption

Building automation and control systems (BACS) have proved to be an effective alternative and replacement of technical systems inspections and bring energy and resources savings. Their installation was already encouraged by EPBD Article 8, and their definition was then developed in the EU directive 2018/844[44] as *systems comprising*

42. https://eda.europa.eu/docs/default-source/events/eden/phase-ii/guidance-document/cfsedssii-guidance-document.pdf.
43. https://eda.europa.eu/docs/default-source/events/eden/phase-ii/guidance-document/cfsedssii-guidance-document.pdf.
44. 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/eli/dir/2018/844/oj.

all products, software and engineering services that can support energy efficient, economical and safe operation of technical building systems through automatic controls and by facilitating the manual management of those technical building systems.

This directive introduces the concept of the "smart readiness indicator" (SRI), whose definition, use and methodology for calculation are developed by a delegated regulation of October 2020[45] establishing an optional common Union scheme for rating the smart readiness of buildings, defined as an indicator to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings. The SRI should serve to raise awareness about the actual savings of those new enhanced BACS functionalities.

BACS and SRI implementation status in the defence sector[46]

In spite of the fact that the MoDs recognise the importance of installing BACS and metering in their real estate at site and building level as a means to monitor and control appropriate operation of technical building systems and maximise energy savings, they do not, in general, make use of the full range of BACS that are now available. Moreover, only a few MoDs have integrated smart metering, BACS and management systems installed at site level covering a number of buildings and facilities, which facilitates active energy management. Thus, there is no sound quantitative data to research on the impact of that installation of BACS may have in energy savings. The lack of a proper building stock inventory and an energy consumption baseline that is suitable for comparison purposes, along with the high initial investment cost and personnel expertise required were highlighted as the main obstacles for their installation.

c) Green mobility and support infrastructure in defence

Article 8 of the EPBD foresees, with regard to new non-residential buildings and non-residential buildings undergoing major renovation, with more than 10 parking spaces, the installation of at least one recharging point (in accordance with Directive 2014/94/EC) and ducting infrastructure for at least one every five parking spaces to enable the installation at a later stage for electric vehicles.

The successful transformation of internal combustion engine vehicles (ICEVs) into battery electric vehicles (BEVs) or hybrid vehicles requires the implementation of an efficient vehicle fleet management system. Moreover, such management system must be fed with detailed information about the vehicle fleet such as vehicle fleet size, mileage, frequency, time and moment of use, or age of vehicles, among others. If we aim to succeed in developing a solid business case from a life-cycle cost (LCC) perspective; this is mainly due to the fact that capital costs are comparatively much higher in low emission vehicles than in traditional ones. However, there may be cases where the environmental business case justification, which is normally taken for granted, may fail, as the manufacturing of batteries has a higher footprint than that of manufacturing combustion engines and the energy mix of the electricity supply influences heavily the carbon footprint of the electric and hybrid vehicles, with cases where internal combustion vehicles may result in net lower carbon emissions than battery or hybrid vehicles if electricity is produced from coal in high percentages. Moreover, support infrastructure represents an added cost which may heavily impact the financial case of these initiative, with charging installation costs varying from 1/1,2k EUR for slow charging 3,7/7,4 KW (10/5 hours charge time) to 65k EUR for superfast charging 50/150 KW (40/15 minutes charge time).

45. Commission delegated regulation (EU) 2020/2155 of 14.10.2020 supplementing Directive (EU) 2010/31/EU of the European Parliament and of the Council by establishing an optional common European Union scheme for rating the smart readiness of buildings, https://eur-lex.europa.eu/eli/reg_del/2020/2155/oj.
46. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

Green mobility and support infrastructure status in the defence sector[47]

According to the data available in 2019 very few MoDs, have embarked on any pilot project to demonstrate feasibility of full-scale initiatives for transformation of their vehicle fleets. This is due to a number of reasons including budget constraints, legal obstacles and limited political direction. Policies for installation of supporting infrastructure are, thus, not in place for now.

Based on initial inputs from some MoDs, their vehicle fleets are in general comprised of hundreds of different vehicle types, mainly motorbikes, utilitarian cars, and different sizes of busses and trucks, both petrol and diesel, normally fully owned, and a wide range of ages. However, more detailed information from a much higher number of MoDs is needed in order to properly assess the existing situation and reach sound conclusions on the potential of these initiatives and the obstacles preventing from implementing them, with limited political direction, lack of legal framework and of financial incentives for public authorities to transform their vehicle fleets being anticipated as the main hindrances.

Despite the obvious risk of increasing the vulnerability against cyber threats that accompanies the adoption of high-tech solutions, both in terms of designing new and/or retrofitting existing buildings and in terms of installing new "smart" equipment in them, this can't be considered as an obstacle to endorse this modernisation trend. On the contrary, it can be considered as a challenge and an opportunity for the military domain to drive new technological solutions which can enhance the resilience of the defence infrastructure in cyber security regards.

1.5.5. Funding / Financing tools and instruments

Implementation of energy efficiency measures require careful planning and availability of financial resources, either internal, in the form of budget, or external, typically in the form of grants awarded by EU or national public agencies or loans by private and or public financing entities, to cover the typically high initial investment costs and the resources needed for an efficient management and maintenance of the installations through their life cycle so as to realise the expected energy and cost savings in time, normally with long pay-back periods. This obstructs the implementation of energy efficiency measures by the defence sector where priorities are of different nature and assigned budget lines are normally small and short-sighted, impeding the development of the necessary long-term vision, strategies and planning to this purpose.

Funding energy efficiency measures status in the defence sector[48]

In accordance with information collected from questionnaires circulated among the CF SEDSS MoD's in February 2017 (Phase I of the CF SEDSS), MoDs' budget lines are mostly (in around 67% of the cases) inadequate to cover a satisfactory level of buildings renovations. Moreover, only around 41% of the MoDs have developed some type of mechanism or process within their organisations, but not dedicated teams, to apply for external funding, mainly for grants, with only 1 MoD having the option to apply (either directly or through the central government) for a loan (**Figures 1.18-1.20**).

47. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.
48. Guidance document. CF SEDSS II Results and Recommendations for Sustainable Energy in the Defence and Security Sector. EDA, July 2019.

Figure 1.18. Budgets with respect to deep renovations of building stocks (February 2019)

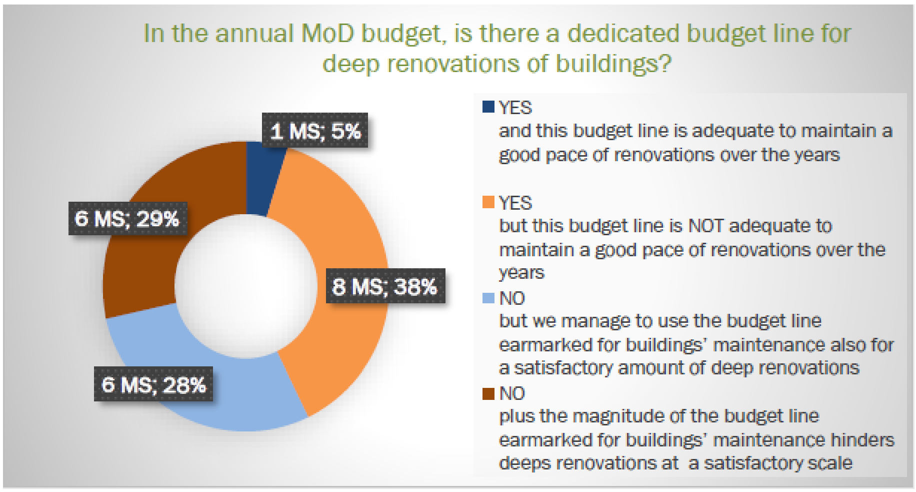


Figure 1.19. MoDs' Status on internal mechanisms to uptake external funding (February 2019)

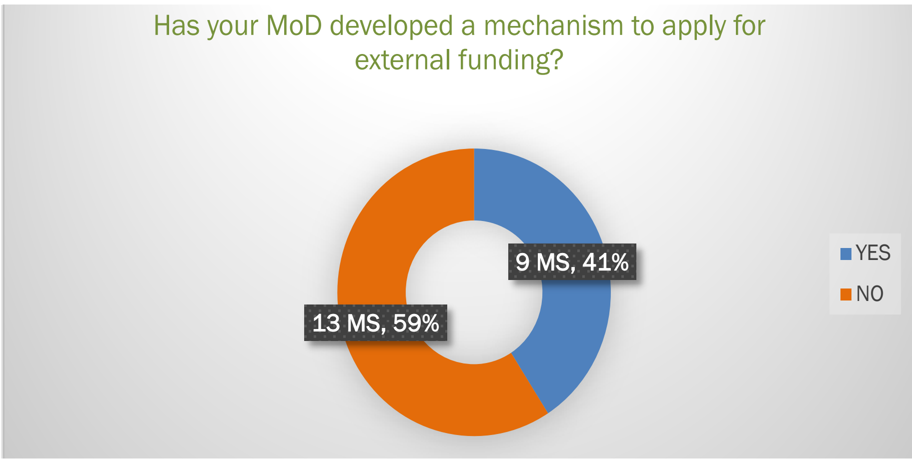
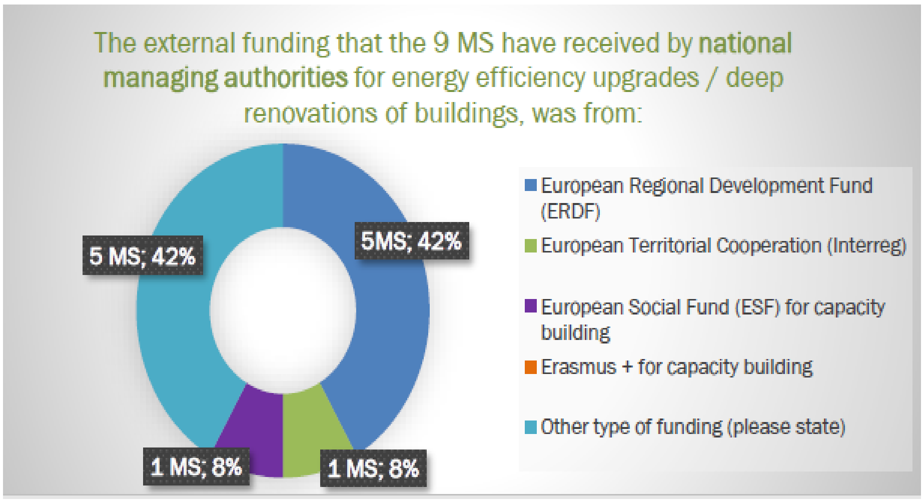


Figure 1.20. Types of external funding MoDs have received for energy efficiency upgrades (February 2019)



1.6. EU defence sector energy efficiency tools and instruments implementation scoring

The following indicators, which are demonstrated below in **Figures 1.21-1.23**, reflect a qualitative assessment of the progress achieved by the EU defence public sector in the implementation of each of the energy efficiency tools and instruments aiming at attaining energy savings described in this chapter. For the purpose of this study, we will refer to them as **D**efence **E**nergy efficiency **T**ools and implementation Indicators (DETI). The methodology and factors used to calculate these DETI have been developed for the purpose of this document from a qualitative perspective and are partly based on the available statistical data as presented in subchapters above. They are, thus, subject to slight refining adjustments and variations, which may render the DETI more accurate, based on future availability of more abundant information about the defence sector and changes to the existing legislation or development of new tools and instruments aiming at energy savings. The scoring of the DETI ranges from 1 to 10 and levels of implementation and areas to pay attention to in more or less urgent way can be easily identified by their color code, ranging from red (0 to 2,49 scoring), to yellow (2,5 to 7,49) and green (7,5 to 10). The obstacles and problems found as well as the lines of work proposed for MoDs for improvement of implementation of tools and instruments is summarised for each one of the indicators, as a basis for the subsequent development and implementation of the Defence Roadmap for Energy Efficiency and Buildings (REEB) in the next chapter.

Figure 1.21. Policy tools and instruments

POLICY TOOLS AND INSTRUMENTS.	3,3
National energy & climate plans (NECPs).	2,4
Energy efficiency and environmental strategies in defence.	4,5
Long-term buildings renovation strategies, logbooks and renovation passports.	3,8
Energy performance certificates.	5,0
Energy performance contracting.	2,1
New EU Level(s) framework and indicators.	0,0
Green Public Procurement.	4,4

Figure 1.22. Management tools and instruments

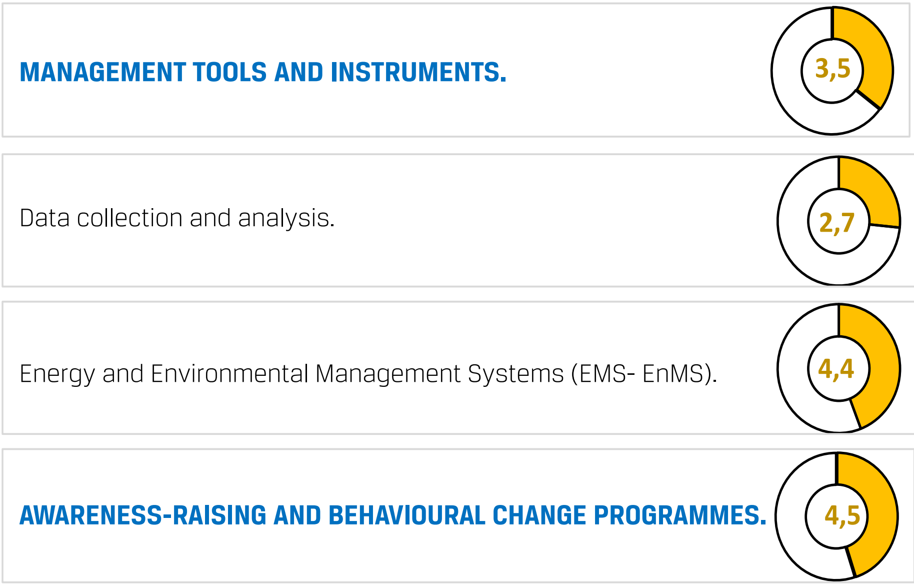
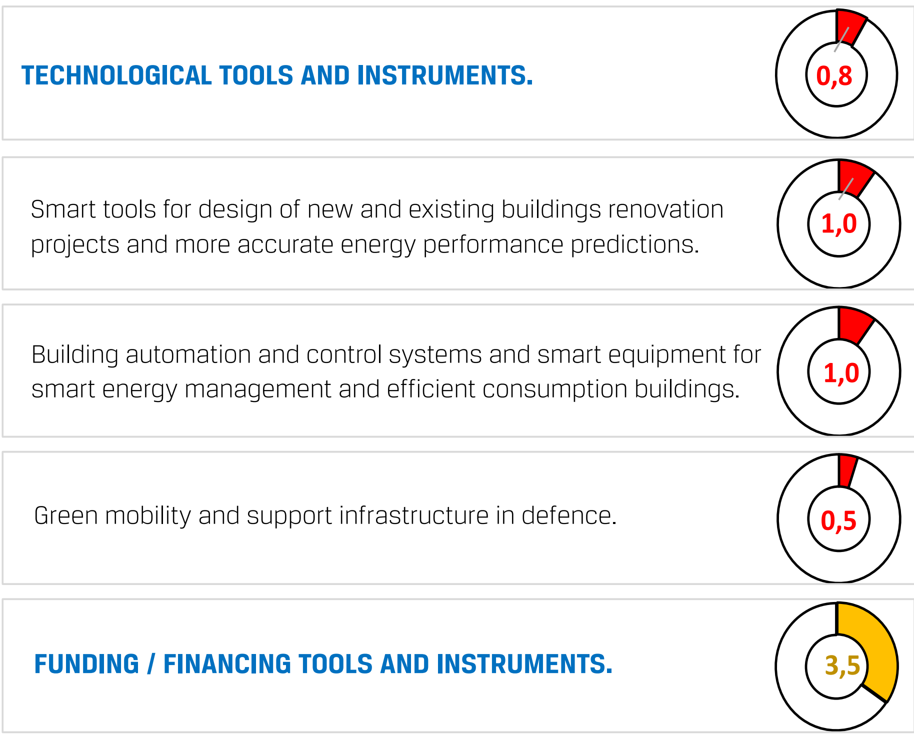


Figure 1.23. Technological and financial tools and instruments



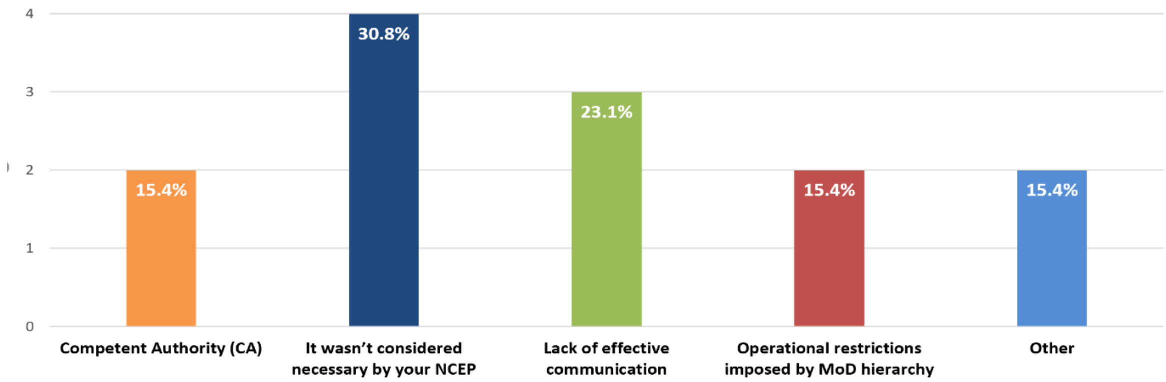
1.7. Guidance, roadmaps and recommendations

1.7.1. Defence Roadmap for Energy Efficiency and Buildings (REEB)

As specifically cited in previous chapters of the study, the EU defence sector is considered as a major infrastructure owner and energy consumer within the wider EU public domain. Therefore, it has to take (if it has not done, so far) initiatives in order to exemplarily participate and actively contribute to each EU MS **efforts to increase energy efficiency, upgrade the status of the public building stock and promote the rapidly rising technological solutions in the area of e-mobility, as long as it doesn't increase cyber and data capture risks.** As explained before (in section 5), the EED offers the main regulatory framework for that: the National Energy and Climate Plans (NECPs)[49]. Each EU MS develops this strategic plan for climate and energy issues, **setting out a detailed roadmap regarding the attainment of specific energy and climate objectives by 2030**.

Therefore, it is considered of outmost importance that the **defence ministries participate in the periodic revision of the NECP targets consultation** dialogue with their Competent Authorities in order to define their roles and specific contributions in achieving the partial operational goals beforehand. During the CF SEDSS II roundtable discussions, it was vastly recognised that this was not the case in many MS. **During the first part of Phase III**, a specific **survey** showed that this situation remains the same. Out of the 17 MS that answer the respective question, 13 of them reported that they weren't included in the consultation dialogues. The **reasons why are listed in Figure 1.24 below**. As far as the rationale for this situation is concerned, NCA's views and lack of effective communication are demonstrated as the main drivers.

Figure 1.24. Reasons for non-involvement of the MoDs in the NECP drafting process



1.7.2. Defence REEB governance policy axes

Along with the adoption of a REEBP policy in the organisations, the establishment of a tailor-made REEBP governance, laying down the appropriate structure of organisational hierarchy, practices, regulations and procedures to facilitate the type of effective decision making and management that will deliver the long-term success we are aiming for, is crucial to attain the REEBP policy vision, goals and overall objectives. However, such governance cannot possibly

49. https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en.

be designed and then implemented within our MoDs without the allocation of a multidisciplinary **Defence Energy Task Force/Project Team** dedicated to the elaboration, execution and implementation monitoring of the REEBP policy and also to the design and implementation of the REEBP governance itself. Policy, governance, personnel, and resources are all, in view of the authors, interrelated in such a manner that the failure of one will bring the failure of the whole enterprise.

Starting with the **Defence Task Force/Project Team,** and to ensure the effectiveness of this assignment, it is strongly recommended that it be comprised of an **adequate number of competent multidisciplinary personnel**, with the necessary **resources** at their disposal in terms of access to information and of availability to funding mechanisms that allows them to subcontract the conducting of specific studies and the development of mathematical or other statistical tools which would enable the quantification of necessary energy data. It is also important to ensure the **consistency and continuity of this team**, so that potential political, governmental or other administrative changes do not affect the anticipated unimpeded fulfilment of its tasks.

It is also worth mentioning that due to the fact that this team has to coordinate its actions with the NECP CA and related stakeholders, it is necessary to put in place a **cohesive process** for ensuring both the effective implementation of the policy measures included in the Defence Long-Term Renovation Strategy and the redrafting of existing measures and the drafting new ones in order to attain the objectives and maximise synergies between cross-sectoral policies.

The governance process as a whole will incorporate, also as a procedure, the development of certain **critical performance indicators** for the measures and policies and how these will contribute to the attainment of the policy priorities set out in the renovation strategy. These indicators will take into account, inter alia, the degree of implementation in relation to the initial scheduling of policies and measures, the cost-benefit ratio of energy objectives and their potential degree of interdependence and complementarity.

The development of a **single governance framework**, to monitor and assess in a cohesive manner both all the policy measures laid down in the Defence Long-Term Renovation Strategy by 2030 and the stakeholders' contribution during their implementation is a key priority. The implementation of such single governance framework will ensure **continuity of the policies and measures to be implemented and consistency of both MoD and external institutional bodies** involved in the implementation of these policies and measures.

A fundamental component of the single governance framework is developing **an integrated monitoring mechanism for the policies and measures under implementation.** This mechanism will include procedures for the continuous monitoring of both the attainment of the individual objectives and the performance and impact of each policy measure individually, based on the use of relevant critical performance indicators, that will take into account, inter alia, the degree of implementation in relation to the initial scheduling of policies and measures, the cost-benefit ratio of energy objectives and their potential degree of interdependence and complementarity.

A critical aspect of the monitoring mechanism is its capacity for assessment and redesigning of existing measures marked with lower performance levels on one hand and, on the other, promoting more intensively those marked with much higher performance levels. The continuous assessment of the policy measures under implementation is crucial for taking timely decisions about the redesign or replacement of existing policies, or the adoption of new policies that would need to be launched to prevent putting the attainment of the objectives at risk.

A similar approach and a relevant model will be **used in designing and implementing financing mechanisms and programmes.** More specifically, the ultimate objective of this framework is to utilise existing resources and mechanisms to launch the implementation of the mix of policy measures initially envisaged in the context of the Renovation Strategy or those to result from the assessment procedure through the monitoring mechanism, with particular emphasis placed on designing appropriate financing mechanisms in the new programming period 2021-2027, as well as on ensuring the optimal utilisation of other financing funds.

1.7.3. Defence REEB policies

An indicative (suggested) list of the main policies regarding energy efficiency and energy performance of buildings is the following:

- Improvement in energy efficiency of MoD's buildings in the framework of the exemplary role of public sector – Improvement of urban public space microclimate in defence installations.
- Promoting energy efficiency contracts by energy service companies.
- Promoting innovative financial instruments to ensure private capital leverage and financial sector involvement.
- Framework for the replacement of MoD's fleet of polluting passenger vehicles and other types of vehicles (preferably electric ones/ e-mobility).
- Energy efficiency improvement of defence electricity and gas infrastructures.
- Promoting measures for modernising defence water supply / sewage and irrigation infrastructures.
- Promoting efficient heating and cooling.
- Training & informing MoD's personnel on energy – efficient equipment and rational use of energy.

1.7.4. Defence REEB implementation measures

A corresponding list of the main implementation measures regarding energy efficiency and energy performance of buildings is comprised of detailed action steps, in terms of promoting specific measures for every shortfall identified in section 5 and quantified in Chapter 6 of this study. These measures, coupled together with the deriving obstacles /problems, are described in **Tables 1.1- 1.14** below:

Table 1.1. NCEPs

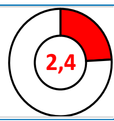
National energy & climate plans (NECPs) 	
Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Defence sector potential for contributions towards national targets not fully understood or perceived by MS energy transition Competent Authorities. • Insufficient data to support the case of defence sector contributions to national targets. • Insufficient interaction between defence sector and other national public bodies. There is a tendency to see and consider the defence sector as a standalone, complex isolated sector and keep it out of national civil sector related policies and provisions. • Insufficient participation and involvement of defence sector with national Energy Competent Authorities in the elaboration of energy policies and targets.	• Engagement with the appropriate internal and external stakeholders, establishing and reinforcing communications and relations between defence and other public sectors, especially with energy Competent Authorities, as well as industry and other relevant actors. • Promote the understanding by national central governments and national energy Competent Authorities of the defence sector's special characteristics and the integration of defence-specific provision in EU and national energy policies and strategies. Get the commitment from the appropriate levels in your hierarchy. • Justify and defend the case of defence sector contributions towards national energy savings and reduction of CO_2 emissions. • Adoption of a defence sector's proactive, rather than reactive role in the definition of EU and national energy policies and objectives. Anticipate defence needs and constraints and promote defence peculiarities inclusion in national legislation rather than wait and be forced to comply with unsuitable requirements.

Table 1.2. Energy efficiency and environmental strategies

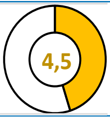
Energy efficiency and environmental strategies in defence. 	
Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Inadequate translation of the existing energy policies and strategies (aligned with defence operational capabilities policies and strategies) into action plans. • Inadequate allocation of funding and resources to execute action plans. • Disconnection with energy Competent Authorities in the elaboration of defence energy policies and strategies and thus, with national energy policies and targets. • Underestimation or inadequate understanding of energy as an operational capability enabler by the hierarchy, leading to its under prioritisation and lack of planning and commitment in the organisation.	• Promote the understanding within the organisation of energy as an operational capability enabler. Translate energy savings potential into meaningful defence indicators for defence personnel (equivalent amount of fuel saved, equivalent mileage/hours of military equipment, equivalent number of fuel supply missions avoided, equivalent number of peacekeeping missions, etc.). Get the commitment from the appropriate levels in your hierarchy. • Assess your existing situation, needs and constraints and define realistic goals and SMART objectives for critical energy performance indictors (EnPIs), in coordination and alignment with EU and national energy policies and strategies and defence specific operational policies and strategies. • Define a bespoke energy strategy and action plans for a staged implementation of the strategy, integrating mechanisms for continuous improvement and reinvestment of financial savings into new energy efficiency projects. • Allocate the necessary resources for implementation of the energy strategy. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, identify and energy "champion/leader" in the organisation to act as the organisation energy manager and provide this role with the right level of decision making, authority, responsibilities and resources).

Table 1.3. Long-term building renovation strategies, logbooks and renovation passports

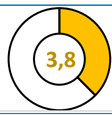
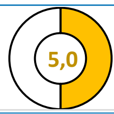
Long-term buildings renovation strategies, logbooks and renovation passports.	
Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Inadequate record and update of building stock inventory information, of buildings energy consumption and performance and of renovations and energy efficiency measures adopted. • Planning for buildings renovation and energy performance improvements takes place only on a short/medium term horizon. • Energy efficiency is not among defence sector's highest priorities and thus funding and resources are not properly allocated.	• Span your organisations understanding of the importance of the energy baseline information as one of the pillars enabling energy performance. Get the commitment from the appropriate levels in your hierarchy. • Improve the detail and quality of information on your building stock inventory and keep it updated. Develop procedures and instructions to assure information is updated as needed and recorded in a structured way through building "renovation logbooks" or "renovation passports". • Map and categorise your buildings on the basis of their actual energy performance, energy saving potentials and investment required to achieve those energy saving potentials. • Assess your existing situation, needs and constraints and define realistic goals and SMART objectives for buildings renovations into NZEB/Net-Zero standards, in line with EU and national energy policies requirements. • Explore availability and assess feasibility of non-intrusive and easily mountable Commercial of the Shelf (COTS) solutions for deep renovations to NZEB/Net-Zero standards (consisting normally of customised off-site manufactured prefabricated modules for the façade and roof, plug-in technical building systems and roof solar panels). • Define a bespoke long-term and staged building renovation strategy and action plans, prioritising and focusing on those where the impact and cost-benefit are higher, and allocating the necessary resources for implementation of the strategy. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.4. Energy performance certificates

Energy performance certificates.



Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Perception that the defence sector is not obligated to comply with energy performance certification provisions. • Perception that raising the performance of some buildings may not be cost effective and of commercial added value to defence buildings. • Lack of proper energy consumption benchmarks for defence buildings. • Perception that existing energy performance certificates do not have into account the full concept of sustainability and circularity of the building throughout its whole life cycle. • Difficulties in predicting the real energy performance of the building during its operational life.	• Span your organisations understanding of an energy performance certification plan as a tool to help achieve energy and cost savings, rather than as a goal on its own or a blunt and not very useful legislative requirement. Get the commitment from the appropriate levels in your hierarchy. • Engage with national Competent Authorities and other relevant stakeholders to acquire knowledge and guidance on how to implement a comprehensive and meaningful energy performance certification strategy that is at the same time aligned with your organisations policies, goals and objectives. • Develop a bespoke comprehensive energy performance certification strategy and plans that serve as a starting point for development of a long-term staged building renovation strategy. Identify suitable sites for implementation of pilot-scale projects for demonstration of energy performance certification programmes feasibility and benefits. Monitor the progress through the EnPIs and analyse results. • Explore the use of BIM tools to improve estimations of existing buildings before and after the renovation and help decide on optimal renovation solutions. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.5. Energy performance contracting

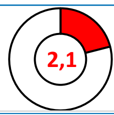
Energy performance contracting.	
Problems/Obstacles preventing implementation: • Limited knowledge and experience in the drafting of contract clauses and in the adequate definition of performance indicators. • Difficulties in defining adequate performance measurement, monitoring and verification procedures throughout the lifecycle of the contract. • Obstacles imposed by national policies and accounting rules. • Lack of, or inadequate baseline building stock and energy consumption data. • Uncertainties on the future uses and occupation of buildings and land in the long term.	**Lines of work for improvement of implementation:** • Span your organisations understanding of energy performance contracting and ESCOs as a mechanism to help facilitate and de-risk investments through externalisation of services, and measurement and verification of indicators and goals. Get the commitment from the appropriate levels in your hierarchy. • Engage with national Competent Authorities and other relevant stakeholders to acquire knowledge and guidance on how to implement Energy Performance Contracting mechanisms and procedures in your organisation and help you overcome accounting and legal difficulties. • Engage with ESCO's and explore different EPC options that may match and suit better with your organisational culture, goals and objectives in terms of financial risk. • Assess your existing situation and future short, medium and long term needs. • Design a bespoke strategy and plan for implementation of energy performance contracting and identify suitable sites for implementation of pilot-scale projects for demonstration of EPC feasibility and benefits. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.6. New EU Level(s) framework and indicators

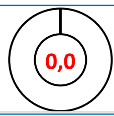
New EU Level(s) framework and indicators.	
Problems/Obstacles preventing implementation: • Novelty of framework. Perceived as too ambitious to achieve in the short term when existing and better known environmental and energy efficiency legislative packages are still to be fully implemented.	**Lines of work for improvement of implementation:** • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.7. Green public procurement

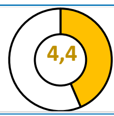
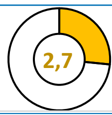
Green Public Procurement	
Problems/Obstacles preventing implementation: • Excessive costs of energy efficient equipment and certified service providers. • Predominant criteria within organisations of lower purchase cost against lower life-cycle cost. • Lack of standardised GPP requirements defined by the organisations' procurement departments.	**Lines of work for improvement of implementation:** • Span your organisations understanding of Green Public Procurement as a philosophy to help integrate standardised provisions for procurement of optimal life cycle costing and energy and environmental solutions for products and services. Get the commitment from the appropriate levels in your hierarchy. • Engage with national Competent Authorities and other relevant stakeholders to acquire knowledge and guidance on how to implement Green Public Procurement mechanisms and procedures in your organisation and help you overcome legal difficulties. • Consult existing Green Public Procurement policies, handbooks and standards, explore different approaches to procurement (centralised vs decentralised) and develop a bespoke procurement policy, strategy and handbook specific to your organisation. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.8. Data collection and analysis

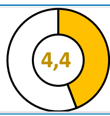
Data collection and analysis.



Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Energy consumption metering is most of the times done at base level, rather than at building level, rendering it difficult to identify particular energy saving opportunities. • The type and granularity of collected data, the use of smart meters and the level of record keeping is normally not optimal for a comprehensive analysis. • Energy performance indicators (EnPIs) have not been adequately and widely developed and used. Normalisation of EnPIs is done without taking into account all relevant variables. • Absence of defence-specific energy consumption benchmarks that represent the specific consumption characteristics of defence operational buildings. • Information cybersecurity risks.	• Span your organisations understanding of the criticality of collecting and analysing energy consumption data as a baseline to achieve energy savings through energy efficiency strategies and plans. Get the commitment from the appropriate levels in your hierarchy. • Explore the availability of non-intrusive COTS solutions for smart automated data collection and analysis devices that allow to measure energy consumption of different types of equipment using algorithms to disaggregate electrical signatures. • Justify the business case and develop a staged strategy for deployment of smart meters and/or smart single algorithmic devices at building level in the context of secure cloud-based platforms. • Identify and monitor significant energy uses, and define adequate EnPIs. Monitor the progress through the EnPIs and analyse results. • Obtain/confirm energy consumption benchmarks and investigate on affecting factors and variables in order to define and develop relevant meaningful EnPI. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.9. Energy and environmental management systems (EnMS-EMS)

Energy and Environmental Management Systems (EMS- EnMS).



Problems/Obstacles preventing implementation:	Lines of work for improvement of implementation:
• The scope and complexity of EnEM/EMS, as well as the resources required to achieve their implementation and maintenance in a comprehensive manner to the whole organisation are too wide and costly.	• Span your organisations understanding of the EnMS/EMS as central tools to assist in increasing and continuous improvement of the energy performance. Get the commitment from the appropriate levels in your hierarchy. • Assess energy consumption baselines, identify no/low cost actions that can boost the initial steps of implementation of an EnMS/EMS and define adequate normalised EnPIs. • Integrate EnEM/EMS approach and procedures into the organisation's culture, energy policies, strategies and procedures. • Develop a strategy and action plan for a staged implementation of an EnEM/EMS, or for the enlargement of the scope of the existing EnEM/EMS in place, and their continuous improvement across the whole organisation. Identify suitable sites for implementation of pilot-scale projects for demonstration of EnEM/EMS feasibility and benefits. Monitor the progress through the EnPIs and analyse results. • Monitor the progress through the EnPIs and analyse results. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.10. Awareness raising and behavioural change programmes

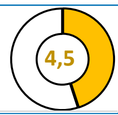
Awareness-raising and behavioural change programmes 	
Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Comprehensive behavioural change programmes have yet to be implemented and, consequently, there is no information available on their potential impact. • Difficulties to monitor, measure and control human behavioural variables (inexact by nature) and then to correlate them with the results.	• Span your organisations understanding of the importance of human factors as enablers for improvement of the energy performance. Get the commitment from the appropriate levels in your hierarchy. • Assess your organisations' personality profiles' specific features across the hierarchy in terms of education/background, ultimate motivations, behavioural patterns, level of responsibilities and authority, and opportunities to act, and design and adapt your awareness raisings and/or behavioural change programmes messages and lines of actions to each particular personality profile. Translate energy savings potential into meaningful defence indicators for each personality profile (cost savings, equivalent amount of fuel saved, equivalent mileage/hours of military equipment, equivalent number of fuel supply missions avoided, equivalent number of peacekeeping missions, equivalent number of lives saved, etc.). • Develop a strategy and action plan for a staged implementation of awareness campaigns and behavioural change programmes. Identify suitable sites for implementation of pilot-scale projects for demonstration of awareness campaigns and behavioural change programmes feasibility and benefits. Monitor the progress through the EnPIs and analyse results. • Include energy efficiency awareness and motivational aspects right from the start of personnel's career paths through the syllabus in military academies and the basic training of recruits/conscripts. • Establish a mechanism of rewarding the units and individuals on exemplary performance for using efficiently the energy resources. • Expand your campaigns and programmes to subcontractors whenever possible. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.).

Table 1.11. Smart tools for design of new and existing buildings renovation projects and more accurate energy performance predictions

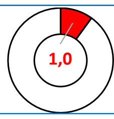
Smart tools for design of new and existing buildings renovation projects and more accurate energy performance predictions. 	
Problems/Obstacles preventing implementation: • Lengthy and effort demanding process required for migration from classical CAD tools towards BIM tools and capacities. • Trained personnel and investment required are normally not available in the defence organisations. • Cyber and data breach / capture risks.	**Lines of work for improvement of implementation:** • Span your organisations understanding of the importance of BIM tools as enablers for improvement of the energy performance. Get the commitment from the appropriate levels in your hierarchy. • Develop a strategy and action plan for a staged migration from classical design tools to BIM tools. Monitor the progress and analyse results. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.). • Create appropriate protection solutions that would provide adequate resilience against cyber security / data breach-capture risks.

Table 1.12. Building automation control systems and smart equipment for smart energy management and efficient consumption buildings

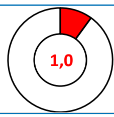
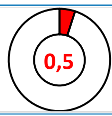
Building automation and control systems and smart equipment for smart energy management and efficient consumption buildings. 	
Problems/Obstacles preventing implementation: • Inadequate/Lack of data integrated smart metering, BACS and management systems installed at site level covering a number of buildings and facilities facilitating active energy management. • Absence of sound quantitative data to research on the impact that installation of BACS may have in energy savings. • Inadequate/Lack of a proper building stock inventory and an energy consumption baseline that is suitable for comparison purposes. • Impact on the resilience of the MoDs' buildings and sites due to the risk of failure or malfunctioning of smart devices. • Cyber and data breach / capture risks.	**Lines of work for improvement of implementation:** • Span your organisations understanding of the importance of BACS as enablers for improvement of the energy performance. Get the commitment from the appropriate levels in your hierarchy. • Explore the availability of COTS solutions for BACS that allow automating and controlling the technical building systems to provide optimal comfort conditions for users while maintaining optimal levels of energy efficiency. • Develop a strategy and action plan for a staged deployment of BACS across the organisation. Identify suitable sites for implementation of pilot-scale projects for demonstration of BACS feasibility and benefits. Monitor the progress through the EnPIs and analyse results. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.). • Create appropriate protection solutions that would provide adequate resilience against cyber security / data breach-capture risks.

Table 1.13. Green mobility and support infrastructure in defence

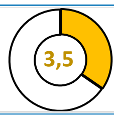
Green mobility and support infrastructure in defence.



Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Budget constraints, lack of legal framework and of financial incentives for public authorities to transform their vehicle fleets. • High number and mixed types and sizes of vehicles with different ages and utilisation and using both diesel and petrol fuels. • Lack of quantitative more detailed information to justify the case and properly assess their potential. • Limited political direction. • The deployment of recharging points capable of smart charging can increase cyber and data breach / capture risks and have impacts on the electrical networks of the sites and thus disrupt the MoDs' buildings and sites' resilience.	• Span your organisations understanding of the importance of low/zero emission vehicle fleets in their contribution towards your national environmental targets, reduction of costs and increased mobility in urban areas. Get the commitment from the appropriate levels in your hierarchy. • Study your vehicles fleets characteristics, usage, operational costs and emissions and investigate on available COTS low/zero emission solutions (vehicles, support infrastructure and management system) suitable to your needs. • Explore new procurement and utilisation more efficient models, such as leasing or combined leasing and ownership, as well as sharing of vehicles with other public/private bodies. • Evaluate your future needs and existing and future environmental constraints to design a bespoke strategy and action plan for a bespoke staged replacement/conversion of your actual vehicle fleet into a low/zero emission vehicle fleet matching your needs and constraints and in compliance with legislation. Identify suitable sites for implementation of pilot-scale projects for demonstration of technological solution feasibility and benefits. Monitor the progress and analyse results. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.). • Create appropriate protection solutions that would provide adequate resilience against cyber security / data breach-capture risks.

Table 1.14. Financing tools and instruments

Funding / financing tools and instruments.



Problems/Obstacles preventing implementation:	**Lines of work for improvement of implementation:**
• Budget lines for energy efficiency measures are mostly inadequate to cover a satisfactory level of performance improvements. • Inadequate/Lack of mechanisms and dedicated teams within their organisations to seek and apply for suitable external funding.	• Span your organisations understanding of the importance of finding additional external funding for implementation of energy efficiency projects and the resources and effort required. Get the commitment from the appropriate levels in your hierarchy. • Build and/or develop capacity in the organisation (train personnel, create dedicated teams, etc.). • Evaluate your organisation's needs and find suitable external lines of financing for their implementation. • Develop systematic procedures for elaborating funding applications.

Despite the obvious requirement to specify the analysis of each line of work to address tailor-made solutions for every problem, it is worth noticing that all relevant lines of measures follow a general plan, the steps of which are summarised below:

- Engage the MoD stakeholders with the national Competent Authorities (CAs) and establish an effective channel of communication.
- Promote the defence related specificities for each energy efficiency and building performance element to the CAs.
- Explore existing technological and/or managerial solutions and provide suitable measures identification with corresponding budgetary line proposals.
- Promote the outcomes of the discussions with NCAs to internal hierarchy. Foster capacity building and span of understanding of leaders, for obtaining consensus.
- Develop appropriate implementation strategies and consequent action plans.
- Inform, educate and train MoD personnel involved in the aforementioned processes.

Conclusions

There is a worldwide recognition of the massive importance of the climate change related issues and phenomena have on global living conditions and consequently to every economic activity associated including security. The energy aspect, with special regards to the efficient operation of the building sector, represents a significant portion of GHG emissions and energy consumption, thus it vastly affects climate change impact. Hence, the involved EU institutions (European Commission, Council of the EU and European Parliament) have already set a whole nexus of ambitious goals to tackle climate change and environmental degradation effects, with specific focus on rendering the European Union area the first carbon-neutral geographical area, by 2050. This nexus is being legislatively transformed under the flagship programme of the "European Green Deal".

This new overarching endeavour has subsequently set a series of legislation initiatives in terms of Council Decisions, EU Regulations and Directives, action plans, packages, etc., with dedicated reference to the energy efficiency and buildings performance domain. These initiatives have one of many common things, which is the exemplary role that the EU public buildings domain is called to play. Therefore, the inevitably massive involvement of military building's stock in becoming pioneers, to achieve the respective energy efficiency and energy consumption reduction targets, is of outmost importance.

Considering this momentum, it would have been expected that the defence would play a significant consultation role during the drafting of the various pieces of legislation (at the national and EU level) as well as during the implementation of the provisioned action tools. Although, this is partially the case at the EU level, considering that DG ENER, CINEA, EDA, and EEAS have undertaken specific coordination tasks towards this aspiration, the situation is not as valid at the MoD's level where more engagement is required. Notwithstanding the fact that energy efficiency and buildings performance are considered very or fairly (at worst case) important with regards to operational and non-operational defence activities, the military domain has not been an active stakeholder when it comes to consulting or implementing specific policy instruments and tools, such as the National Energy and Climate Plans or the Long-Term Renovation Strategies in the public building sector. Lack of effective communication with National Competent Authorities and consequently low visibility and comprehension of the defence role within this concept, are identified as the main reasons. In addition to this setback, there is notably a wide insufficient ability, which hinders the MoDs from having an effective access to both national and EU funding, so that national defence renovation programmes (of either small or medium-term duration) continue to lack appropriate financial support.

Another significant associated challenge which is identified through this study, has to do with the lack of adequate metering infrastructure (such as individual metering devices per each building), a fact that stresses the lack of effective data collection and analysis and has a cascade negative effect in establishing benchmarks for the defence building stock. Although, a fair (but invalidated) assumption is that non-operational buildings (such as offices, hospital, residents, etc.) which are situated within barracks "behave in similar energy terms as the corresponding civilian buildings do", there is not sufficient back-up evidence for purely operational ones. A very recent advice of the Legal Service of the European Commission (CINEA) has provided the defence authorities with the ability to address (individually or collectively) the problem by seeking EU funding, under the concrete condition that this request is solely related to the contribution of the military domain to either national or EU efforts for reaching decarbonisation goals and not affiliated to the enhancement of their operational capabilities[50]. Therefore, there is now a clear opportunity for both EU institutions and individual MS to launch dedicated attempts for establishing such defence energy benchmarks and indicators.

50. This information is limited to the EU MODs. In case of publication either the Commission needs to confirm that can be public available or it will be removed from the text.

A positive sign is the fact that in nearly every MS MoD, there are in place education, training and raising awareness processes and programmes, which are addressed to the Armed Forces' personnel. These processes are either supported by specific classes, lectures, training modules or even special animation films with short but very clear and distinct messages to motivate people. Hence, the human factor is a fairly significant driver towards mitigating energy consumption and applying energy efficient solutions in the building's domain. Nevertheless, there is still a lot to be done in this area, because it is usually difficult to quantify results, to articulate benefits and transpose them into monetary value and subsequently to persuade the highest levels of military authorities to increase the allocated visibility to energy matters.

The aforementioned lack of metering information and data collection – analytical process is the main reason why smart metering and their functionalities with regards to both technical building management and changing occupants energy behaviour have so far little positive impact on meeting the energy targets of the MoDs. In addition, other similar management tools like Energy Performance Certificates and Energy Performance Contracting have not achieved a wide application potential in the defence sector. Consequently, a lot needs to be done in these fields in order to render Energy Performance certificates and contracting useful tools towards facilitating effective defence energy renovation initiatives.

On the contrary, one of the most successful management tools in the defence energy sector is the implementation of Environmental Management Systems with notable reference the ISO 14001 and more recently the Energy Management System according to the respective ISO 50001. National initiatives are enhanced by the overarching successful launching and application of the DEMC, which corresponds to a combined training and mentoring programme of dedicated technical personal of the Armed Forces as Energy Managers, having led to significant energy consumption reduction (by more than 5 million KWh) of more than 50 different participating defence installations.

Green Public Procurement also represents a significant management tool which aims at incorporating energy efficiency principles and the life-cycle cost (LCC) assessment approach in the defence procurement procedures covering the areas of energy services, materials and the execution of works (including energy renovation ones). Based on the feedback acquired both through this study and similar inquiries made in previous Phases of the Consultation Forum, it seems that there isn't in place, so far, a substantial number of the MoDs which is implementing a GPP Policy and existing initiatives lack the application of the LCC approach in their policies. Specific analysis will be given through another dedicated contracting study executed in the framework of the CF SEDSS III WG1.

The capacity of technological tools and instruments, such as last generation design tools to better and more accurately simulate the performance of different scenarios, or last generation BACS to automate the monitoring and optimal control of technical building systems on the basis of users' comfort requirements and optimal (minimum) energy consumption, is still to be fully exploited through their organisational deployment and implementation. Their potential to improve other aspects of energy performance such as the more rapid and effective attainment of the whole building stock energy performance certification, or the assistance to generate multiple design solutions configurations and facilitate optimal decision making, through the automation and application of artificial intelligence to menial tasks is of paramount importance to achieve significant results and energy savings while reducing the effort and resources required for such endeavour. The defence sector should embrace the opportunities offered from the implementation of smart technology in their facilities, as long as this trend is accompanied by the endorsement of suitable protection solutions against cyber threats and data breach/capture risks in the framework of the wider effort to improve their energy performance and contributions towards the national and EU objectives in the medium and long term.

The "E- (or Green) mobility Concept" in defence is another area of increased energy efficiency interest, for which more detailed analysis should be addressed. So far, the limited information acquired (for the scope of this study), demonstrates that almost half of the MoDs have not put in place a gradual phase–out programme of existing combustion vehicle fleets. The main reasons for this shortfall identified, are related to the lack of energy data, which would sustain in efficient terms the success of a potential phase-out attempt, and the lack of economic evidence to support a quick payback period of the relative programme. Other notable reasons refer to the complexity of defence procurement processes and difficulties of the defence sector to access national funding tools offered for this reason.

In overall terms, the limited involvement of the defence sector in national legislative, managerial and technological energy efficiency and building performance tools and consequently a limited access to national and EU funding opportunities have led to the conclusion that such existing schemes (notably speaking about EED, EPBD, GPP, NECPs, LTRS and EPCs), have low or average impact on defence. The upcoming adoption of revised energy efficiency targets stemming from the implementation of the Renovation Wave (with the strategic aim to double the rate of the annual renovation rate of public buildings) would inevitably affect vastly also the defence community.

Therefore, the adoption of a defence tailor-made Roadmap for addressing this challenge should be a top national priority of the defence domain. Main milestones of this roadmap are referring to the active involvement of MoDs in implementing NECP goals, the establishment of effective Long-Term Renovation Strategies, the promotion of the massive application of existing and emerging technological solutions in these strategies whilst addressing appropriately the cyber risks, the adoption of GPP principles and guidelines to their acquisition procedures, the conduct of suitable supporting evidence for applying E-mobility programmes of the defence conventional (combustion) fleet, the establishment of permanent mechanisms which ensure effective management of energy and climate-related considerations and MoDs access to national and EU funding schemes, the application of suitable energy efficiency policy instruments such as Energy Performance Contracting and Energy Performance Certificates and the continuing application of adequate training and educative programmes of the Armed Forces' personnel.

Last but not least, the study encompasses some specific recommendations, at EU level, for certain Articles as well as some more generic provisions of both Energy Efficiency Directive (EED) and Energy Performance of Buildings Directive (EPBD). They mainly refer to the following elements: the **creation of legislative amendments** that allow a smoother **implementation** of both EED and EPBD's **policy tools and instruments** in the EU public/defence sector (with the ESCO tool as the primary indicative example), the **promotion of defence** as a **key stakeholder** of EED's provision about **NECP** periodical strategic amendments, the creation of relevant benchmarks and indicators for the military operational buildings and the inclusion of a provision in related Articles of the EED that **would allow the use of suitable KPIs and thus quantify the achieved improvement of energy efficiency through capacity building/education and training programmes**. These recommendations aim to pave the way for a more effective involvement of defence in the implementation of energy efficiency and building performance measures. They also can be utilised, as part of a larger scale proposal of EDA to the EU related Institutes (DG ENER, CINEA, etc.) for the future revisions or amendments of both the EED and EPBD, in the framework of the Renovation Wave flagship policy endeavour, and in the framework of the application of respective provisions included in the EU Climate Change and Defence Roadmap and in the "Fit for 55 Package".

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2. Green Public Procurement (GPP) options in the EU defence sector

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Abstract

This report analyses the status quo of green public procurement (GPP) implementation by defence sector organisations in Europe. Drawing upon research carried out under the auspices of the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS), it identifies the key challenges and opportunities for GPP. The broader context provided by the European Union (EU) and national legislation on energy, climate and circular economy is presented. The risks attached to non-action by defence sector organisations is highlighted, and specific recommendations are made for actions to be taken at the strategic, operational and tactical levels to successfully implement GPP.

Note on Changes to Relevant EU Legislation: Renewable Energy Directive and Energy Efficiency Directive

This report was finalised in February 2022, however changes to EU legislation which are relevant to the content of the report were adopted in 2023. Of greatest significance are the adoption of the following directives:

- Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency (revised EED); and
- Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 as regards the promotion of energy from renewable sources (revised RED)

Provisional agreement between the European Parliament and Council on the revised Energy Performance of Buildings Directive (EPBD) was reached in December 2023, with the Directive expected to be formally adopted in the first quarter of 2024.
While it has not been possible to amend all sections of this report to reflect the new legislation, the most relevant changes are noted in Section 2.4.

Executive summary

The defence sector in Europe spends some €44 billion annually on research, development and procurement of equipment, accounting for over 22% of total defence expenditure[51]. In order to deliver against their energy and climate goals, defence sector organisations need to ensure that this spend is allocated to actual sustainable products and services – not just those with the lowest purchase price or offered by familiar contractors. Green Public Procurement (GPP) offers the opportunity both to address the environmental impact of purchases and to boost resilience in supply chains by ensuring sustainable practices in production and consumption of goods, services and works.

This study places GPP within the rapidly evolving policy and legislative context at the EU level, including the European Green Deal/Fit for 55 legislative package and the Circular Economy Action Plan. It examines the status quo of GPP amongst defence sector purchasers in Europe, drawing both on published resources and questionnaires circulated to ministries of defence participating in Phase III of the CF SEDSS. The current gaps in application and challenges for greater defence sector implementation of GPP are identified, and concrete measures proposed at the strategic, operational and tactical levels to increase take-up.

51. EDA (2021) Defence Data 2019-20: Key findings and analysis, p 6. The total value of defence sector procurement, including services and works, is substantially higher.

The challenges and opportunities for GPP in the defence sector are analysed, and solutions proposed based on the experience of the broader public sector in implementing GPP successfully. A more detailed analysis of the available GPP criteria and tools is provided for three key categories:

- Buildings.
- ICT products and services (including data centres).
- Heating and cooling equipment (including on-site renewable energy generation).

The key challenges currently limiting uptake of GPP in the defence sector include: a lack of knowledge/understanding of the environmental impacts of procurement; lack of good practice examples from the defence sector; concerns about the impact on cost or operational performance of green products and services; and the need for specific skills to evaluate and compare bids based on environmental criteria. Some respondents to the survey indicated that mandating GPP in legislation would be the best way forward. However, simply making GPP mandatory without putting in place the necessary skills and structures to manage it effectively is unlikely to achieve the desired outcomes.

The report recommends a strategy with six strands to successfully implement GPP in the defence sector:

- **Strand 0:** Adoption by MoDs of a GPP policy, reflecting energy and climate commitments.
- **Strand 1:** Setting priorities and targets for GPP; monitoring and evaluation.
- **Strand 2:** Needs assessment (internal) and market engagement (external) for GPP.
- **Strand 3:** Pilot and demonstration projects for GPP in the defence sector.
- **Strand 4:** Upskilling of defence sector procurement staff to implement GPP.
- **Strand 5:** Adoption of common GPP criteria and tools by MoDs across the EU.

Each of these strands involves activities which have been closely associated with the success of GPP in the broader public sector. The report concludes by highlighting the opportunities linked to GPP implementation in the defence sector as well as the risks associated with failure to act.

2.1. Introduction

2.1.1. Introduction to the problem

Green Public Procurement (GPP) is defined as a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured[52]. In addition to helping governments to achieve climate, energy and other environmental goals, GPP can send a strong signal to the market to develop more sustainable products and services, given the significant value of public procurement. It is often pursued as part of wider policies on strategic procurement – which may target innovation, social responsibility and other objectives.

52. European Commission COM (2008) 400 Public Procurement for a Better Environment.

While the benefits of GPP are well documented[53] its application remains uneven across the EU. GPP is currently voluntary for most defence sector purchasers in Europe, in most areas of spend[54]. As set out in Section 3, the take-up of GPP varies considerably across the EU-27 MoDs, both in terms of its breadth (i.e., the proportion of spend or tenders which include green criteria) and its depth (i.e., the ambition level/comprehensiveness of green criteria, monitoring, and the results obtained). Under the European Green Deal, proposals have been made by the European Commission to make GPP mandatory in a number of areas, for example in the procurement of batteries[55] or energy-using products[56].

For the **defence sector**, there are **several advantages to implementing GPP** on a voluntary basis in advance of (or outside of) EU or national legislation mandating it. The first advantage is in terms of realising environmental benefits, including energy and emissions savings, at an **earlier rather than later date**. The second advantage is in establishing capacity, knowledge and good practice to **ensure that the operational transition to GPP is smooth and to forecast any impacts on cost and performance**. The third advantage is in terms of **shaping supply markets** to provide state-of-the-art sustainable goods and services which meet the specific needs of the defence sector, meaning defence purchasers can be lead customers for environmental innovation rather than having to accept products or services designed without taking their needs into account.

2.1.2. Objectives of the study

This study analyses the status quo of GPP amongst defence sector purchasers in Europe, the current gaps in its application, and proposes concrete measures at the strategic, operational and tactical levels to increase take-up. It places GPP within the rapidly evolving policy and legislative context at EU level, including the European Green Deal[57]/ Fit for 55 legislative package[58] and the Circular Economy Action Plan[59]. Specifically, this study:

- Demonstrates how GPP contributes to the achievement of defence environmental policy goals relating to climate change adaptation and use of energy resources.
- Provides a profile of existing green procurement initiatives in the defence sector, drawing upon information submitted by MoDs participating in the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS) and other sources.
- Identifies gaps and potential obstacles and barriers to harmonised implementation of GPP in the defence sector.
- Provides an assessment of the main GPP criteria/techniques relevant to three procurement categories with a high energy and climate impact (building design and construction, ICT services, and heating and cooling equipment).
- Proposes a strategy to increase take-up of GPP in the defence sector and recommends specific actions at the strategic, operational and tactical levels.

2.1.3. Methodology

This study draws upon qualitative and quantitative methods to establish the current status of GPP amongst defence sector purchasers in the EU. As a first step, analysis of data published on Tenders Electronic Daily (TED) over a two-year period was carried out, to identify the bodies responsible for defence sector procurement in each Member State. This

53. For a summary of the environmental and economic benefits of GPP see https://ec.europa.eu/environment/gpp/benefits_en.htm.
54. The EU Procurement Directives do not mandate the inclusion of environmental considerations, outside of a limited obligation for contractors to comply with applicable environmental legislation. However, other EU legislation does create mandatory GPP obligations when purchasing specific products or services, e.g. energy-using products in accordance with the Energy Efficiency Directive. See Section 2 for further discussion.
55. COM (2020) 798 Proposal for regulation concerning batteries and waste batteries.
56. COM (2021) 558 Proposal for a Directive on energy efficiency (recast).
57. COM (2019) 640 The European Green Deal.
58. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.
59. COM (2020) 98 A new Circular Economy Action Plan for a cleaner and more competitive Europe.

was done in order to establish the target audience for any policy or support measures targeting GPP in the defence sector. A questionnaire focusing on current levels of GPP, barriers/challenges and support needs was issued to all MoDs participating in Phase III of the CF SEDSS, the results of which are presented in Section 3.

Further evidence regarding current levels of GPP implementation in the defence sector was collected from previous questionnaires issued to CF SEDSS participants and from a review of published case studies and other materials documenting GPP application in the defence sector. Based on these sources, an assessment of the current status of GPP implementation in the defence sector in the EU-27 is made, with attention drawn to both to the areas where progress has been made and the challenges facing many defence sector organisations.

Section 4 presents a more in-depth analysis of the barriers and opportunities for GPP in the defence sector, with a particular focus on risk management related to energy, climate and security of supply. The synergies/connections between GPP and other policies linked to innovation, climate change and energy are also highlighted. Section 5 proposes solutions to address the identified barriers and opportunities, drawing upon available resources at EU level, examples of successful implementation at national/regional level, and the need for alignment with forthcoming EU legislation in the energy domain in particular. Section 6 presents specific recommendations for actions to boost the uptake of GPP amongst defence sector purchasers, and the support structures that will be needed. The study concludes by highlighting the need to act quickly to widen and deepen GPP in the European defence sector, to avoid the costs and risks linked to late adoption.

2.2. Context

2.2.1. EU policy and legislative context for GPP

GPP has been supported at EU level since 2008, with the European Commission (Directorate General-DG Environment) providing policy coordination and producing guidance[60]. Common EU GPP criteria have been developed which currently cover 20 product and service groups[61]. The development of the criteria is led by the Commission's Joint Research Centre (JRC) in Seville, with input from the GPP Advisory Group comprising representatives from all Member States plus five representatives of other stakeholders (i.e. civil society, industry, SMEs, public procurement and local authority). The development process is open, with all interested stakeholders invited to comment on the draft criteria. Due to the rapid evolution in product standards, GPP criteria must be regularly updated to ensure they reflect the current state of the art and most recent legislation.

The EU GPP criteria are based on life-cycle assessment (LCA) studies which quantify and compare the impact of different products and services throughout their life-cycle, including impacts on biodiversity, air, water and soil pollution as well as greenhouse gas emissions. They address not only the use phase of a product or service (e.g., how much energy a building or computer consumes in use) but also the embodied impacts linked to extraction, manufacturing and other production/distribution processes, and the end-of-life stage (e.g., whether a product can be repaired, reused, recycled, etc.) The EU GPP criteria also reflect applicable EU legislation for each product/service category, for example the REACH legislation on safe chemicals or Ecodesign regulations. The criteria are translated into all official EU languages. The EU GPP criteria are voluntary for public sector bodies to apply, but in some MS mandatory national criteria have been adopted which are based on the EU criteria[62].

60. All GPP resources are available at https://ec.europa.eu/environment/gpp , including the 2016 edition of the Buying Green Handbook and a large collection of GPP Good Practice examples.
61. The criteria can be accessed at https://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm.
62. This is the case for example in Croatia, Estonia, Finland, Greece, Italy, Slovakia and Slovenia.

In 2014, new versions of the EU Procurement Directives were adopted, covering the public and utility sectors[63], as well as concession contracts[64]. The revision of the Directives focused, inter alia, on clarifying the ways in which environmental, social and innovation objectives can be addressed in the award of contracts. The use of non-price criteria in the award of contracts, including environmental criteria, is fully supported in the Directives, as is the use of environmental specifications, selection criteria, labels, management systems and contract performance clauses[65]. Member States are required to ensure that in the performance of public contracts, economic operators (including both contractors and subcontractors) comply with applicable obligations in the fields of environmental, social and labour law[66]. While the Defence Sector Procurement Directive was not updated in 2014, all of the possibilities for including environmental criteria which are available under the Public Sector Directive are also possible in relation to the procurement of arms and associated works or services[67].

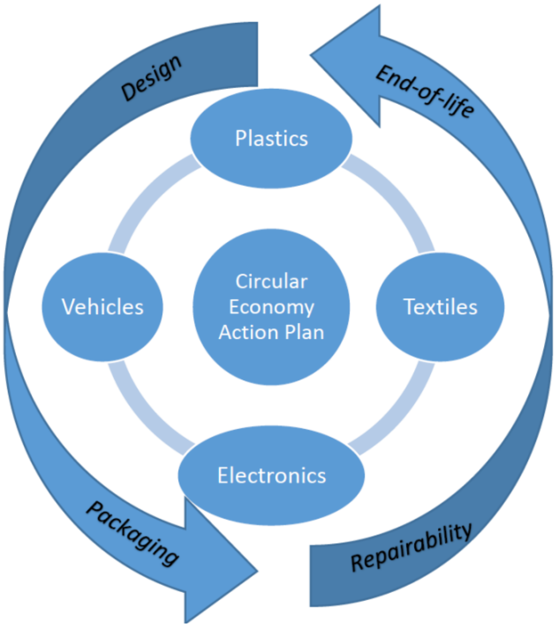
GPP may, on the one hand, be seen as one strand of broader policies linked to strategic public procurement, encompassing social responsibility and innovation. Due to the large volume of public procurement spend, it is seen as a major opportunity to influence supply markets to provide more sustainable, innovative and socially responsible solutions. At national level, GPP is often embedded in broader policies related to strategic or sustainable procurement and may also be supported by agencies responsible for innovation[68]. GPP is also an increasingly prominent part of broader environmental, energy and climate change policy, both at EU and national level. The role of GPP within the European Green Deal/Fit for 55 legislative package, including the Circular Economy Action Plan and revisions to legislation in the energy domain, is discussed in the following sections.

2.2.2. Circular economy action plan

The Circular Economy Action Plan (CEAP) was adopted by the European Commission in March 2020. The transition to more circular models of production and consumption is essential for Europe to meet its climate and resource efficiency targets. The linear model of 'take-make-waste' must be replaced with approaches which maintain the use value of materials and resources, allowing them to be recycled and reused. This affects everything from product design to purchase/ownership models, and what happens to products or other assets at their end of life. It also has profound implications for public procurement, including in the defence sector. One example of circular procurement is the approach taken by the Dutch Ministry of Defence to procure textiles (overalls and towels) which include a minimum percentage of post-consumer recycled fibres, and which are taken back at their end of life for recycling. This resulted in impressive savings in terms of CO_2 emissions, energy and water, and has been promoted as a good practice both nationally and at EU level[69]. Further examples of circular procurement have been published by the Commission[70] **(Figure 2.1)**.

63. Directive 2014/24/EU (Public Procurement Directive) and 2014/25/EU (Utility Sector Procurement Directive).
64. Directive 2014/23/EU on the award of concession contracts.
65. Relevant articles of Directive 2014/24/EU include Article 67.2, 68, 42, 43, 56.1, 57.4, 58, 62 and 70.
66. Article 18.2 of Directive 2014/24/EU.
67. Directive 2009/81/EC, as amended. Relevant articles include 18.3, 18.6, 20, 24, 42.1(f), 44, 47.1 and Annex III.
68. This is the case for example in the Netherlands (PIANOo) and Sweden (UHM).
69. See https://ec.europa.eu/environment/gpp/pdf/news_alert/Issue77_Case_Study_153_Dutch_Defence.pdf.
70. European Commission (2017) Public Procurement for a Circular Economy: Good practice and guidance.

Figure 2.1. Circular economy and GPP: Key sectors and concepts



The CEAP identifies a number of key sectors for circular economy initiatives, including plastics, vehicles, electronics and textiles. It also addresses the built environment, for example through the planned revision of the Construction Products Regulation[71]. Importantly, the CEAP also indicates that **mandatory GPP criteria will be proposed on a sectoral basis** – the first example of this can be found in the proposed **Batteries Regulation**[72] – and **mandatory reporting on GPP** introduced.

The shift to a circular economy has a number of specific implications for procurement, including:

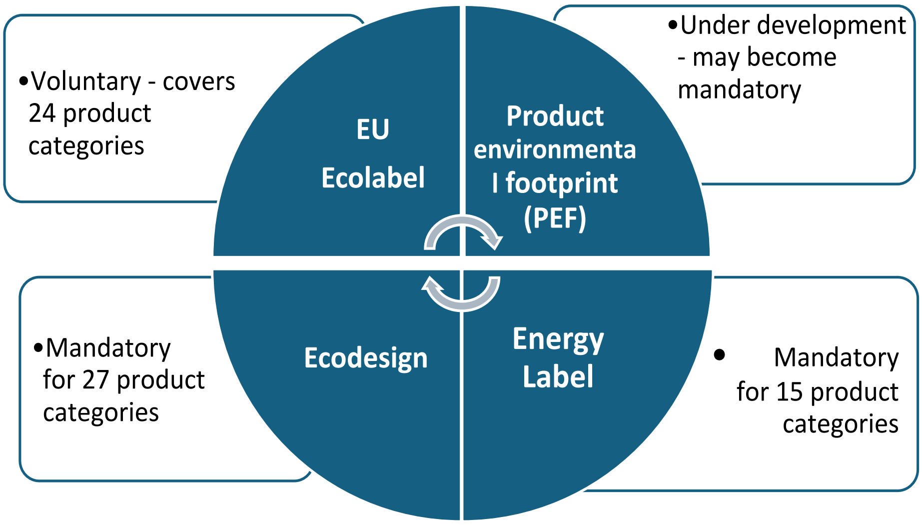
- The need to **evaluate the embodied carbon and energy** in materials/products, as well as the in-use impacts. This evaluation may either be used to set minimum technical specifications for products/services, or to award marks to more sustainable alternatives.
- The need to consider **service arrangements** (e.g., leasing, take-back schemes, energy performance contracts, service level agreements) as an alternative to simple purchasing. Service arrangements often help to maintain the value of an asset over time.
- The need to consider the **end-of-life phase** in all procurements, for example how buildings or equipment can be disassembled and materials reused/recycled at their end of life.
- The need to test new product designs, e.g., those incorporating recycled materials, in an operational setting. This may be done through pilot projects or **innovation procurement,** including **pre-commercial procurement**[73].

71. See https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-revision-of-the-construction-products-regulation for updates on the revision progress.
72. See COM (2020) 798 Proposal for a Regulation concerning batteries and waste batteries. Agreement on the final text of the Batteries Regulation has not been achieved at the time of writing.
73. Pre-commercial procurement (PCP) is a means of procuring R&D services (including prototyping) which is not covered by the Procurement Directives. See: https://digital-strategy.ec.europa.eu/en/policies/pre-commercial-procurement An example of PCP in the defence context is the development of unmanned oceanographic vehicles by the UK Defence Science and Technology Laboratory/National Oceanography Centre. PCP does not allow for commercial scale purchasing of the developed solutions as part of the same procedure. To enable this, the innovation partnership procedure can be used to develop, test and purchase new products/services.

2.2.3. EU product policy

To date, GPP has been supported primarily through EU product policy, with links to **Ecodesign**, the **EU Energy Label**, the **EU Ecolabel** and **Eco Management and Audit Scheme** (EMAS). Work is progressing to develop a **Product Environmental Footprint** (PEF) label which will assist consumers (including public procurers) in comparing the environmental impact of different products[74]. Such initiatives are important to ensure the credibility and measurable impact of GPP, by avoiding greenwash **(Figure 2.2)**. For the public sector, the introduction of binding carbon budgets will heighten the need to capture all emissions, including those embedded in products and services supplied via procurement.

Figure 2.2. EU product policies affecting GPP



Capturing the full range of environmental impacts of products and services in a consistent, credible, comprehensive and comprehensible way is challenging. In the **construction sector**, the use of **environmental product declarations** (EPDs) is one way of comparing the environmental impact of materials. EPDs are based on life-cycle assessment studies and include information about a range of environmental impacts in addition to carbon footprint. In Europe, EPDs must conform to the standard EN 15804. Product Category Rules (PCRs) determine the information to be included and methodology, so that EPDs enable comparison between products fulfilling the same function[75].

While EPDs or other product-level information can be useful to help choose between alternative building materials, buildings are more than just the sum of their components. To truly capture the life-cycle impact of a building, a more comprehensive 'systems level' approach is needed. This is typically achieved through specification of an external standard to be achieved (e.g., LEED, BREAAM, Passivhaus) together with use of **Building Information Modelling** (BIM) software. The LEVEL(s) framework, discussed in Annex II, is also an example of a systems level approach to sustainable buildings which can be an important reference for GPP.

74. See https://ec.europa.eu/environment/eussd/smgp/initiative_on_green_claims.htm.
75. Further information about EPDs is available at: https://ec.europa.eu/environment/ipp/epds.htm.

2.2.4. Fit for 55 legislative package

As part of the **Fit for 55 legislative package** the Commission proposed amendments to three key directives with an impact on GPP: the **Energy Efficiency Directive** (EED)[76], **Renewable Energy Directive** (RED)[77] and **Energy Performance of Buildings Directive** (EPBD)[78]. **Figure 2.3** illustrates the key measures proposed within each of these Directives which can be expected to have a direct impact on public procurement, including in the defence sector.

Figure 2.3. Measures proposed in RED, EED and EPBD

Renewable Energy Directive	Energy Efficiency Directive	Energy Performance of Buildings Directive
• Sets targets and rules on use of renewables for specific sectors (transport, heating and cooling, buildings, industry) • Defines sustainable biomass and sets rules on use • Defines 'green' hydrogen and sets targets for use by industry • Labelling products made with renewable energy • Support for power purchase agreements and cross-border pilots	• Binding targets for energy efficiency • Obligation for public sector to reduce energy consumption • At least 3% of area of all public buildings renovated to NZEB each year • Obligation to only purchase highly energy-efficient products and services extended to all public bodies, excuses removed • Fossil fuels cannot count towards energy savings	• Requires renovation of 15% worst-performing buildings in each MS • New public buildings must provide for 100% renewable on-site energy consumption by 2027 • Life-cycle emissions must be measured for new buildings • Smart charging for electric vehicles must be supported • Revision to content and format of Energy Performance Certificates

The measures can be categorised as follows:

Type 1: Measures that **require or encourage public investment in energy-efficiency measures** (e.g., the obligation under the EED to renovate 3% of the floor area of public buildings each year; obligation to renovate bottom 15% of buildings under EPBD).

Type 2: Measures that **set minimum mandatory environmental standards for public procurement** (e.g., the obligation on public bodies to purchase highly energy-efficient products under the EED; the obligation to purchase low and zero emission vehicles under the Clean Vehicles Directive).

Type 3: Measures that **set minimum mandatory environmental standards which apply to all products in a category**, which will in turn impact the products and services procured by the public sector (e.g., Ecodesign of products; requirements for sustainable biomass).

GPP criteria incorporate all three types of measures, and also generally go beyond legislative compliance to target the best-performing environmental technologies on the market. The EU GPP criteria, as well as most national criteria, are designed to be applicable to different procurement routes, e.g., purchasing cloud services as well as physical ICT infrastructure (Annex III). They aim to achieve a good balance between environmental performance, cost considerations, market availability and ease of verification. They are divided into the **core** criteria, which are expected to have minimal impact on cost or product/service availability, and the comprehensive criteria which deliver additional environmental benefits.

76. COM (2021) 558 Proposal for a Directive on energy efficiency (recast).
77. COM (2021) 557 Proposal for a Directive as regards the promotion of renewable energy.
78. COM (2021) 802 Proposal for a Directive on the energy performance of buildings (recast).

2.2.5. Defence sector context

GPP is strategically aligned with the core missions of the defence and security sector in Europe. As set out in the Climate Change and Defence Roadmap[79], the climate-security nexus requires the EU and its Member States to develop new capabilities and operating procedures to respond to emerging or increasing threats such as extreme weather, food insecurity, population displacement and forced migration. Failure to address the environmental impact of procurement creates risks and costs which can ultimately limit the ability to respond effectively to such threats. In addition to directly tackling the energy and carbon footprint of defence sector organisations, GPP helps to build capability to address these threats by developing more diverse and robust supply chains. As seen during the Covid-19 pandemic, in times of crisis, organisations are only as strong as the weakest link in their supply chains. **Defence sector organisations may be particularly vulnerable to supply chain disruptions due to a lack of diversification in their supplier base, linked to the specialised nature of defence procurement.**

The role of GPP in strengthening the resilience and sustainability of supply chains is recognised in many public and private organisations. However, in the defence sector, procurement is often still seen as an administrative, rather than strategic function – as evidenced by the responses to the questionnaire summarised in Section 3.3. This undermines the ability of procurement officers to engage with the market and apply procedures and criteria which deliver more sustainable solutions. **For GPP to succeed, it needs the support of senior leadership, budget holders and internal users of the goods and services procured.**

In some cases, GPP will have impacts on purchase costs or performance where a conventional product or service is replaced with a more sustainable alternative. For example, replacing a fossil-fuel boiler with a heat pump will have implications in terms of budget, installation and maintenance procedures. Adopting a clear organisational policy on GPP can help to ensure these elements are managed and do not become barriers to adoption, for example by requiring **life-cycle costs**, rather than just purchase price, to be considered in financial evaluations.

Many of the activities carried out under the auspices of the CF SEDSS, in particular within WG1, have direct links to GPP. However, they may not be labelled as such, and may have been implemented on a pilot basis rather than forming part of a consistent policy on GPP. **This means that even where valuable experience/capacity has been gained in procuring sustainable products or services, this may not be reflected in the broader procurement practices of the organisation, or shared with other organisations.**

EDA initiatives such as the **Incubation Forum for Circular Economy in European Defence**, which includes a group on green procurement, may help to disseminate expertise and build capacity. The recommended actions set out in Section 5 aim to establish GPP as an operational policy within the defence sector, based upon internal and external stakeholder engagement, pilot/demonstration projects, upskilling of staff and adoption of common GPP criteria and tools. Implementation of these actions will require dedicated resources and a clear mandate from senior leadership.

79. EEAS (2020) 1251 Climate Change and Defence Roadmap.

2.3. Current levels of GPP implementation in the defence sector

2.3.1. Overall profile of GPP within the defence sector

GPP implementation within the defence sector appears to largely reflect national levels of implementation[80]. For the European public sector generally, levels of GPP vary significantly between countries and regions which were 'early adopters' (Austria; Belgium, especially Flanders; Denmark; France; Germany, especially Berlin, Bremen and other cities/regions; Finland; Netherlands; Norway; Spain, especially Catalonia and the Basque Region; Sweden); those which started applying GPP around the time that EU policy support was put in place (2008-2010); and those which have been late adopters. The most recent published analysis of levels of uptake of GPP suggests that **defence sector purchasers accounted for less than 5% of the procedures including green, social or innovative criteria** in the 10 countries included in the study[81]. It is very difficult to accurately quantify the number/value of public tenders which include GPP criteria, due to the incompleteness of TED data[82] and the absence of monitoring in most Member States. This is a problem affecting analysis of GPP (and other forms of strategic procurement) throughout the public sector. While some Member States and regions have implemented monitoring systems which allow for better data collection on GPP, this is the exception rather than the rule. It reflects a larger problem regarding the availability/completeness of data on public procurement, which is beginning to be addressed through approaches such as the Open Contracting Data Standard. **The availability of reliable large-scale data on GPP, including in the defence sector, would help to develop more effective policies to support its uptake.** As a starting point, this study offers a partial mapping of current levels of GPP implementation amongst the MoDs participating in the CF SEDSS, set out in the next section. However, given the voluntary nature of the questionnaires and relatively small sample sizes, the results cannot be considered fully representative of the status quo across the EU-27. To support GPP in the defence sector, it is useful to know which bodies are carrying out defence procurement in each Member State. In addition to MoDs, this may include regional or national agencies, central purchasing bodies, private companies and international organisations. **Analysis of notices published on TED from 2018-2021 indicates that in Germany, for example, over 50 different defence sector organisations carried out EU-value public tenders.** While defence procurement is more centralised in some other MS, it is clear that for GPP policy to be effective it must extend beyond MoDs. Developing a list of organisations active in defence procurement across the EU could be a useful resource for planning the actions recommended to further support GPP implementation.

Due to the large number of organisations involved in procurement, and their different mandates and areas of focus, it can be difficult for GPP support measures (e.g., calls for demonstration projects, events, training or guidance) to reach the correct audience. The contacts and baseline information on GPP gathered through the CF SEDSS are extremely valuable in this regard. **Input from the organisations and contacts identified should be sought in order to develop policy supports which respond to the needs of defence sector purchasers**, noting that the profile of these purchasers varies considerably both across and within Member States. Many organisations involved in defence procurement have little or no interaction with EU-level or cross-border initiatives, and may not see such activities as part of their mandate. While GPP has largely been driven to date by a 'coalition of the willing', the move to a more mandatory approach under the EU Green Deal/Fit for 55 legislative package means that all purchasers must be reached.

80. Exceptions to this could apply where the defence sector is either exempt from a national policy mandating GPP, or has adopted GPP outside of or beyond national policy. However, based on the research conducted, there appears to be a large degree of alignment of GPP levels between the defence sector and general public sector in each Member State.

81. PwC (2015) *Study on strategic use of public procurement in promoting green, social and innovation policies: Final report* (European Commission, DG GROW), p 63. The countries included in the study were Austria, France, Latvia, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden and the United Kingdom. The findings were based on analysis of TED data from 2013. The reliability of this study in indicating overall levels of GPP uptake is questionable (due to the incompleteness of TED data), however there is no reason to believe it would under- or over-represent the share of defence sector contracting authorities in the total number of GPP tenders.

82. Notices published on TED often do not contain full details of tenders, making it difficult to determine if GPP was applied.

2.3.2. Information collected in phases I-III of the CF SEDSS

The role of GPP in supporting the sustainable energy transition has been addressed at several points during Phases I-III of the CF SEDSS. A summary of the relevant findings/developments is given here.

Phase I (2015-2017): Working Group 1 on Energy Management included a focus on energy-efficiency in procurement and energy performance contracting. In May 2017 a questionnaire on these topics was distributed to the participating MoDs. The 21 respondents represented 93.2% of EU defence expenditure and 86.0% of EU defence personnel[83]. The findings were that **the majority of respondents had incorporated the relevant requirements under the 2012 Energy Efficiency Directive in relation to Ecodesign and Energy Labelling into their tender specifications in supply contracts**. However **only a minority (40%) had incorporated these requirements in service contracts.** Likewise, in contracts for purchase or rental of buildings, **only 40% had incorporated the relevant requirements included in the Energy Performance of Buildings Directive regarding minimum levels of energy efficiency**[84]**.** When asked about the main challenges for implementing these requirements, respondents referred to the **lack of availability of compliant products and services, cost issues, absence of a central mandate or guidelines in internal procurement processes, and gaps in the training and motivation of procurement officers**[85]**.** Experience with energy performance contracting was limited amongst the respondents, with only four MoDs having signed such contracts. However, a significant number expressed the intention to pilot EPCs within their organisations in the near future[86]. The Phase I guidance document set out a Roadmap of suggested further actions linked to energy efficiency in procurement and energy performance contracting, including for example the **training of staff and support for pilot projects**[87]**.**

Phase II (2017-2019): While no dedicated questionnaire on GPP was distributed, three questionnaires on areas directly related to GPP were issued: *Funding Mechanisms for Energy Projects, Energy Data and Renovation Roadmaps* (October 2018); *Energy Performance Contracting* (February 2019); *Energy Strategies, Energy Management Systems, Energy Auditing* (May 2019). The relevant findings from these questionnaires included the following[88]:

Energy performance contracts

- Five of the respondent MS were implementing energy performance contracts, of which two included renewable energy systems.
- Plans to implement energy performance contracts were underway in a further five MS.
- A number of national and organisational barriers continued to inhibit uptake of energy performance constracts, for example inability to reinvest energy savings and lack of baseline data about buildings.

Nearly zero energy buildings (NZEB)

- There was a lack of dedicated plans by MoDs regarding renovation of buildings to meet the NZEB standard and few deep renovations had taken place.
- Given the campus layout of many defence buildings, a cluster approach to meeting the NZEB standard was considered appropriate.
- The role of high quality, energy-efficient temporary buildings (or permanent demountable buildings) should be considered, with attention to their entire life-cycle and utilisation.

83. https://eda.europa.eu/docs/default-source/events/eden/phase-i/guidance/consultation-forum-for-sustainable-energy-in-the-defence-and-security-sector---guidance-document.pdf, p 17.
84. Ibid, p 36-38.
85. Ibid, p 39.
86. Ibid, p 40.
87. Ibid, p 74-75.
88. CF SEDSS Phase II Guidance document, p 68-80.

Energy audits

- Most MoDs were carrying out some form of audit programme on selected buildings (mainly new buildings or deeply renovated buildings) and preparing energy performance certificates.
- Four MoDs conducted energy audits in all their buildings.
- There was a mixture of internal and external personnel carrying out certification.

Energy Performance of Buildings (EPBD) requirements

- The application of the EPBD requirements regarding energy performance certificates to defence sector buildings were interpreted differently in the MS, ranging from no obligation to full coverage.
- While the value of having baseline information about a building's energy performance was recognised, the applicability/importance of the EPBD requirement to display EPCs was questioned.
- More accurate modelling of energy performance at design stage, and comparison with real performance in the use phase, was needed.
- More detailed guidelines on procurement of energy-efficient HVAC systems was needed.
- Some MS were using Building Automation and Control Systems (BACS) to manage energy across multiple buildings/ facilities on a site, however there was a lack of consistent reporting.

Low emission vehicles and support infrastructure

- While the business case for purchasing battery electric vehicles (BEVs) was solid, this required a reduction in fleet size and increase in utilisation of vehicles – an efficient vehicle management system was key to success.
- New procurement and utilisation models, such as leasing, or combined leasing and ownership, as well as sharing of vehicles between different bodies, may have to come into place to reduce the number of vehicles needed and maximise benefits.
- Concerns remained about the carbon footprint of BEVs in MS with a less green energy mix, with installation of solar PV charging infrastructure one way of addressing this.
- A more detailed survey on the types of vehicles in MoD fleets was recommended for Phase III.

Funding energy efficiency measures

- Only 41% of the MoDs (9 out of the 22 MS that replied) had already developed mechanisms to apply for external funding.
- The external funding collectively received over the previous 10 years was extremely small (~63 million euros (half of which was provided to one MS only for combined environmental and energy projects).
- National governments need to allocate reasonable external funding for deep renovations of the MoDs' large building stocks, if the public sector is to fulfil its exemplary role under the EED.
- Lessons learned from responding to funding calls included the need for flexibility and speed, technical expertise, and management commitment to free up human and financial resources.

2.3.3. Results of targeted GPP questionnaire

In September 2021, a targeted questionnaire on GPP was issued to all MoDs participating in the CF SEDSS, through Working Group 1. The questionnaire sought specific information about current levels of GPP implementation, the product/service sectors involved, examples of implementation, the barriers/challenges encountered, and the type of support needed from the EU. A total of 18 responses were received, representing 16 Member States[89]. A summary of the responses to each of the questions is given in **Figures 2.4-2.9**, followed by discussion and analysis in Section 4.

89. In respect of two MS, two separate responses were received. The respondent MS were: FR, CZ, IT, NL, LT, EL, MT, IE, AT, SK, PL, DE, CY, SI, PT, LU.

Figure 2.4. Question 1 – Are green criteria (specifications, selection/award, and/or contract performance clauses) included in your organisation's procurement?

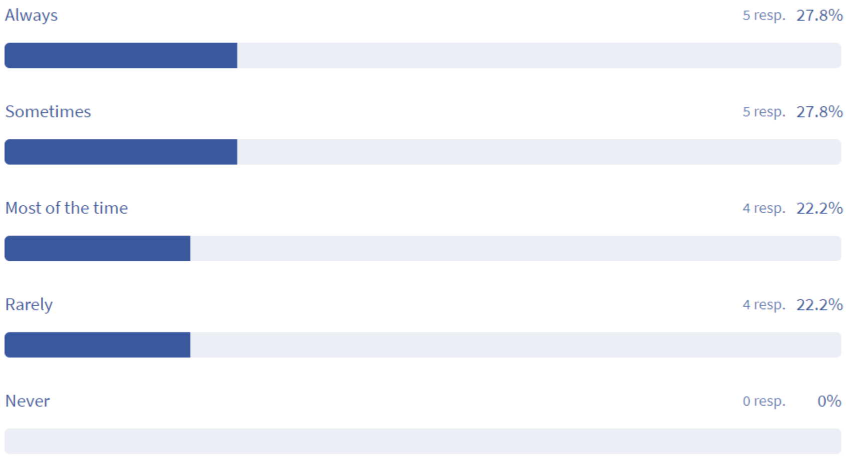


Figure 2.5. Question 2 – Does your organisation have a GPP or sustainable procurement policy in place?

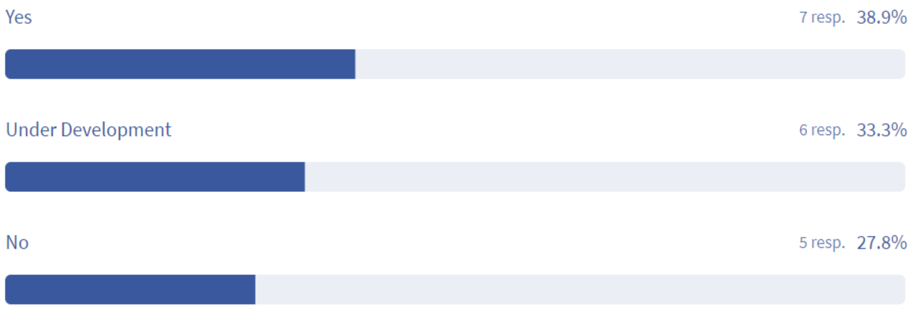


Figure 2.6. Question 3 – If your organisation relies on a central purchasing body to carry out some or all of its procurement, does this body regularly apply green criteria?

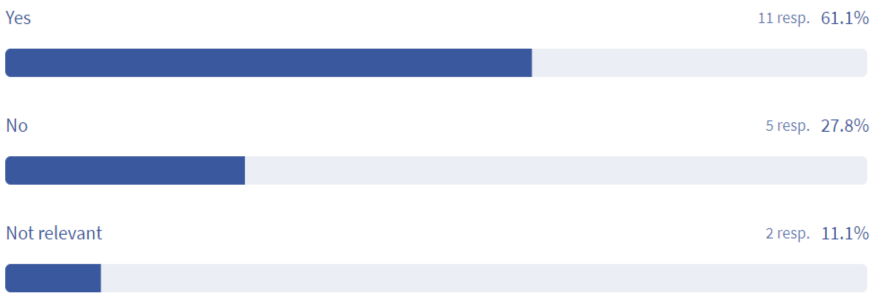
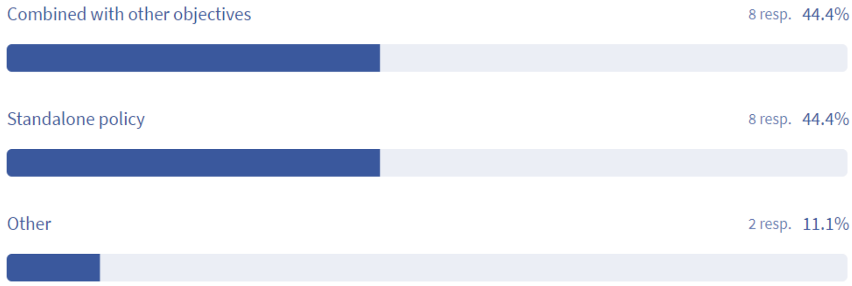


Figure 2.7. Question 4 – Is GPP combined with other strategic objectives for procurement (e.g., social responsibility, innovation) or pursued as a standalone policy?



Question 5 – Please briefly describe the biggest challenges for applying GPP in your organisation

- *"Difficulties lie in evaluating the reality of "green" commitments in bids".*
- *"Lack of senior management support".*
- *"To widely spread green procurement principles throughout all the organisation in a short time".*
- *"Lack of deep knowledge and cost perceptions concerning the whole cost cycle of a component or system".*
- *"Taking responsibility (top management and project leaders), clear objectives, monitoring, not embedded in procurement process".*
- *"No pressure from above to implement. At present GPP is viewed as a guideline, not a requirement. In some cases, defence sectors focus on operational output which can be to the detriment of GPP".*
- *"Lack of knowledge, cost perceptions, unavailability of sustainable products".*
- *"Lack of solid data, confirming sustainability of certain standards".*
- *"Lack of qualified staff [who] understand the impact of energy renovation of buildings on the environment".*
- *"Small size of organisation, lack of knowledge, unavailability of sustainable products/services".*

Figure 2.8. Question 6 – For which categories of purchase are GPP criteria applied (tick all that are relevant)?

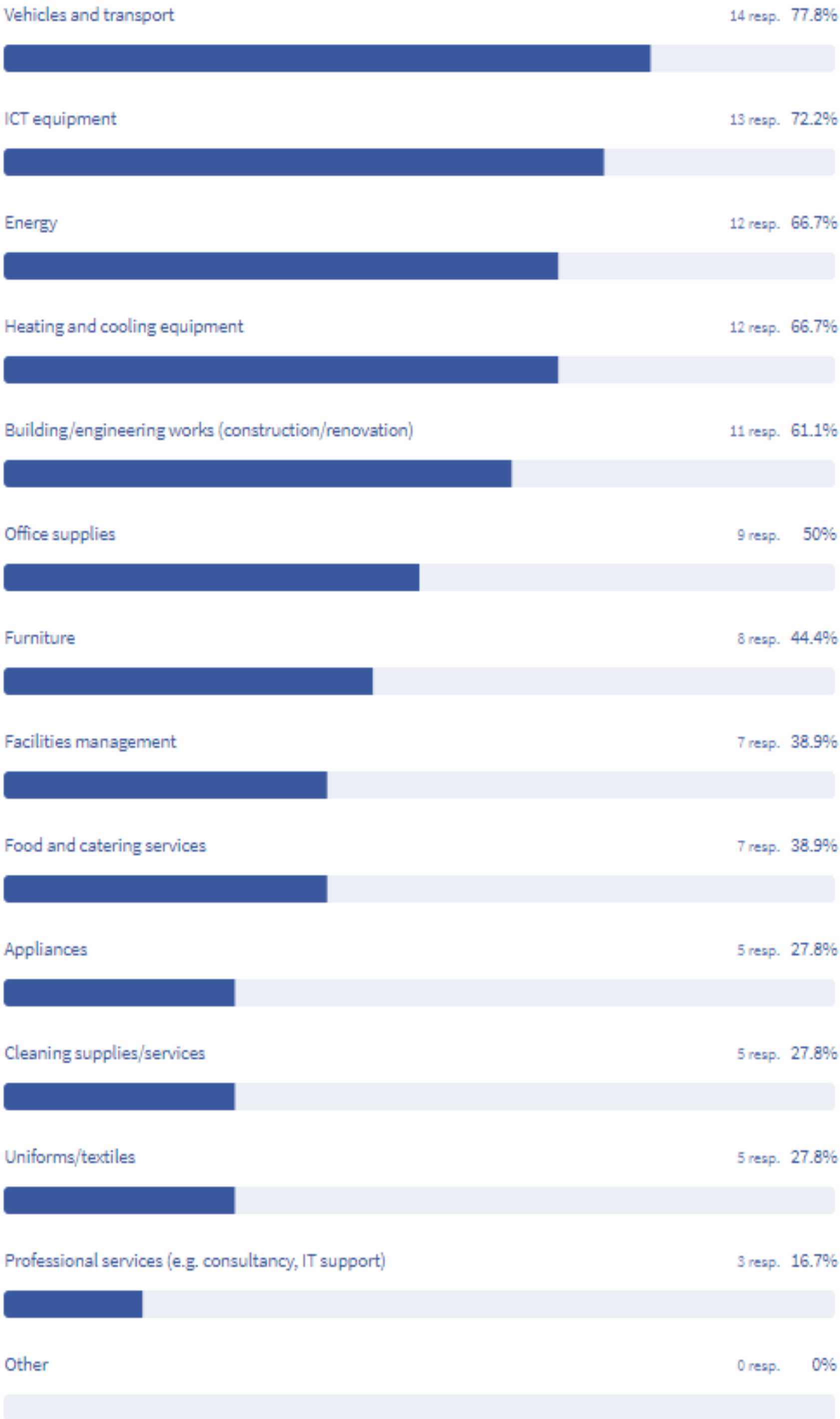
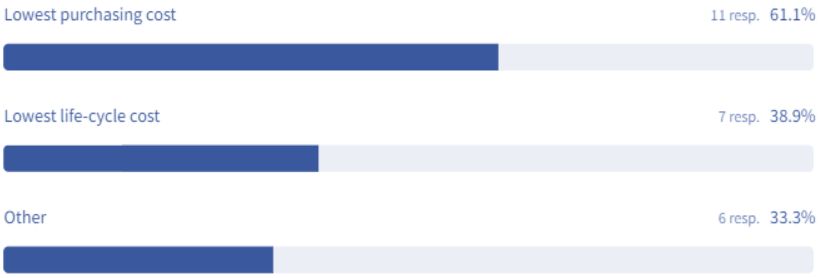


Figure 2.9. Question 9 – Which of the following cost criteria does your organisation apply in the procurement process?



Question 10 – What one change would be most important to increase GPP/circular procurement within your organisation?

- *"A larger offer from the companies."*
- *"Support in the law."*
- *"To consider, in the purchase phase, the costs of entire life-cycle of products in order to evaluate its cost-effectiveness."*
- *"Projects to enhance cooperation among the Member States and increase knowledge [of GPP]"*
- *"A more detailed European or national directive for specifying/quantifying circular procurement requirements."*
- *"The formulation of professional GPP requirements which can be 'easily' used in procurement projects."*
- *"Enforce it as a statutory requirement and provide detailed training/workshops and audits to ensure compliance."*
- *"Informing personnel about GPP, circular procurement saving resources."*
- *"Bottom-up approach: drafting requests for equipment, cars or services is [an] essential step in public procurement. Having laws and internal directives in place is great but those who are drafting requests for public procurement need to be familiar with sustainability and other environmental criteria. And those who are approving the requests. Public procurement should not be solely focused on the lowest price."*
- *"Increased availability of sustainable products/services at favourable price[s]."*
- *"Compulsory rule, that must be applied."*
- *"[A] GPP/Sustainable Procurement Policy in the Organisation (now under development)."*
- *"Easily applicable GPP criteria. Education and awareness."*
- *"Benchmarks and labels at EU level (as a small organisation, we are very much dependent on existing goods, products & services)."*

Question 11 – In your opinion, how could the EU/EDA further support MoDs in applying GPP in the defence sector?

- *"By funding innovative projects. Messages: GPP is on the long term less expensive. To invest in GPP is to support your own mission."*
- *"By sharing common practices and examples of GPP."*
- *"Provide training and templates which can easily be introduced into tendering process. Include relevant case studies."*
- *"Good communication strategy and sharing best practices among the States since some MS are much more experienced in this field while others (especially in Eastern / Central Europe) are still at the beginning."*
- *"Produce clear and concise guidelines for the applicability of GPP criteria in contracts."*
- *"Developing benchmarks & labels for goods, products and services."*
- *"Other countries' information, data and experience sharing could be very helpful."*
- *"GPP information sharing with MoDs, development of GPP Best Practices in the Defence Sector."*
- *"EU trainings and exercises, setting common requirements."*

2.3.4. Key findings

A number of key findings emerge from analysis of the questionnaire responses:

1. There is significant variation in the application of GPP criteria by defence organisations across the MS. While half of the respondents include GPP criteria in their procurement always or most of the time, the other half only do so sometimes or rarely. For the most part, the degree of GPP implementation is aligned with national levels. Where central purchasing bodies are used, these appear to apply GPP criteria more frequently.

2. The majority of respondents have a GPP or sustainable procurement policy either in place or under development. These policies are evenly divided between those which target GPP in isolation and those which also include other objectives, such as social responsibility or innovation. Where GPP is a standalone policy, it is important to highlight the links/synergies with other forms of strategic procurement, so that these are not seen as competing objectives.

3. GPP is most often applied in purchases of vehicles/transport and ICT equipment, followed by energy, heating/cooling equipment and buildings and engineering works. For several categories with a heavy environmental footprint, such as cleaning services and uniforms/textiles, only a minority of respondents indicated that GPP had been applied. For professional services, which can have a significant indirect environmental impact (e.g., project management, design services, ICT consultancy), GPP is rarely applied. This is probably due to the lack of readily available GPP criteria for many professional services, as well as a lack of understanding of the environmental impact of these services.

4. Less than 40% of the respondents indicated that their organisation considered life-cycle costs (even some of the time) in procurement. This represents a significant missed opportunity to ensure the true cost of ownership (including ecological costs) is evaluated during tenders.

5. The main challenges for GPP can be divided between **structural factors** (lack of senior management support, lack of legal mandate), **technical factors** (lack of capacity/skills/knowledge amongst procurement staff, lack of data/standards/criteria) and **market factors** (lack of sustainable product/services, cost perceptions). Correspondingly, in identifying the most important changes to support GPP respondents pointed to structural changes (e.g., laws or policies mandating GPP), technical support (e.g., common criteria, benchmarks and labels, cooperation projects) and market developments (e.g., increased availability of sustainable products/services).

6. Most respondents were able to cite at least one example of GPP/circular procurement within their own organisations, including in the construction, energy, ICT, transport and waste management categories. Others simply referred to compliance with applicable national or EU legislation, while some were unable to cite any specific examples.

7. In terms of the support which could be provided by the EU/EDA, respondents identified a need for project funding, training, guidelines and templates and the sharing of data, case studies and good practice between MS. The provision of benchmarks and labels for sustainable products and services was also requested. While many of these resources/supports exist as part of the European Commission's GPP programme and under other initiatives such as Horizon Europe/EAFIP project funding, **there is a lack of dedicated support mechanisms for GPP in the defence sector**.

2.4. Problem analysis

Analysis of the responses to the questionnaires suggests that there are several challenges currently limiting GPP application in the respondent organisations. These are summarised below, with an indication of potential approaches to address each challenge. The approaches are elaborated into recommendations in Sections 5 and 6.

Challenge: Procurement is often seen as an administrative, rather than strategic function. Its impact on organisational objectives linked to climate, energy and security may not be recognised at the higher levels of an organisation. It sometimes takes a serious problem arising from procurement – which may have severe operational, reputational and cost repercussions – to draw attention to the important role it plays. For example, discovering that a contractor or subcontractor has been involved in illegal dumping of waste or unsafe working practices.

Proposed approach: There are two proven approaches to raising the profile of GPP within an organisation, thereby securing the support and resources needed to successfully implement it. The first is a 'top down' approach, which involves formal adoption of a GPP/SPP (Sustainable Public Procurement) policy, linked wherever possible to high-level organisational objectives and targets (e.g., carbon and energy reductions). The second is a 'bottom up' approach, where individual projects/procurements are used to demonstrate the role and impact of GPP. These approaches can obviously be combined, but some organisations find it is easier to advance one approach or the other first. Given that the majority of MoDs appear to either have a GPP policy in place or under development, the recommendations in this report focus on how to successfully develop and implement GPP in practice.

Challenge: GPP criteria and tools developed for application by the general public sector may not be directly applicable to the defence sector. For example, many defence sector buildings are different both in terms of operation and management to civil sector buildings, meaning the same energy solutions may not be appropriate. Defence sector buildings often form part of a campus, and may not be separately metered. Periods of occupation are also more variable than for the general public sector[90].

Proposed approach: There is a need to examine available GPP criteria and tools in detail, to determine where these are appropriate for defence procurement and where adjustments or additions are needed. It is proposed to establish working groups (for example, as sub-groups of WG1) to review the available criteria and tools in critical GPP categories (e.g., buildings[91], ICT, vehicles, textiles, cleaning, food and catering). The working groups could produce recommendations for all MoDs, and potentially play a role in evaluating implementation as part of the next phase of the CF SEDSS or other initiatives.

Challenge: Life-cycle costing is only applied by a minority of defence sector organisations in their procurement. Public sector budget and political cycles are typically not long enough to achieve payback on major energy investments. Individual organisations may not be able to reinvest energy savings.

Proposed approach: GPP requires a shift away from lowest-price purchasing. Applying life-cycle costing can have both environmental and financial benefits, as it allows the true costs of assets (including operational and end-of-life costs) to be taken into account. It is particularly important for categories with high energy consumption or maintenance/disposal costs, such as buildings, heating and cooling equipment, vehicles and ICT. To apply LCC successfully, review of available tools and upskilling of procurement staff is recommended.

90. Phase II Guidance Document, p 39.
91. This working group could provide input into the revision of the EU GPP criteria on buildings, which will take place in 2022. This will help to ensure that the criteria take account of the perspective of the defence sector, e.g. by being applicable to campuses as well as standalone buildings. Further details are available on this page: https://susproc.jrc.ec.europa.eu/product-bureau//product-groups/408/project-plan.

Challenge: Rotation of military staff can mean that they have to change positions before having time to fully understand and implement knowledge about energy efficiency, renewable energy, etc.

Proposed approach: GPP needs to become part of standard procurement procedures and to be reflected in the training, evaluation and promotion of staff. Sharing of expertise and networking between defence organisations on GPP could also help to embed knowledge/capacity and ensure that this is reflected in the ongoing practices of procurement teams.

Challenge: "Even if MoDs were to renovate their building stock at a 3% a year refurbishment/replacement rate, as required by the Article 5 of the EED, it would take over 33 years to bring the building stock up to current standard, let alone keep pace with technical developments over that time"[92].

Proposed approach: The targets set at EU and national level for energy efficiency, renovation and carbon savings should be seen as a starting point, and used to leverage support for broader and deeper GPP implementation. In addition to pilot projects, support is needed for scaling up, addressing skills shortages and reassessing needs (e.g., in terms of the volume of office space or other accommodation needed and the potential to share resources amongst organisations/units). Pilot and demonstration projects on GPP should explicitly consider the potential for replication both within the host organisation and by other MoDs.

2.5. Solution implementation

2.5.1. Risks of inaction and the case for coordination/collaboration

The 'do nothing' approach to GPP implementation by defence organisations would involve waiting for EU or national legislation to mandate the inclusion of environmental criteria in purchasing. Such legislation already exists for various sectors/categories, including vehicles, energy-using products and buildings. However, this approach poses clear operational and reputational risks to defence organisations:

1. Legislative standards which extend to procurement **may not be stringent enough, and may not come into effect soon enough,** to enable defence organisations to meet their energy and carbon-saving obligations.
2. Investing in green solutions at a later, rather than earlier date, means that the opportunity to build capacity and skills for GPP implementation prior to mandatory legislation coming into effect is missed. **This will make the operational transition to green products and services more difficult, as less time for adaptation is available.**
3. Being at the rearguard, rather than vanguard of GPP implementation means that defence organisations will be **'market takers'** rather than **'market makers'** in the development of new green technologies and services. Failure to engage and challenge suppliers with green criteria in procurement means that innovation will happen in response to the needs of other customers, and may not reflect defence sector priorities.

92. Phase II Guidance Document, p. 38.

These risks, and the corresponding opportunities/benefits for GPP have already been recognised by most MoDs. However, only a minority have implemented GPP as their 'business as usual' approach. The challenges set out in Section 4 are real, and **organisational change requires sustained support and motivation**. **The case for EU level action, including collaboration and coordination between MoDs on GPP, can be summarised as follows**:

1. Successful GPP implementation requires significant investment in pilot projects, upskilling staff and adapting procurement systems and procedures. Many of these activities will be similar across defence organisations, meaning there is potential to share resources/experiences and thus **avoid duplication of effort and resources.**
2. The application of common GPP criteria and tools can help the market to adapt more quickly and limit research and development **costs,** which are typically passed on to purchasing organisations. It also helps to ensure the **availability** of products and services which meet recognised GPP standards.
3. Coordination and collaboration between MoDs on GPP has the potential to deliver greater financial and environmental benefits from GPP, through the **pooling of demand.** This could be in the form of cross-border collaborative procurement, or coordination of needs, specifications and evaluation methods.

The following sections outline the main actions needed to avoid the above risks and realise the benefits of coordination and collaboration on GPP, drawing upon the existing framework of the CF SEDSS and European Commission support.

2.5.2. Recommended actions at strategic, operational and tactical levels

a) At strategic level, the following actions are recommended:

- **Adoption of organisational policies/commitments to GPP.**
- **Integration with sustainability, climate and energy policies.**

Explanation: Adoption of a GPP policy or strategy provides visibility and authority for operational and tactical actions. It provides an indication of support/approval from senior leadership, and can help to ensure appropriate resources are made available to implement the policy. It also helps to define the GPP roles and responsibilities within an organisation, including lines of reporting, how actions will be evaluated, and ambition increased over time. A GPP policy should be clearly linked to the organisation's larger policies/objectives in the sustainability, climate and energy domains. This helps to ensure that procurement reinforces and contributes to the organisation's targets in terms of emissions, energy savings, resource use and other impacts.

b) At operational level, the following actions are recommended:

- **Setting of targets and priority categories.**
- **Upskilling of procurement staff.**
- **Monitoring and evaluation of GPP implementation.**

Explanation: Most organisations will struggle to implement GPP across all categories of spend simultaneously. Even where GPP is already well established, there is a need to continually assess whether the appropriate level of ambition is being applied for each category, and to set new targets. A number of different techniques are applied to prioritise in GPP: based on environmental impact; value of spend/volume of contracts; combining 'quick wins' with categories requiring longer-term planning; or focusing on areas where the organisation enjoys a strong position vis-à-vis suppliers. Once priorities and targets have been set, an assessment of the current capacities and skills of procurement staff should be undertaken, gaps identified and appropriate training put in place. This may also involve revisions to job descriptions, work flows and qualification and promotion frameworks. Finally, an essential operational aspect of GPP is to put in place monitoring and evaluation. Examples of metrics used to monitor GPP implementation include:

- Number and value of contracts in which GPP criteria are applied.
- Compliance and performance in relation to GPP criteria in tenders.
- Compliance and performance in relation to GPP criteria in contract delivery.
- Impact of GPP measures in terms of emissions, energy, resource use, waste etc.

The inclusion of monitoring measures during the contract performance phase is particularly important, to ensure that GPP commitments are verified in real conditions and not only 'on paper'. For example, the actual energy performance of buildings or heating equipment should be monitored, with appropriate penalties for not meeting the promised performance levels.

c) At tactical level, the following actions are recommended:

- **Needs assessment and market engagement.**
- **Pilot and demonstration projects.**
- **Adoption of common GPP criteria and tools.**

Explanation: Needs assessment is an essential first step prior to adopting procedural changes to implement GPP. It establishes lines of communication between procurement officers and internal stakeholders/clients, to ensure that any changes to specifications or criteria will continue to meet organisational needs. In some cases, needs assessment may allow for reductions in volume of purchasing, or the elimination of certain categories entirely. Following on from this step, market engagement allows the purchasing organisation to announce its intention to apply GPP criteria and to seek feedback from potential bidders. This must be done in an open and transparent manner to ensure no bidder has an unfair advantage or disadvantage. Initial applications of GPP may take the form of pilot or demonstration projects, particularly in technically challenging categories where no obvious solution exists on the market. Ultimately, GPP criteria and tools (e.g., life-cycle cost or carbon calculators) should become part of standard operating procedures for procurement.

2.5.3. Summary of recommendations

Figure 2.10 and **Table 2.1** summarise the recommended actions to support uptake of GPP in the defence sector as part of the transition to sustainable energy and resource use. The actions have been organised into a set of six strands – adoption of a GPP policy is designated as Strand 0 reflecting the fact that this has already been undertaken by a majority of MoDs. While there are various co-dependencies/synergies between the strands, there is no strict chronology for their implementation. In practice, some organisations will find they are able to progress multiple strands at the same time, while others may choose to wait for the outcomes of pilot projects (for example) before adopting changes to training and procedures.

The recommended actions have all been associated with successful GPP implementation by public sector bodies, including those in the defence sector. Guidance, tools, case studies and training materials to support each of these actions are listed in Annex I.

Figure 2.10. Recommended actions: Overview

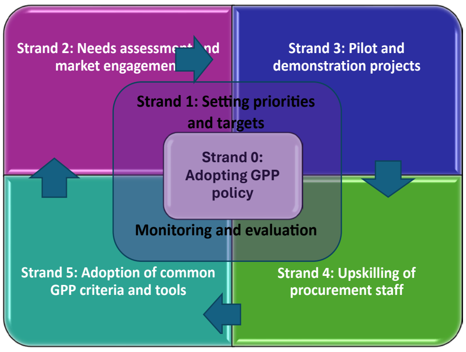


Table 2.1. Recommended actions

Strand 0: Adoption of GPP policies by MoDs, reflecting energy and climate commitments			
Strand 1: Setting priorities and targets for GPP; monitoring and evaluation			
Strand 2: Needs assessment & market engagement	**Strand 3: Pilot & demonstration projects**	**Strand 4: Upskilling of procurement staff**	**Strand 5: Adoption of common GPP criteria and tools**
2a) Consultation with internal users to determine the scope for GPP specifications and award criteria in priority categories	3a) Calls for GPP demonstration/pilot projects in the defence sector, addressing both pre-commercial and commercial procurement	4a) Training of procurement staff on GPP, including verification of green claims and life-cycle costing	5a) Setting up category-specific working groups on GPP (e.g. buildings, ICT, vehicles, textiles, cleaning, food and catering)
2b) Market engagement in priority categories (e.g. infrastructure) to ensure buyers are aware of the state of the art, and suppliers can respond to GPP criteria[i]	3b) Technical support provided to GPP projects (e.g. to measure the carbon and energy impacts, evaluate LCC)[iii]	4b) Secondments/ shadowing of procurement officers between MoDs with different levels of GPP implementation	5b) Review by working groups of EU and national GPP criteria to determine applicability to defence purchasing
2c) Evaluating use of pre-commercial procurement/ innovation partnership where GPP solutions are not mature	3c) Dissemination of lessons learned/best practices from projects to EU MoDs and other defence purchasers	4c) Incorporation of GPP into assessment and promotion frameworks for procurement officers	5c) Recommendations from working groups on GPP criteria and tools to be applied in the defence sector
2d) Evaluating use of collaborative procurement amongst MoDs to scale up demand for green products and services	3d) Support for scaling-up/replication of projects (e.g. through use of open framework agreements)	4d) GPP networking events/activities to support exchange of expertise across EU MoDs and other defence purchasers[iv]	5d) Evaluation of application, reporting on levels of compliance and impact, updating criteria and tools as necessary

i. Market engagement is particularly important in categories with rapidly developing technologies and solutions, including buildings, ICT and heating and cooling equipment. Market engagement is a 'two way street': it serves both to inform the purchaser and to inform potential bidders about requirements.

ii. Pre-commercial procurement targets research, development and limited-scale production of new products or services, but cannot be used for large-scale commercial acquisition. The innovation partnership can potentially cover the full process from early R&D through to acquisition. See page 12/ FN 23 of this document for further information.

iii. One approach would be to establish an EU Defence Helpdesk to assist defence sector procurers in greening their purchasing decisions with the application of GPP. Successful examples of helpdesks focused either on general procurement or GPP specifically exist both at EU and national level.

iv. The targeted outcomes of such activities could include promotion and replication of MoDs' work on GPP and best practices, as well as generating projects, research and tools to address common shortfalls/interests.

Conclusions

Defence sector procurement is about management of risks and costs along supply chains, and increasingly these costs and risks are associated with climate and energy. A reactive implementation of GPP by the defence sector would be limited in the short term to compliance with EU and national legislation mandating its application – and would represent a significant missed opportunity to address climate and energy risks along supply chains. **Proactive strategies for GPP implementation, as outlined in this study, will ensure that the defence sector is not left behind as the market responds to demands for more sustainable products and services.** Timely and coordinated adoption of GPP across Europe's defence sector purchasers offers the best chance of ensuring these new products and services **reflect the sector's specific needs**.

For GPP to achieve broad uptake in the defence sector, the challenge facing implantation need to be recognised, and concrete resources and tools provided to purchasers. While at present more sustainable and efficient products and services are often still associated with higher purchase costs, over time **the position is expected to shift so that unsustainable products and services become unaffordable**. While defence sector purchasers may in some cases still be reluctant to adopt cutting-edge technology due to concerns about functionality, security and costs, the costs of inaction are rapidly increasing. **Simply adopting common GPP criteria is not sufficient to achieve the transition to sustainable energy and resource use, as there is a need to build capacity and skills on both the supply and demand side to actually deliver sustainable contracts.** This report recommends the adoption of a common strategy by defence sector organisations across the EU, divided into six strands:

- **Strand 0:** Adoption by MoDs of a GPP policy, reflecting energy and climate commitments.
- **Strand 1:** Setting priorities and targets for GPP; monitoring and evaluation.
- **Strand 2:** Needs assessment (internal) and market engagement (external) for GPP.
- **Strand 3:** Pilot and demonstration projects for GPP in the defence sector.
- **Strand 4:** Upskilling of defence sector procurement staff to implement GPP.
- **Strand 5:** Adoption of common GPP criteria and tools by MoDs across the EU.

A majority of MoDs have already adopted a GPP policy or have this under development (Strand 0). To support implementation of the subsequent strands, a number of specific tactical and operational activities are recommended in Section 5. An overview of the existing GPP criteria and tools has been provided for three key procurement categories with a significant environmental footprint:

- **Buildings.**
- **ICT products and services** (including data centres).
- **Heating and cooling equipment** (including on-site renewable energy generation).

It is hoped that the findings and recommendations set out in this report provide a clear starting point for more harmonised GPP implementation amongst defence sector organisations, and that this work will be taken forward under the CF SEDSS and related initiatives.

Annex I - General resources to support implementation of GPP

Table 2.2. General resources to support GPP

Strand 1 **Setting priorities and targets**	**Strand 2** **Needs assessment & market engagement**	**Strand 3** **Pilot & demonstration projects**	**Strand 4** **Upskilling of procurement staff**	**Strand 5** **Adoption of common GPP criteria and tools**
Procura+ Manual – Chapter II Buying Green Handbook – Chapter 1 GPP Training Toolkit – Module 2 Sustainable procurement prioritisation tool	Buying Green Handbook – Chapter 2 SPP Regions Project – Best Practice Report on Market Engagement GPP Training Toolkit – Modules 4 and 6 How to engage the market guide	Horizon Europe – multiple themes relevant to GPP EAFIP funding for pre-commercial procurement and innovation procurement EDA Identifunding tool List of current GPP projects	GPP Training Toolkit – all modules ProcureCompEU Framework German Competence Centre for Sustainable Procurement	EU GPP criteria EU tools for life-cycle costing Overview of national GPP criteria and tools with links German LCC tool picker UNEP tools and international criteria

Annex II – Overview of GPP criteria and tools – Buildings

Building and engineering works are one of the most important GPP categories due to the heavy environmental footprint and long-term impacts of the built environment. Until recently, GPP criteria for buildings tended to focus primarily on energy-efficient design, however the importance of other life-cycle impacts is increasingly recognised in EU and national GPP criteria, including:

- Impact of raw material extraction and production of building materials.
- Use of recycled and recyclable building materials.
- Incorporation of renewable energy systems.
- Impacts of the construction process: transport, noise, energy, water and waste.
- Ventilation and air quality.
- Use of building energy management systems and correct maintenance of equipment.

The current (2016) EU GPP criteria for Office Buildings cover the design, construction, use and demolition phase of office buildings. They address energy efficiency, the use of renewable energy sources (RES), construction materials and products, waste and water management as well as other aspects influencing the environmental impacts of construction: design team experience, monitoring and user aspects. The EU GPP criteria focus on buildings as a system instead of just an accumulation of components. The criteria can be used in tendering procedures for the construction of new buildings, as well as for renovation and maintenance contracts. The criteria were informed by a Technical Background Report and the Commission also published a Procurement practice guide for green office buildings.

In 2021, the revision of the EU GPP criteria for office buildings was announced. The revised proposals will seek to, as much as possible, reflect the priorities set out in the Commission Communication A Renovation Wave for Europe and the New European Bauhaus' initiative. The proposals will also aim to build upon the new European framework for sustainable buildings – LEVEL(s), and consider, among others, revision of the Energy Efficiency Directive and Energy Performance of Buildings Directive. It is also possible that the scope of the criteria will be extended to cover other common building types, such as schools.

THE LEVEL(S) FRAMEWORK FOR SUSTAINABLE BUILDINGS

As legal requirements regarding energy efficiency for buildings have been tightened, there is increasing focus on other environmental impacts within the construction sector. This includes everything from the extraction and processing of raw materials, to the impact of design on health and wellbeing, to construction and demolition waste. These impacts can be difficult to capture within procurement and planning process. As part of the ***Renovation Wave***, the European Commission launched an assessment and reporting framework that provides a common language for the sustainability performance of buildings, called ***Level(s)***.

Level(s) promotes lifecycle thinking for buildings and provides a robust approach to measuring and supporting improvement from design to end of life, for both residential buildings and offices. It uses core sustainability indicators, tested with and by the building sector, to measure carbon, materials, water, health and comfort, and climate change impacts. It also takes into account lifecycle costs and value assessments. The revision of the EU GPP criteria will build upon this approach and can be followed here. Level(s) is open source and freely available to all. Further information and resources are available on the dedicated European Commission webpage on Level(s).

Relevance of EU and national GPP criteria and tools to the defence sector

Defence sector buildings differ to the general public building stock, for example due to the higher use of temporary structures, barracks and campus arrangements. For this reason, EU and national GPP criteria may not be directly relevant for defence organisations. To address this, the following activities are recommended as part of Strand 5:

5a) Setting up a cross-MS working group on GPP for defence sector buildings (this could be a subgroup of WG1 of the CF SEDSS).
5b) Review by the working group of current GPP criteria for buildings to determine their relevance to defence organisations. Participation in the consultation on the new EU GPP criteria for buildings, to ensure the defence perspective is reflected to the extent possible.
5c) Recommendations from working group on GPP criteria and tools to be applied for buildings in the defence sector.

In carrying out these activities, the working group will be able to draw upon the research and resources developed by WG1 to date. In addition, under Strand 2 pilot projects applying pre-commercial procurement or innovation procurement to defence sector buildings could be developed. An example of such a project is using the internet of things to deliver remote automated building management (**Table 2.3**).

Relevant standards

- ISO 14025 and EN 15804 on Environmental Product Declarations.
- ISO 14040/14044 and EN 15978 on Assessment of Environmental Performance of Buildings.
- ISO 13790 and EN 15603 on Energy Performance of Buildings.
- EN 15251 on design and assessment of energy performance of buildings.
- EN 13779 on ventilation for non-residential buildings.
- ISO 50001 on energy management.

Table 2.3. Tools and resources for GPP of buildings

Title	Description	Source
EU GPP criteria for Buildings (2016)	Criteria for the design, build, renovation and management of office buildings	European Commission
ÖkoKauf Wien criteria (2020-21)	Criteria covering building construction and materials	City of Vienna
Belgian criteria for sustainable construction procurement	Criteria cover a number of construction categories	Guide des Achats durables (BE)
Commande publique et économie circulaire dans le secteur du bâtiment	Booklet examining circular procurement of buildings with several examples	RESECO (FR)
Public Procurement of Zero-Emission Construction Sites	Lessons learned from a collaboration of cities as part of the Big Buyers Initiative	Big Buyers Initiative
Public Procurement of Circular Construction Materials	Key takeaways from the Big Buyers Initiative working group	Big Buyers Initiative
Baubook	Austrian database of sustainable building materials with tools to calculate carbon and choose specifications	Vorarlberg Energy Institute
GPP Good Practice examples on buildings	Collection of over 30 examples of GPP implementation in buildings from across the EU	European Commission

Annex III – Overview of GPP criteria and tools – ICT products and services

ICT accounts for an increasing proportion both of procurement spend and emissions/energy consumption in most organisations. The demand for frequent upgrading of devices and hardware has a heavy footprint in terms of raw materials, emissions and pollution linked to production processes, and the management of electronic waste. In the defence sector, security considerations as well as the specialised nature of some ICT equipment can limit the possibilities for refurbishment or reuse. Certain components of ICT equipment (e.g., rare earths) are also linked to conflict and human rights violations, with supply chains vulnerable to disruption.

While the shift to cloud computing and virtualisation has reduced the demand for hardware on client sites, there is increased awareness of the impact on energy demand of **data centres** and the need to take this into account in procurement of outsourced ICT solutions. At EU level, GPP criteria have been developed for computers, monitors, tablets and smartphones (2021) and data centres, server rooms and cloud services (2020). ICT represents one of the most common categories for GPP implementation, with a large number of examples of green contracts and frameworks available. It is also a category where life-cycle costing is particularly relevant, due to the potential to save on operational costs by investing in highly efficient equipment. In 2019, the European Commission published a spreadsheet tool to assist in applying LCC in procurement of computers and monitors. **Table 2.4** summarises the key environmental impacts of ICT and the relevant GPP approaches.

Table 2.4. ICT: Key impacts and GPP approach

Key environmental impacts	GPP approach
Climate change effects linked to energy consumption of ICT products and services Impact on air, water, soil, biodiversity and human health of hazardous substances found in ICT products Climate change effects and natural resource depletion linked to the manufacturing, delivery and disposal of products Impact of mining and processing of rare earths and other components Environmental impacts of battery production and disposal End-of-life impacts including release of hazardous substances	Specify highly energy efficient ICT products and data centres Specify ICT products which are free of hazardous substances or contain these in minimal amounts considered to be safe Measures to extend product lifespan including service level agreements, warranty, availability of spare parts and repairability of products Measures to improve battery endurance and performance Testing for durability Criteria to ensure interoperability and reusability of components Encourage the use of recycled plastic in ICT equipment Application of life-cycle costing Ensure equipment can be effectively recycled or reused; require reporting on end-of-life destination

Relevance of EU and national GPP criteria and tools to the defence sector

As noted, some of the ICT equipment and services used by the defence sector are distinct from civilian versions. This may limit both the ability to apply certain GPP criteria (e.g., relating to refurbished equipment, or end-of-life treatment) and the ability of the market to respond, if a more limited pool of contractors is relied upon by the defence sector. To determine the scope and relevance of any such constraints, and to support the development of common GPP approaches across MoDs, a working group should be established to review and comment upon the existing EU and national GPP criteria for ICT **(Table 2.5)**. In areas where defence organisations have distinct ICT needs, and there is currently a lack of sustainable solutions available on the market, **pilot projects applying pre-commercial procurement and/or innovation procurement** to develop relevant solutions should be supported.

Relevant ecolabels

- EPEAT/IEEE 1680.
- TCO Certified.
- TÜV Green Product Mark.
- Blue Angel.
- GreenScreen Certified.
- Energy Star (no longer applicable to products unless they are marketed in the US or Canada. See further information on the expiry of the EU-US Agreement on EnergyStar – see here).

Table 2.5. Tools and resources for GPP of ICT

Title	Description	Source
EU GPP criteria for computers, monitors, tablets and smartphones (2021)	Common criteria addressing the main environmental impacts of ICT equipment	European Commission
EU GPP criteria for data centres, server rooms and cloud services (2020)	Common criteria addressing the main environmental impacts of data centres and associated services	European Commission
Life-cycle costing tool for computers and monitors	Spreadsheet based tool to facilitate LCC application in tenders	European Commission
Topten.eu	Independent ranking of most efficient products on EU market, including laptops, screens, phones	Topten Switzerland/EASME
Swedish GPP criteria for ICT	Criteria covering computers and screens, imaging and AV equipment	Swedish Agency for Public Procurement
Dutch GPP criteria for ICT	Criteria covering ICT hardware and networks	Government of the Netherlands
Advice on greening ICT procurement	Memo providing tips for green and circular ICT procurement	Municipality of Aalborg
GPP Good Practice examples on ICT	Collection of examples from across the EU	European Commission

Annex IV – Overview of GPP criteria and tools – Heating and cooling equipment

Heating and cooling systems, including the use of on-site renewable energy systems, can be one of the more technically challenging areas for the application of GPP. While EU legislation and product standards have evolved to support such systems, and in some cases incentives and subsidies are available, take up is still limited by perceived and actual technical, operational and financial barriers. For example, replacing fossil fuel boilers with heat pumps can require prior works to buildings to make them suitable for upgrading, and may also require retraining of facilities managers. Initial purchase/installation costs may only be compensated for by lower operational costs over many years.

EU GPP criteria currently exist for Water-based heaters (2014), and other aspects of heating and cooling equipment are covered in the criteria for Office Buildings (2016). National criteria are also available to cover specific technologies such as heat pumps and solar thermal heating equipment.

Relevant legislation and standards

EU Energy Label: A new space or water heater or solid fuel boiler (up to 70 kW) comes with an energy label showing its energy efficiency class. As of 1 January 2019, suppliers (manufacturers, importers or authorised representatives) need to register products requiring an energy label in the European Product Database for Energy Labelling (EPREL). For individual products, ratings may range from G (least efficient) to A+++ (most efficient). It is also possible to buy a combination of technologies, such as a boiler with a solar hot water storage tank, in order to reach an A+++ energy efficiency rating. Under the current **Energy Efficiency Directive**, public bodies should purchase products in the highest available energy class, unless this would lead to insufficient competition. **Article 6 of the current EED** requires central government contracting authorities to apply the minimum energy-efficiency and Ecodesign requirements set out in Annex III to the Directive. However, it is possible to justify deviations from these requirements where they are inconsistent with cost-effectiveness, economic feasibility, wider sustainability, or sufficient competition. **It is proposed to remove this justification under the revised EED**. A specific clause in the current EED provides that the requirements only apply to armed forces contracts to the extent that they do not cause any conflict with the nature and primary aim of the activities of the armed forces, and that they do not apply to procurement covered by the Defence Procurement Directive. **It is proposed to retain this justification under the revised EED.** The **Ecodesign** regulations set requirements for energy efficiency, nitrogen oxide emission levels, volume for storage water heaters, heat losses from hot water storage tanks, and a range of other criteria. From September 2018 space heater and combination heaters must meet all of the requirements set out in Regulation (EU) 813/2013 and water heaters must meet all of the requirements set out in Regulation (EU) 814/2013. From 1 January 2020 all solid fuel boilers must meet the requirements of Regulation (EU) 2015/1189. The revisions proposed to the RED, EED and EPBD in 2021 will significantly impact the classification of sustainable heating and cooling equipment, for example through the application of definitions of sustainable biomass and minimum energy standards for public sector buildings.

Relevance of EU and national GPP criteria and tools to the defence sector

As with the buildings category, procurement of heating and cooling equipment by the defence sector may differ from typical civilian public sector applications. This may present opportunities as well as constraints/challenges – for example, the use of district heating may be facilitated by campus-style configurations of buildings. For this reason, it is recommended that a working group be established to review available EU and national criteria for heating and cooling and develop ideas for pilot projects **(Tables 2.6-2.7)**.

Table 2.6. GPP approach for heating and cooling

Key environmental impacts	GPP approach
Energy consumption in use phase Hazardous substances used in production process Emissions of greenhouse gases, NOx, OGC, CO and PM in use-phase, due to fossil fuel combustion or heat pump refrigerant leakage Suboptimal performance due to incorrect usage or maintenance Noise in use phase	Specify minimum energy efficiency levels, ensure compliance with ecodesign principles and correct installation and commissioning Award marks for products with lower GHG and pollutant emissions, refrigerants with lower global warming potential Require comprehensive user instructions to be provided with products and contract clauses to ensure contractor is responsible for ongoing environmental performance Award marks for products with noise emissions below set limits

An example of public procurement targeting renewable heating systems is Oslo, Norway. Twelve proposals were put forward as part of the competition and four were awarded. Some of the technologies include ground solar heat collectors, ground heat pumps and air-to-liquid heat pumps. Bio-oil, bio-gas, solid biofuel, and various combinations of these are also now used instead of fossil fuels in Oslo's schools.

Table 2.7. Tools and resources for GPP of heating and cooling equipment

Title	Description	Source
EU GPP criteria for water-based heating equipment (2014)	Criteria addressing a range of heating technologies including biomass boilers, cogeneration, heat pumps and solar collectors	European Commission
EU GPP criteria for Buildings (2016)	Criteria for building design and facilities management including HVAC systems	European Commission
Irish GPP criteria for Energy-related products (2021)	Includes air conditioning and solar devices	Irish Environmental Protection Agency
Belgian criteria for sustainable procurement	Criteria include heating and cooling equipment	Guide des Achats durables (BE)
ÖkoKauf Wien criteria (2018-2021)	Criteria covering a wide range of heating and cooling technologies	City of Vienna
French guidance on sustainable procurement	Covers numerous categories including heating and cooling equipment	French Ministry of the Economy
Topten.eu	Independent ranking of most efficient products on EU market, including various types of heating and cooling equipment	Topten Switzerland/EASME

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European Commission COM (2020) 98 *A new Circular Economy Action Plan for a cleaner and more competitive Europe*

European Commission COM (2020) 798 *Proposal for a Regulation concerning batteries and waste batteries*

European Commission COM (2021) 558 *Proposal for a Directive on energy efficiency (recast)*

European Commission COM (2021) 557 *Proposal for a Directive as regards the promotion of renewable energy*

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3. Barriers to success and solutions to implementing energy efficiency measures in defence buildings and sites

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Abstract

The European Defence Agency (EDA) and the armed forces of its member states are committed to reducing green-house gas (GHG) emissions in line with European Union (EU) and national targets. The overall target is to achieve net zero emissions by 2050 at the latest with an intermediate target of a 55% reduction by 2030. Many of the EDA member states have already started the journey to significant GHG reductions. The achievement of these targets requires considerable effort and planning both at strategic and tactical levels. The various solutions available include energy conservation, energy efficiency, fuel switching and renewable energy. Of the solutions available energy conservation and energy efficiency are the lowest cost[93] and the quickest to implement. However, they are not achieving their potential in the defence sector, in common with many other sectors of our economies. The purpose of this report is to investigate the barriers to successfully implementing energy efficiency measures in the defence sector and to propose solutions to those barriers. The opinions of all the member states are examined in conjunction with the experience of the contractors in supporting the implementation of energy management systems and energy efficiency measures among EDA members.

Executive summary

This study was conducted in the context of the work of the CF SEDSS III Working Group 1 on Energy Efficiency and Buildings. EDA member states are committed to reducing green-house gas emissions in line with European Union targets of achieving net zero emissions by 2050 with an intermediate target of 55% reduction by 2030. International research, including the recent IPCC AR6 report, has shown that energy efficiency is one of our most important tools in achieving these targets. Indeed, energy efficiency is regarded as "the first fuel" by the EU and by the International Energy Agency (IEA).

Energy efficiency improvements have been implemented throughout all EDA member states for many decades. However, these have often been completed in an unsystematic manner and have not achieved the full potential that exists. The main objective of this study was to highlight the potential that exists for energy efficiency to play a significant role in achieving defence environmental goals, particularly in relation to climate change mitigation. A related objective was to identify the barriers that exist to achieving the full potential that energy efficiency presents to EDA member states and to outline potential solutions to those barriers. Some of the barriers identified are specific to the defence sector but most are common across the public sector and the private sector.

The inputs to the study were the expertise and experience of the authors in relation to energy efficiency and decarbonisation in the private and public sectors internationally and specifically in the defence sector in Europe. The learnings from the EDA Defence Managers' Energy Course (DEMC) were also considered as well as the responses from EDA members to a questionnaire developed as part of the study. The study highlighted the 4 R's of decarbonisation planning (UNIDO, 2015). There are Reduce, Reuse, Refuel, and Redesign. The first step (Reduce) being based on reducing energy waste and improving energy efficiency. The more energy efficient an installation is, the less energy is required from all sources including renewable energy.

93. Note that some energy efficiency measures have relatively low cost and fast financial paybacks while others such as deep retrofitting of building fabric are typically high cost with very long payback periods. The financial viability of the higher cost measures will be significantly influenced by the availability of financial supports and grants, whether these be from the EU or from the relevant MoD.

In addition to being a critical first step in the transition to net zero emissions, energy efficiency has many other benefits. These include:

- Reduced cost and reduced exposure to volatile energy prices.
- Improved security of supply, which is currently of paramount importance in the context of the energy crisis resulting from the invasion of Ukraine by the Russian Federation.
- Reduced local pollution and consequent reduced health risks from the combustion of fossil fuels within military installations.
- Improved comfort levels, process stability, and productivity resulting from improved operational control of buildings energy consuming systems.
- Reduced exposure to attacks on logistics convoys in deployments, and refuelling operations of ships and aircraft in theatre operations.

If the recommendations of this study are followed, the results will be significant in terms of climate change mitigation and all the other benefits listed above. The most common barrier identified by the respondents to the questionnaire was "lack of priority given to energy efficiency". This corresponds with the professional experience of the authors in the public and private sectors. It also corresponds closely with the experience gained during the EDA DEMC. The DEMC produced many very impressive results in specific installations. It also produced very poor results in others. The most critical success factor was commitment from senior leaders connected to enthusiasm from the energy managers and the energy teams. High levels of commitment and leadership will result in increased levels of priority, increased levels of funding, increased awareness, and increased support from senior levels. One of the important solutions is increased levels of knowledge among relevant personnel of several topics:

- Principles of energy efficiency.
- Decarbonisation strategy, planning, and target setting.
- Technical knowledge of building energy systems including automation systems.
- Energy related data collection, analysis, and interpretation. This applies to the development of energy and carbon baselines and energy and carbon performance indicators and the understanding of decision makers of what they mean.

An overarching solution to all the identified barriers is the development of a strategic approach to decarbonisation based on the systematic management of all its components including people management, information management, and technology management. This will be aided by the new extension standard to ISO 50001 under development by ISO. The new standard integrates decarbonisation activities into energy management systems and includes energy efficiency, renewable energy, fuel switching etc.[94]

The next steps could include:

1. Promulgate this study to decision makers including the presentation of the results at CF 2023, Malaga, Spain.
2. Include some sessions at CF 2024 on developing solutions to the identified barriers and to any other barriers considered by the delegates.
3. Promote increased levels of commitment, leadership, and support among senior decision makers in the defence sector.
4. Develop a capacity building programme around an integrated approach to decarbonisation management. The scope of this study is limited to energy efficiency, but other components are required, and they don't stand alone. For example, fuel switching, and renewable energy sources are other critical components of the pathway to decarbonisation.
5. Consider using a hybrid EnMS as the basis of a decarbonisation management system.

94. Liam McLaughlin, the lead author of this study is the co-leader of the new ISO decarbonisation standard. He represents the United Nations Industrial Development Organisation in this role.

3.1. Introduction

3.1.1. Problem analysis

Energy efficiency is widely viewed as one of the most effective ways to achieve multiple economic, social, and environmental benefits and is at a core of making significant progress towards Sustainable Development Goals (SDGs). It is also recognised that significant progress is being made in energy efficiency. However, the improvements are not fast enough to reach the rate necessary for limiting global temperature rise of no more than 2 degrees Celsius (and preferably 1.5 degrees) by 2050 as stated in the Paris Climate Agreement (UNECE, 2017).

Energy efficiency is regarded as "the first fuel" by the EU and IEA. It is one essential component of strategies to decarbonise military buildings and is the lowest cost and quickest part of these strategies. The Defence Sector has been active in implementing energy efficiency measures and initiatives for many years and adapts well to changing legal and other requirements at a high level. It is apparent however, that at individual site/building level, there is often a difficulty implementing basic energy efficiency measures. Where these are successful and where behavioural issues are addressed, it may be the case that maintaining momentum in subsequent years is also difficult. This creates situations where previously addressed issues are occurring again. There are many potential reasons for this, including high turnover of military personnel and/or to a lack of sufficient resources and expertise.

The infrastructure on most of the military sites includes older building stock. This is usually maintained by a small pool of military, Ministry of Defence (MoD) or externally contracted personnel. It is possible that basic measures addressing energy efficiency in infrastructure could yield significant savings if carried out in a prioritised manner and at scale. In many cases, maintenance personnel have the technical ability of implementing these works but fail to do so in an efficient and effective manner. In addition, this low cost, high reward work is not normally prioritised in the context of larger energy and non-energy-related infrastructural projects which have more tangible outputs.

The purpose of this study is to investigate, in the context of sound policy implementation at strategic and operational level, what if any, are the barriers to successful implementation of energy efficiency measures at the tactical (site / building) level and what are the proposed solutions to these barriers. The study will provide a list of clear recommendations applicable in the defence sector. Recommendations will be used for a variety of purposes by MoDs such as supporting business cases for employment of personnel, training, and education, including up/re-skilling and investment in infrastructure and technology (EDA 22.RTI.PO.350 Service Request).

3.1.2. Aim of the study

The aim of this study is primarily to identify the barriers to energy efficiency in defence buildings and to propose solutions to these barriers to maximise the potential benefits of energy efficiency in the defence sector in EDA member states. As demonstrated elsewhere, energy efficiency is a critical component of the transition to a decarbonised future.

3.1.3. Study objective

The objectives of this study are:

- Demonstrate how energy efficiency contributes to decarbonisation strategies and the achievement of defence environmental policy goals relating to climate change adaptation and the use of energy resources.
- Align with the requirements of an effective systematic approach to energy management such as that developed by the EDA Defence Energy Managers Course (DEMC) programme or equivalent. These would be based on the requirements of ISO 50001. [It is notable that ISO committee 301 with responsibility for energy management within the International Organisation for Standardisation (ISO) is currently developing materials and supports to increase the effectiveness of ISO 50001 and its sister standards around decarbonisation management.]
- Provide a profile (partial) of existing energy efficiency initiatives in the defence sector. Relevant sources may (indicatively and not exhaustively) refer to feedback from MoDs through dedicated questionnaires circulated in the previous phases of the CF SEDSS project as well as during Phase III and search of Tenders Electronic Daily (TED) to identify relevant notices, etc. The contractor may call on previous documented experience, if any, working with the defence sector.
- Provide a comparison detailing similarities between difficulties experienced in the defence sector and in other (non-defence) sectors.
- Identify gaps, potential obstacles, and barriers to a harmonised implementation of energy efficiency.
- Consider these gaps, obstacles, and barriers in the context of sound policy implementation at higher strategic and operational levels (for present and future situations).
- Provide a detailed list of recommendations which will aid MoDs address energy efficiency gaps, obstacles, and barriers at the tactical level.
- Included in the recommendations, provide a flowchart (or aide memoire) easily detailing prioritised measures to address energy efficiency in military buildings. This should be aimed at maintenance personnel with technical skills but not necessarily energy-specific technical skills. It should allow maintenance personnel to confidently carry out logical upgrades at scale across military building stock making good use of time and resources while gaining value for money.
- Propose indicative actions that the EU should undertake to contribute to the MoDs to implement the proposed solutions.

(Source: EDA 22.RTI.PO.350 Service Request)

3.1.4. Conceptual approach of the study to address the problem

Personal experience of the authors, results of questionnaires, and interview are combined with literature research to objectively identify the relevant barriers to energy efficiency and to propose practical solutions to these barriers. The authors have extensive experience of working with EDA member states in supporting the improvement of energy efficiency in military buildings. This experience includes developing and running the EDA Defence Energy Managers Course over a period of 6 years, interacting with, and visiting many military installations across Europe. The DEMC highlighted many strengths and weaknesses and many common barriers among participants.

3.2. Methodology

The methodology used in this study was to review existing literature from EDA and other sources on barriers to energy efficiency. This was combined with questionnaires completed by EDA member states as a further source of information. The personal experience of the authors based on over 20 years working in energy efficiency in the private sector, public sector, and the defence sector have also influenced the study. A particularly relevant piece of experience was the development and delivery of the EDA DEMC. That programme was very relevant to this study.

Another input to the study were interviews conducted with personnel from member states with knowledge of the topic of energy efficiency in military buildings.

3.3. Context

Working Group 1 on Energy Efficiency and Buildings Performance of the CF SEDSS III is concerned with knowledge management and capacity building around energy efficiency and buildings energy performance in the defence sector. While these topics are central to the effective decarbonisation of buildings in the defence sector, previous research and experience shows limited success. This study aims to support the bridging of the gap between current reality and potential benefits. Energy efficiency is a critical pillar of decarbonisation activities across all of society and nowhere more than in buildings.

Care is needed in the use of the term energy efficiency. In engineering terms energy efficiency is thought of as output divided by input, e.g., we talk of a boiler being 80% efficient. Simply increasing the energy efficiency of an energy systems does not necessarily reduce the energy consumption and corresponding greenhouse gas (GHG) emissions from that system. To reduce GHG emissions through energy efficiency measures, we need to reduce absolute consumption of fossil fuels and move to the use of energy sources with reduced or no associated GHGs.

There are two types of GHG emission associated with military buildings:

1. Scope 1[95] emissions are GHG emissions directly emitted from the facility. In the context of energy consumption of military buildings, scope 1 emissions result from the combustion of fossil fuels in heating systems.
2. Scope 2 emissions are from purchased energy where the emission occurs outside the boundary of the facility. The most common scope 2 emissions are from the use of electricity imported from the local electrical grid. District heating systems are another example of scope 2 emissions in use in European defence forces.

To reduce scope 1 emissions related to energy use, it is necessary to reduce the quantity of fossil fuels combusted onsite. This can be achieved through energy conservation[96], energy efficiency and/or through fuel switching including electrification of some processes where the emission factor of the electricity is less than the emission factor [97]of

95. The terms Scope 1 and Scope 2 come from the Greenhouse Gas Protocol (https://ghgprotocol.org/) GHG Protocol supplies the world's most widely used greenhouse gas accounting standards. The Corporate Accounting and Reporting Standard provides the accounting platform for virtually every corporate GHG reporting programme in the world.
96. The difference between energy conservation and energy efficiency can be ambiguous. In this study the term energy conservation is used to mean no cost or low-cost energy saving measures, similar to the concept of operational control in ISO 50001. The cost of energy conservation measures can typically be met from operational budgets (OPEX). Energy efficiency is used for energy saving measures which require capital expenditure (CAPEX).
97. An emission factor (EF) is a coefficient that describes the rate at which a given activity releases greenhouse gases (GHGs) into the atmosphere. For example, natural gas might have an EF of 184 g/kWh. They are also referred to as *conversion factors*, *emission intensity* and *carbon intensity*.

the fossil fuel being replaced. A practical and common example of electrification is the substitution of a fossil fuelled heating boiler with an electrically powered heat pump. Partial decarbonisation can also be achieved by switching to a boiler fuel with a lower carbon emissions factor than fossil fuels. These can include biofuels and biomass. Care is needed in selecting these fuels to ensure that they are genuinely and certifiably low carbon.

And to reduce scope 2 emissions, it is necessary to reduce the quantity of electricity, district heating or district cooling energy imported or to reduce the emissions factor of the electricity consumed. Electricity emission factors are reducing throughout Europe as electrical grids are decarbonised. Onsite generation of electricity using renewable sources such as solar photovoltaic or wind turbines will also reduce the emission factor to zero for the renewably produced electricity. Offsite generation of electricity using a Power Purchase Agreement (PPA) will have the same result.

The decarbonisation of military buildings has many components including energy conservation, energy efficiency, heat recovery, fuel switching, electrification, renewable energy generation, etc. This study will focus on energy conservation and energy efficiency.

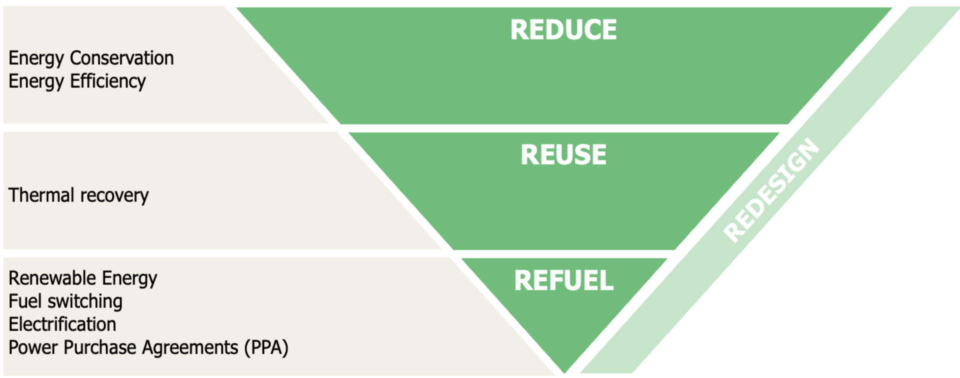
3.3.1. The 4R's of decarbonisation planning

Figure 3.1 shows the 4Rs of decarbonisation planning:

- Reduce
- Reuse
- Refuel
- Redesign

The concept being that we should reduce consumption as the first step, we should then reuse energy, typically through heat recovery. The remaining energy requirements should be provided from renewable sources (Refuel). The content of this report will touch upon all 4 of these with the main emphasis on REDUCE through energy conservation and energy efficiency.

Figure 3.1. The 4R's of decarbonisation planning



3.4. Problem analysis

3.4.1. Benefits of improving energy efficiency

The main benefits of improved energy efficiency in the defence sector include:

1. Reduced cost of energy through reduced energy consumption.
2. Reduced exposure to rising, and increasingly unpredictable, energy prices.
3. Improved security of supply, particularly considering the impact on energy supplies amidst the ongoing Russian – Ukraine war.
4. Reduced GHG emissions from the consumption of energy.
5. Reduced local pollution from combustion of fuels together with corresponding reduction of health risks.
6. Improved comfort levels in buildings through improved operational control and other energy efficiency measures.
7. Improved health through more stable indoor environmental conditions.

Additional benefits outside the scope[98] of this study include:

1. Increased operational capability and energy resilience of the armed forces.
2. Reduced exposure to attacks on logistics convoys in deployments, and refuelling operations of ships and aircraft in theatre operations.

It is notable that even though energy efficiency is the lowest cost and fastest to implement component of decarbonisation planning, it often faces the highest barriers. There is a wide range of measures that can be taken to reduce the energy consumption of buildings. The implementation cost and financial returns of these vary significantly. There is a continuum of financial returns from measures that can return their cost on days or weeks to others that have financial return over two or three decades. The latter includes deep retrofitting of buildings. The latter will require significant financial investment with a requirement for a very strategic approach to their planning. It is recommended that the lower cost items be implemented first as they will typically reduce the cost of all other subsequent measures.

The following are examples of energy conservation/energy efficiency measures with increasing cost of implementation and increasing payback times:

1. Adjustments of settings in building management systems or equipment including time schedules, operating temperatures and pressures, condensing temperatures, together with switching off unnecessary equipment such as boilers, pumps, chillers, etc. These items will return their cost in days or weeks.
2. Investment in re-commissioning of building energy systems including balancing of heating systems and associated pumps or the addition of CO_2 control to ventilation systems for large areas especially with variable occupancy or simple draught-proofing of buildings. These measures can return their cost within months.
3. Installation of variable speed drives on pump and fan motors or insulation of hot pipes and vessels or improved control of heating systems including room temperature and boilers. These measures can have paybacks of one to two years.
4. The installation of heat pumps as replacements for oil or gas boilers can have a payback of 5 or more years if the building fabric is suitable for such a measure.
5. Upgrading of doors and windows can have paybacks of 5 to 10 years.
6. Deep retrofit of buildings including insulation of external walls or floors can have payback in excess of 20 years.

98. The scope of this study is limited to energy efficiency in military building in permanent installations. It does not include energy efficiency in military operations.

3.4.2. Introduction

In the initial analysis, the barriers are grouped under three headings, people, technology, and information. The people related barriers are those where human behaviour including decision making are involved. They include knowledge of the necessary processes for improving the energy efficiency of buildings. The technology related barriers are those where technical solutions are required and are not available or not widely understood. It is not expected that there are many technical barriers to improving energy efficiency of buildings. The data related barriers relate to methods used to quantify energy efficiency improvements resulting from improvements made or in developing and understanding different energy performance indicators.

a) People

- Low levels of commitment or support from senior personnel. This is often manifested as:
  - Lack of time to devote to energy efficiency measures.
  - Energy efficiency being a low priority compared to other tasks.
- Limited expertise in relevant technology and/or data collection and analysis.
- The belief that there are no barriers, and that energy efficiency is already in place and is effective.
- Organisational complexity including diverse responsibilities across different structures.
- The need for behaviour change in many aspects of energy use in military buildings. This includes decision making, design, and operational control.

b) Information

- Lack of expertise in the development of effective indicators.
- Lack of expertise in interpreting data for decision making.
- Lack of data due to inadequate metering or data collection processes.
- Lack of data due to delays in sharing information, for example, sharing energy invoices.
- Less than optimum analysis and reporting frequencies, for example reporting monthly, based on 6-week-old information is not optimal for quick and effective response to anomalies.
- Potential to improve knowledge management.

c) Technology

- Conservative approach to the adoption of new technology.
- Difficulty and cost of upgrading older and sometimes listed buildings.
- Limited knowledge of the potential, specification and efficient operation of heat pumps and other equipment and system.
- Limited experience of the potential to recover heat in some applications where cooling towers or chillers are used.
- Knowledge about automation, Internet of Things (IoT) and digitalisation.

3.4.3. Barriers identified by respondents

Table 3.1 shows the barriers identified by the respondents to the first questionnaire. The count column shows the number of mentions of the barrier and the category column groups the barriers in different categories. The list is in order of frequency of mention. Repeated mentions of the same barrier by the same respondent are counted only once. The following pages will discuss each of these barriers. It should be noted that there was a diverse range of responses to each question. Thus, some with many mentions are not seen as barriers in other member states.

Table 3.1. List of barriers identified by respondents to the initial questionnaire

Count	Barriers identified	Category
10	Lack of priority given to energy efficiency	Commitment
9	Significant number of old buildings with low energy efficiency requiring significant investment	Structural
6	Lack of energy metering and data to enable analysis	Data
6	Lack of technical knowledge of energy efficiency in operations and maintenance	Training
5	Lack of funding for investment	Finance
5	Accountability at lower levels (mixed messages, some high, some low)	Management
5	Lack of working knowledge of different types of energy performance indicators	Data
5	Low level of uptake of verification of energy savings from completed projects	Management
4	Lack of knowledge of building automation systems and their functionality.	Training
2	General lack of energy awareness	Management
2	Lack of human resources	Commitment
2	Lack of a coherent energy policy and alignment of goals	Commitment
1	Lack of centralised control systems	Technical
1	Cost of energy is not a priority	Commitment
1	Lack of support from senior levels	Commitment

Each of these barriers is discussed further below.

a) Lack of priority

The most mentioned barrier is the lack of priority given to energy efficiency in routine operations and decision making. This is despite many respondents highlighting that decarbonisation and energy efficiency are important topics at senior levels. This is also despite the persistent messaging internationally about the importance and benefits of energy efficiency.

It is also obviously a very significant barrier in that other issues are unlikely to be addressed appropriately in the absence of an adequate level of priority being assigned to this topic. The causes of this barrier needs to be further analysed and appropriate corrective actions taken. A lack of genuine commitment to decarbonisation is a possible cause. Another possible cause is lack of understanding of the potential offered by energy efficiency.

Military operations and resilience will always take priority over less urgent priorities such as energy efficiency and decarbonisation. However, this is the same in almost all sectors. Normal operations, health, safety, etc will always be a higher priority.

b) *Old buildings*

It was mentioned many times that a large proportion of military building stock are old, in some cases, hundreds of years old. This implies poor standards of insulation, air tightness, controlled ventilation, and other aspects of energy efficiency. The cost of renovation of old buildings is very high and financial paybacks very long for deep retrofit measures. More recently there are public sector financial incentives to mitigate against this. This barrier is inherent in the sector and will require a strategic approach to allocating the large investments required. Some member states already have strategic approaches in place and their experience could be shared across all members.

This process will take time, several decades in most cases. Interim measures to reduce energy consumption and related carbon emissions include the systematic application of energy conservation measures requiring low investment and giving quick financial returns.

c) *Lack of metering and energy data*

While many installations have adequate metering installed, many others do not. Adequate energy metering and appropriate application of energy data analysis techniques have many benefits including:

1. Support for decision making in relation to building upgrades and investment.
2. Identification of deviations from optimum operating conditions.
3. Verification of and demonstration of the effectiveness of implemented energy saving measures.

A related barrier, discussed below, is lack of technical knowledge related to the analysis and interpretation of energy data and energy performance indicators.

3.4.4. Responses to numerical questions

Figure 3.2 shows the responses to the numerical questions in the initial survey.

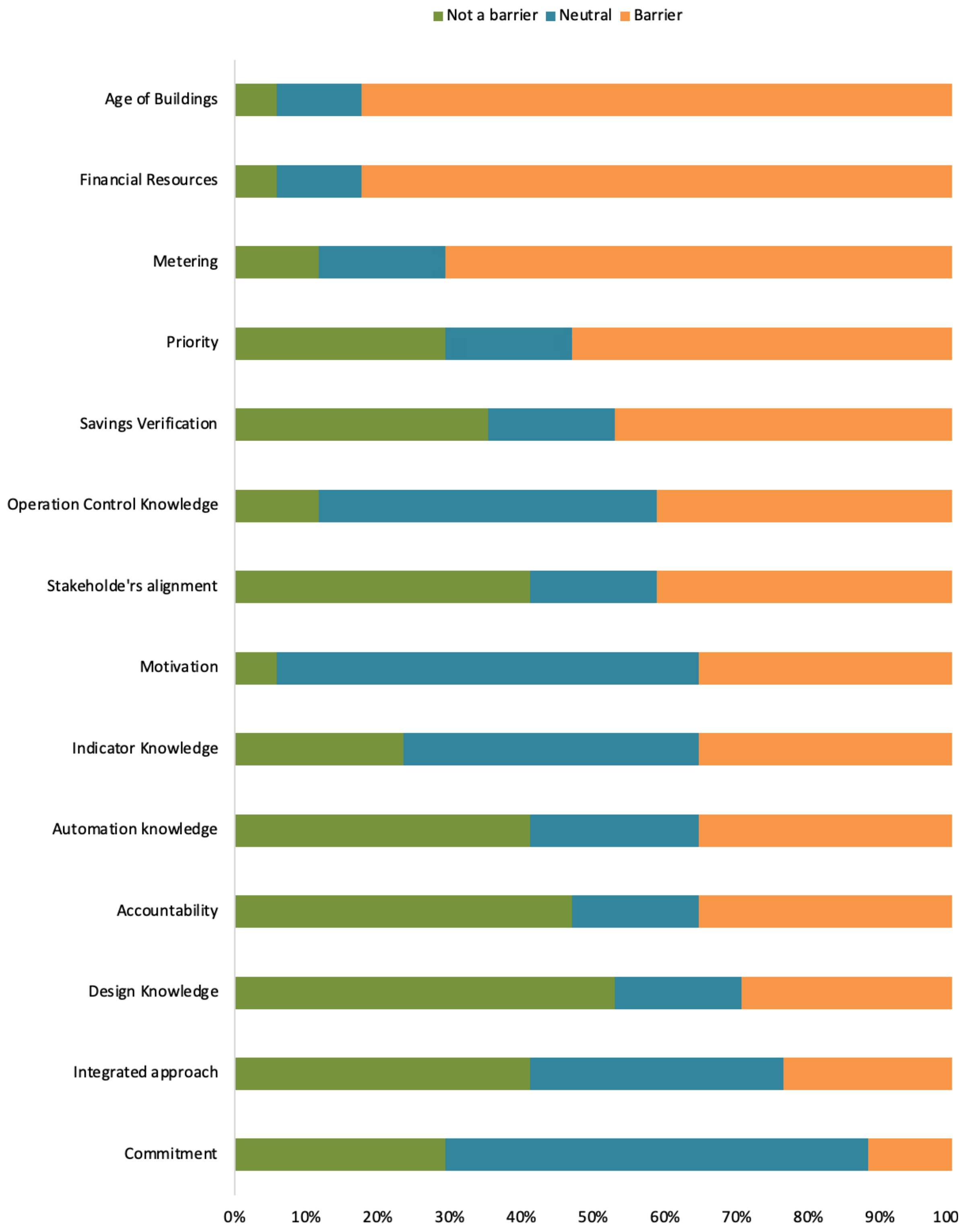
- The orange colour indicates those who saw the barrier as a significant barrier (score 4 or 5).
- The green colour indicates those who did not consider the factor to be a significant barrier (score 1 or 2).
- The blue colour indicates the respondents who were neutral in their scoring (score of 3).

Overall, the scores largely match the observations above. However, these is one area that needs some thought. That is related to the level of commitment of senior decision makes. Only 10% saw lack of commitment as a significant barrier. 30% did not consider it as a barrier and 60% were neutral on the topic. However, some of the other scores seem to contradict the assumption that there is a high level of commitment from senior levels. Specifically, 50% of respondents stated that lack of priority for energy efficiency measures is a barrier. A significant number (30%) also saw lack of motivation and lack of accountability as barriers and 40% saw lack of stakeholder alignment as a significant barrier.

These results seem contradictory. If there is genuine commitment, then one would expect the topic to be given a higher priority, with increased levels of stakeholder alignment, motivation and accountability being in place. It is suggested that this aspect be investigated further to establish if there is strong commitment and support from senior levels in reality.

The top three barriers, age of buildings, financial resources and energy metering could all be considered to be related to each other with the common thread of the need for financial investment. The availability of finance could also be related to lack of commitment from the decision makers who allocate financial resources.

Figure 3.2. Responses to numerical questions in the initial survey



General comment on all the above barriers

One measure that would help to bridge all the above barriers is the effective implementation of a decarbonisation management strategy at the top level accompanied by aligned decarbonisation systems at the tactical levels. This could be readily modelled on the DEMC and use ISO 50001 as a basis. There are significant efforts globally to modify the principles of energy management systems to become decarbonisation management systems. An example is from the US Department of Energy (2022). Another example is in current work by ISO Technical Committee 301, which is developing an extension to ISO 50001 to integrate decarbonisation into energy management systems. Solutions to all the barriers are included in an effective energy management system including the management, data analysis, financial and technical aspects.

3.4.5. Comparison with other sectors

In the experience of the authors there are few sectors where the benefits of energy efficiency have been adequately addressed. There is strong evidence from the research of the United Nations Industrial Development Organisation (UNIDO) of the general lack of progress with energy efficiency in the industrial sector and is pushing for more integrated and systematic approaches to the topic (UNIDO, n.d.). The United Nations Economic Commission for Europe (UNECE) is also working in this area (UNECE, n.d.). Most sectors, including defence, believe that their sector is different to others and that this makes it more difficult for them. In terms of energy efficiency in buildings, the authors do not believe that this is a significant issue.

a) Advantages of the defence sector

The defence sector in general has a higher level of engineering education and experience than comparable organisations in the private sector. This knowledge is not specifically related to practical energy efficiency experience. This is especially the case in relation to buildings energy. Commercial building owners in the private sector do not tend to have in-house technical expertise related to energy efficiency. This is a significant advantage to the defence sector and could be further exploited through increased education and training in the fields of decarbonisation and energy efficiency.

b) Disadvantages in the defence sector

Military officers undergo regular reassignment between roles and locations and thus their knowledge and experience move with them. New appointees must then undergo a learning curve to reach the necessary competence levels in operational energy efficiency. In some cases, military buildings undergo regular change of use, probably more often than other sectors. This requires careful planning to optimise energy efficiency as the use of a building changes. The concepts of Retro-Commissioning (RCx) very much apply.

Financial rules in the public sector often do not align with the necessary needs to effective long-term investments in energy efficiency. Although investment in renewable energy solutions appear to be becoming very common. The private sector has more experience over a longer time in implementing energy efficiency measures and in the more progressive organisations, energy management and energy efficiency have become integral parts of their organisational cultures. The private sector is also more aware of the need for cost control due to their inherent profit motive.

The financial environment is not very favourable for investments in energy efficiency. Familiarity of financial institutions with financing energy efficiency projects and measures is relatively low in many countries of the world, including developed countries and countries with economies in transition in the UNECE region. Financial institutions view financing of energy efficiency projects significantly riskier compared to other types of business projects. Conditions for repayment and servicing energy efficiency loans with savings generated from improved efficiency are considered generally more favourable for projects in the public sector than for projects in the private sector but in most cases, they are not too favourable (UNECE, 2017). This situation is changing in the years since the UNECE report was written in that rising energy costs make energy efficiency investments more economically attractive. A very common barrier across all sectors is the low priority given to energy efficiency as it is not a core business activity. This seems to be particularly strong in the defence sector. Whether it is justifiable or not is debatable given that climate change is seen as a security threat. Low awareness of the multiple benefits of energy efficiency is common across all sectors.

3.4.6. Target group affected by the problem

Personnel/groups who will be affected by the current limited success of energy efficiency measures in military buildings include those with responsibility for:

1. Financial performance within the installation, the defence forces, and public sector.
2. Environmental performance of the installation, the defence forces, and public sector.
3. Those with responsibility for climate action within the installation, the defence forces, and public sector.
4. Health and welfare of building occupants due to improved indoor conditions when buildings are operated efficiently.

These are the groups who will benefit most from the removal/minimisation of the relevant barriers. These groups could be beneficially involved in investigating solutions to the identified barriers.

3.5. Solution implementation

Table 3.2 shows solutions proposed by the respondents to the initial questionnaire. They are in order of frequency with the most frequent shown first. The table is in two parts; the first is those items with more than two mentions and the seconds with two or fewer mentions.

Table 3.2. Solutions proposed by respondents to the initial questionnaire

Count	Solutions	Category
8	Need for significant renovation programmes for military buildings	Finance
7	Increase availability of funding for investment	Finance
7	Training in all aspects of energy efficiency including technical, data analysis, management	Training
6	Increase awareness at all levels of the need for change and the benefits of energy efficiency	Commitment
5	Increase availability of EU funding for energy efficiency in military buildings	Finance
5	Implement a systematic approach to energy management and energy efficiency	Management
4	New energy efficiency organisation with resources and knowledge	Management
4	Implement an energy management system using ISO 50001	Management
3	Educate senior decision makers with evidence	Commitment
3	Increase priority	Commitment
3	Correlation between operational capability, comfort, and energy efficiency (Multiple Benefits)	Commitment
3	Align goals	Commitment

3.5.1. Outline of different solution elements

3.5.2. Need for significant renovation programmes

This aligns with the commonly identified barrier of the age of most military buildings. This would indicate the need for a coherent, integrated, and systematic approach to decarbonisation targets and actions plans. Sources of funding for this large-scale financial investment with low rates of financial return, simple payback will exceed 20 years in many cases.

3.5.3. Increase availability of funding for investment

This is the same as the item above and highlights the need for significant sourcing of finance. Perhaps instruments could be developed to support investment in large projects through savings from lower cost energy conservation measures.

3.5.4. Training

Training was mentioned in relation to almost all aspects of energy efficiency implementation, including technical training, data collection and analysis, and energy management. Increased knowledge of these topics would facilitate improved performance at both tactical and strategic levels.

3.5.5. Increase awareness

Again, there will be both strategic and tactical benefits to increasing awareness of the benefits of and need for improved energy efficiency in the context of the transition to decarbonised military buildings. Increase awareness among senior decision makers of the real potential of improved energy efficiency and of its importance in the context of climate change and evolving decarbonisation legislation in the EU.

3.5.6. Increase EU funding for energy efficiency measures

There are increasing levels of funding available for decarbonisation at the EU level. Increased efforts could be made to increase awareness of these finding streams and to increase access to them for the defence sector.

3.5.7. Systematic Approach to energy management and energy efficiency

This was mentioned 5 times and there were a further 4 mentions of ISO 50001. Between the two this was the most mentioned solution. As stated earlier, a more strategic and systematic approach to decarbonisation could form the basis for solutions to most of the identified barriers. This applies to technical barriers, data analysis barriers and, most importantly, barriers related to support, commitment, and prioritisation of the topic among senior decision makers. There is a new extension to ISO 50001 under development currently. It is due to be published in early 2025. The topic is the use of energy management systems as a foundation for decarbonisation of organisations. It will cover the integration of energy efficiency, renewable energy, fuel switching, carbon capture, etc. into one systematic approach to decarbonisation.

3.5.8. New energy efficiency organisation with adequate resourcing and knowledge

This could readily be incorporated into the systematic approach in the previous paragraph. The approach advocated in the DEMC was to clearly assign roles and responsibilities to the relevant personnel in the installation. This included competency evaluation and training.

3.5.9. Educate senior decision makers with evidence

While decision makers may be interested in the topic and may feel that they are committed and supportive of energy efficiency, there is evidence from the respondents that this does not translate into energy efficiency actions. Increased understanding of the context of decarbonisation and the place of energy efficiency in these activities needs to be understood. Increase their understanding of the significant part energy efficiency must play in decarbonisation. In particular, it is the lowest cost and quickest option to implement while other solutions and their financing are developed.

3.5.10. Awareness of Multiple Benefits

The DEMC demonstrated the extent of multiple or non-energy benefits (NEBs) through numerous examples. These benefits include increased comfort levels in buildings accompanied by increased morale and motivation and in one case there was statistical evidence of reduced day to day health issues. There in increasing research into this topic including from the IEA (IEA, 2019).

3.5.11. Align energy and decarbonisation goals

Again, this has already been mentioned, especially in the context of a strategic and systematic approach to decarbonisation management (**Table 3.3**).

Table 3.3. Solutions proposed by respondents to the initial questionnaire with 2 or less mentions

Count	Solutions	Category
2	Develop energy policy	Commitment
2	Increase resources	Commitment
2	Increase accountability	Management
2	Financial training and improved investment methodologies	Training
2	Integrate with decarbonisation plans	Management
2	Procurement at scale at EU level	Finance
2	Knowledge of available funding streams	Finance
1	Specific Energy Efficiency budget at MoD	Finance
1	Specific goals at senior levels	Commitment
1	Data collection system	Data
1	Include Energy Efficiency in maintenance contracts	Management
1	Audits and classification	Management
1	Link operational and infrastructure budgets	Finance

The items in the table above are largely repeating from other parts of this study. Almost all of them would be part of an effective and systematic approach to decarbonisation.

3.6. Recommendations and way ahead

3.6.1. Develop a sense of urgency

The EU and most national targets for decarbonisation for 2030 are very significant. They are achievable with existing technology. But a strong sense of urgency is required. Significant carbon reduction actions are required every year between now and 2030. Increased knowledge of the context would support an increase in the awareness of the tight timelines that are ahead. Increase the realisation among decision makers of the potential for energy efficiency and the fact that it is the lowest cost and fastest to implement component of decarbonisation strategies.

3.6.2. Increase commitment to improved energy efficiency as part of a more strategic approach to decarbonisation

Consider the items above related to commitment. Lack of commitment was not identified as a barrier by the respondents, but many symptoms related to lack of commitment were highlighted. These include lack of priority, lack of resources, lack of policy and clear goals. If there is a belief that commitment levels are high, when in fact they are not, this can be a significant barrier to improvement. During one meeting for this study, it was stated that there are almost no barriers to energy efficiency and that targets are being met and progress is good. If this belief were mistaken, it is a very significant barrier to improvement. The belief that we are already very good with little need to improve will prevent improvement from happening. Increase understanding among decision makers of the benefits of energy efficiency and their role in ensuring its implementation.

3.6.3. Develop a capacity building programme

Quickly build capacity and knowledge in the areas of weakness identified in this study. These include:

1. Technical knowledge of energy efficient operational control.
2. Data collection and analysis techniques.
3. Financial analysis.
4. Commitment building and people management.
5. Targets setting and action plans aligned with performance metrics.
6. Integration of energy efficiency into a strategic decarbonisation management system.

Consider a model based on Sustainable Energy Authority of Ireland's (SEAI) Large Industry Energy Network (LIEN) as a model for collaboration, reporting, knowledge sharing, etc. (SEAI, n.d.) The learnings from UNIDO's energy management systems and system optimisation capacity building programs could also be used to develop a methodology for this.

3.6.4. Develop an integrated systematic approach to decarbonisation management

- Develop a systematic approach including clear baselines, targets and pathways to decarbonisation including energy conservation, energy efficiency, fuel switching and renewables.
- Interim targets for 2030 based on existing technology.
- Quantify how close to target achievement can be achieved.
- Based on the first questionnaire response and personal experience in the DEMC, the German defence forces buildings appear to be the most efficient in the group with the fewest barriers. Investigate further what can be learned from Germany in the areas of people, technology, and Information.
- ISO is currently developing an extension standard to ISO 50001, Energy Management Systems. The title of the new standard is "Energy Management Systems – Decarbonisation". It requires conformity with ISO 50001 in terms of minimising energy consumption together with additional measures to reduce GHG emissions from the consumption of energy. These additional measures can include renewable energy, fuel switching, grid synchronisation, and carbon capture among other emerging technological solutions.

3.6.5. Next Steps

1. Promulgate this study to decision makers including the presentation of the results at CF 2023, Malaga, Spain.
2. Include some sessions at CF 2024 on developing solutions to the identified barriers and to any other barriers considered by the delegates.
3. Promote increased levels of commitment, leadership, and support among senior decision makers in the defence sector.
4. Develop a capacity building program around an integrated approach to decarbonisation management. The scope of this study is limited to energy efficiency, but other components are required, and they don't stand alone. For example, fuel switching, and renewable energy sources are other critical components of the pathway to decarbonisation. This could take the form of an updated DEMC including both ISO 50001 and its upcoming extension on decarbonisation of energy emissions. The standards are well designed and internationally recognised as a basis of best practice. It is notable that the recast EU Energy Efficiency Directive published in 2023 mandates all large energy consumers to be certified to ISO 50001.

Conclusions

This report is based on the experience of the authors in the defence sector and in other parts of the public and private sectors internationally. It also draws on experience from the EDA DEMC and from the responses from EDA members to the questionnaires developed as part of this study. There has been success over many decades in improving energy efficiency in military buildings in many member states and in many military installations through the EU. However, there is evidence that many significant opportunities remain. Many of these opportunities face barriers in their implementation. Some of the barriers are common to other sectors and some are specific to the defence sector.

A lot is done, and a lot more remains to be done.

The key findings of the report are that there are significant barriers to energy efficiency improvement in military buildings and many of the barriers are common across numerous EDA member states. Several the identified barriers have some common causes. These include lack of priority for energy efficiency, lack of funding, poor accountability, lack of human resources, weak coherence of energy policy and alignment of goals. Despite some claims to the contrary, the opinion of the authors is that there is a common cause for these barriers, and it is that there is often a weak commitment to improving energy performance and to decarbonisation.

This weak commitment could be improved by increasing awareness and understanding of the overall context of the need for significantly improved energy performance of military buildings. This context includes the threat to society from the climate crisis and the global leadership of the EU in combating climate change through a rapid transition to net zero carbon emissions. Many EDA member states have policies that put the public sector at the forefront of their climate actions.

Senior decision makers in the defence forces need to understand the need for improved energy efficiency and they need to understand that significant improvements are possible in most installations. They also need to be presented with an honest appraisal of the barriers that exist and the potential solutions. This should lead to an increase in the urgency of implementing the solutions and in taking action to reduce maximise the potential of energy efficiency in the decarbonisation of defence activities in buildings and elsewhere.

Annex I – Energy Efficient Design (EED) process

The ideas outlined here are based on the Irish Standard IS393:2021 published by the National Standards Authority of Ireland (NSAI). They have been expanded to include the requirements of decarbonisation.

The fundamental steps in EED are as follows:

1. **Service:** The first and possibly most important step is to challenge the service that is being designed. In the case of a building the typical services include ventilation rates, fresh air quantities, winter temperature (for heating systems), summer temperature (for cooling systems), humidification and dehumidification specification (where applicable), light levels, light colour temperature, etc. Each of these specifications should be documented and challenged. This means attempt should be made to reduce specifications to save energy without compromising the actual requirements of building users. Reducing these specifications will result in reduced capital cost, reduced operational costs, and reduced future replacement costs. The results of challenging the service should be documented and approved and retained for future reference and for testing purposes as part of the commissioning process. A common opportunity in the military context is storage spaces. It is very common that items being stored, for example, bedding, tents, weapons, ammunition, electronics, spare parts, etc. require dry conditions rather than being kept warm. This is both a significant energy reduction and decarbonisation opportunity by dehumidifying rather than heating. Try not to have personnel based in the same spaces as materials storage as the operating parameters are different.

2. **Process:** This involves consideration of the process that will be used to achieve the service decided in step 1 above. For example, a heating system might be designed to achieve a winter setpoint of 20oC. The process decision is to decide what process will be used to heat the building. The traditional response might be a natural gas boiler heating radiators. However, in the context of decarbonisation, fossil fuel infrastructures would not be chosen. It would now be more common to choose a heat pump system with the heat being transmitted through underfloor heating after ensuring adequate insulation and air tightness levels. Identify opportunities for heat recovery including from cooling systems and refrigeration. Identify opportunities for cooling recovery to reduce cooling energy as applicable.

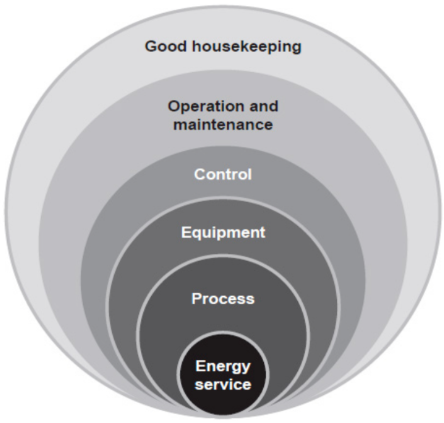
3. **Equipment:** This step involves selecting the equipment that will be used in the process chosen in step 2. It is important to ensure that equipment is not oversised excessively. Oversised equipment will be less efficient in operation. This applies as much to heat pumps as it does to boilers and water pumps. Select equipment including heat pumps, chillers, circulation pumps, air handling systems, and fans to be as efficient as possible under normal operating conditions rather than factory test conditions.

4. **Control:** Consider how the equipment and systems will be automated, giving special attention to automation functionality that will save energy or that has the potential to inadvertently waste energy. See Annex 10.6 below for an outline of some considerations related to building management systems.

5. **Operational and maintenance:** Operational control is how the equipment and systems will be operated and maintained after they are commissioned. Ensure that equipment can be accessed for maintenance and can be operated efficiently. Ensure that the project scope includes training of operational personnel in how the systems should be operated efficiently.

6. **Good housekeeping:** This includes ensuring that instrumentation is in place to facilitate ongoing monitoring of energy performance. This can include instruments for monitoring critical operating parameters such as temperature and pressures in heat pumps and chillers. It also includes energy meters where applicable.

Figure 3.3. Energy Onion Diagram (SEAI. n.d.)



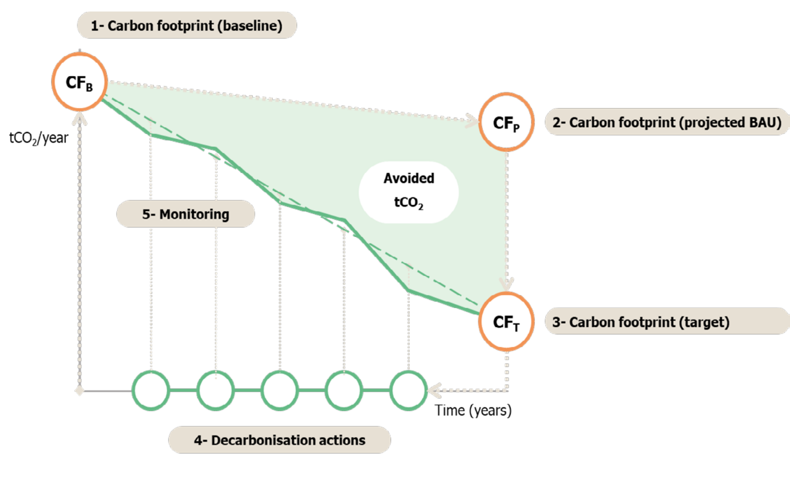
It is important to develop an energy team to conduct the energy efficient design process (**Figure 3.3**). Clear roles and responsibilities and authority are critical to ensure the success of the process. Ideally there should be an energy challenge led by an energy/decarbonisation expert who is independent of the design team and who reports at a senior level in the organisation. This ensures that energy and carbon performance are adequately addressed. The design challenge needs to be carried out in parallel with the project lifecycle. In order to minimise costs and maximise the benefits, the process needs to begin as early as possible in the project plan. If the design process is at an advanced stage, then the potential savings and the disruption to the project schedules may threaten any potential savings and improvements.

An often-neglected part of projects which affects the energy efficiency achieved is the commissioning step. It is critical that the people carrying out start-up activities and commissioning tests understand the design intent and commission accordingly. It is important that controls and automation are tested by someone independent of those who developed the automation system. It is also critical that the completed project is handed over in a systematic way to operational personnel including information on the design intent, operating parameters, automation philosophy, etc.

Steps to decarbonisation

Figure 3.4 illustrates the concept and steps in developing a decarbonisation strategy.

Figure 3.4. Key steps to developing a decarbonisation strategy. (BAU is Business as Usual)



Terminology

- Baseline Carbon Footprint (CF_B): This is the energy related carbon footprint expressed in tonnes of CO_2 equivalent (tCO_2e) emitted in the baseline year.
- Projected Carbon Footprint (CF_P): This is the energy related carbon footprint expressed in tCO_2e projected to be emitted in a specific year in the future assuming that no decarbonisation activities are performed. It is the business-as-usual carbon footprint estimated for that specific year.
- Target Carbon Footprint (CF_T): This is the energy related carbon footprint expressed in tCO_2e targeted to be emitted in a specific year in the future, e.g., 55% reduction by 2030 and 90% reduction by 2040.
- Decarbonisation actions: These are the specific actions that the organisation has taken or plans to take to reduce its carbon footprint.

Step 1 – Establish the Baseline Carbon Footprint (CFB)

To calculate the CO_2 emissions of any activity, two pieces of data are needed; firstly, the activity data and secondly the emissions factor. For energy related emissions, the activity data is the quantity of energy consumed, e.g., kWh per year and the emission factor is the amount of CO_2 equivalent emitted for each unit, e.g., gCO_2/kWh.

Step 2 – Estimate the Projected Carbon Footprint (CFP)

This is the business-as-usual carbon footprint for the projected year. It takes account organisational growth and expected reductions in the national grid but does not include decarbonisation actions.

These changes can have an important impact on the decarbonisation strategy in most organisations, as this variation will help with or make the decarbonisation process more difficult and will need to be considered in long-term planning. It can also reinforce the need for efficient and low-carbon design in new buildings and facilities. Assumptions made in these projections should be documented.

Step 3 – Set the Carbon Footprint Target (CFT)

The target will typically be developed on a top-down basis by deciding a long term and interim absolute emissions reduction target(s) in percentage terms. Targets can also be established on a bottom-up basis, i.e., identifying decarbonisation opportunities and taking their results as the basis of targets. In this case, the projected carbon footprint is essential, as the impact from changes in activity levels needs to be considered in determining the level of absolute decarbonisation that will be achieved.

All targets need to be based on absolute emissions reductions.

Step 4 – Develop and Implement the decarbonisation plan

Once the starting point (CF_B) and the end point (CF_T) of an organisation's decarbonisation strategy is determined, decarbonisation actions, can then be developed and implemented. The decarbonisation actions consist of all activities that the organisation will implement to reduce or eliminate its energy related carbon emissions, and combined they provide a decarbonisation pathway to meeting the targets.

To achieve the challenging targets needed to minimise the impact of Climate Change, all organisations including the Defence Sector, will need to be aware of the cross-cutting technologies that are, and will be, relevant. Using the 4R's structure shown in this report, we suggest the following items in the Defence Sector:

- Reduce:
  - Implementation of Energy Management Systems to promote continual improvement and guide the whole process.
  - Energy conservation measures based on effective operational control.
  - Energy efficiency: LEDs for lighting.
  - Travel reduction.

- Reuse:
  - Heat recovery systems in new and existing buildings.
  - Use of cooling systems as heating sources linked to heat pumps.

- Refuel:
  - Zero-emission fuels:
    - Green Hydrogen (where available, under development).
    - Electrification (based on grid improvement and on-site renewable energy).
  - Renewable fuels:
    - Biomass.
    - Biofuels.

- Redesign:
  - Bioclimatic design and/or rehabilitation:
    - Location and orientation based on minimising energy demand.
    - Optimal % of glass in façades to reduce losses and avoid overheating problems.
    - High levels of insulation in envelope (façades, windows, roofs).
    - Reduced infiltration levels.

The decarbonisation actions need to be reviewed and updated regularly, e.g., annually. Decarbonisation options are evolving rapidly. There will be many cases where the targets cannot be economically met using currently available technology. However, as energy prices and carbon prices increase, the financial viability of available options will improve. New technologies are also coming to market which have varying degrees of potential, e.g., high temperature heat pumps, green hydrogen and carbon capture, utilisation, and storage (CCUS).

Step 5 – Monitor decarbonisation progress

Monitoring decarbonisation progress and comparing the carbon footprint trend against the CF_B and CF_T is important in evaluating the impact of the implemented measures. It is also necessary to react to unexpected results and to take corrective action if progress does not meet expectations.

It is only through absolute reductions in GHG emissions that the impact of the Climate Emergency will be reduced, and so absolute emissions reduction is regarded as the most important indicator. The decarbonisation indicator should be monitored on a yearly basis, at least.

Advantages and disadvantages of different energy performance metrics

Energy management is one of the key concepts in the decarbonisation process. The primary purpose of improving energy management should be to improve energy performance. So, in order to evaluate if we are improving or not, we need to be able to measure energy performance.

Although this seems to be an obvious statement, it includes a certain level of complexity, as it is not easy to compare actual consumption and past consumption, because the external factors (relevant variables in ISO 50001:2018) in both moments are not equivalent (weather, level of activity, etc).

Traditionally, energy performance has been measured using certain indicators that are not properly considering the impact of these external factors:

- Indicators based on absolute figures: In this case, the energy performance is calculated through a simple comparison between the actual consumption and the consumption in the baseline period. Although this is useful as part of cost control activities and carbon footprint calculation, the indicators based on absolute figures are not adequate to measure energy performance because they do not consider the impact of the relevant variables.
- Indicators based on ratios: Although indicators based on ratios are more common in industrial sites, it is possible to find performance indicators based on ratios also in other sectors. This methodology assumes that all the energy consumption is proportional to one single variable. As a result, the indicator is a ratio like kWh/person, kWh/degree-day or similar. This is not a right performance indicator, because it assumes that the baseload is negligible and that there is one single variable, which is rarely true.

These ratios are also used very frequently as a benchmarking indicator (kWh/m3, kWh/person). Considering that ratios are not adequate to measure changes in performance in one single site (before and after), it is risky to use them as a basis of comparison for different buildings, in different locations, and different systems.

- Indicators based on normalisation: Normalisation is a process that aims to enable comparison and assessment of energy performance at different points in time under equivalent conditions. A proper normalisation needs to consider the weight of the relevant variables. Since operating, raw material, weather, etc. conditions are constantly changing, normalisation process always involve the use of some statistics, including regression analyses. Through these analyses, it is possible to calculate a dynamic baseload that is automatically adapted to the current conditions, and this allow to directly compare that expected consumption against the actual consumption from the meter.

Based on the above, in practice, the use of normalised indicators is the only acceptable methodology to measure energy performance. The steps in developing the energy baseline are as follows:

1. Decide on the energy consumed that is to be measured. This could be electricity, fuel, compressed air, steam, or any other energy type that is measured and that data is available for.
2. Establish what data is available. This can range from monthly data from energy invoices to electronic data collected at 15-minute intervals. The available data will help in the decision about the interval to be used in analysis and reporting.
3. Decide the baseline period to be analysed. In the context of an energy management system, this is usually the previous year.
4. Consider what are the relevant variables for the energy being considered. Make a list of all possible relevant variables. From this list decide which variables can physically be measured and then consider which of those can be measured economically. Consider also what data is already available and at what frequency.
5. Tabulate available data, both the energy consumption data and the data for the relevant variables. The data interval for both needs to be the same (daily, weekly, or monthly).
6. Complete regression analysis using the data from the baseline period: energy data as the dependent variable and the relevant variable data as the independent variable.
7. Interpret results considering the technical knowledge about the process and the actual operation in the organisation.
8. Start using the calculated baseline to monitor performance in the reporting period.

The use of inadequate indicators is a major barrier to improve energy performance for several reasons:

- They can hide problems or inefficiencies in the buildings as they are not considering the impact of relevant variables properly.
- For the same reason, they can point at deviations that does not exist. This means wasting time in investigating problems that do not exist. This is especially important as the lack of human resources has been identified as a barrier as part of this study.
- Also linked with one of the existing barriers found in the study, the lack of resources.
- Demotivation of staff, because hard work and commitment is not reflected in the official indicators, even when the actions are effective.
- Bad decision making, due to the use of unprecise or wrong indicators. This includes wrong decisions in strategy, energy efficiency investments, design decisions etc. For example, taking certain buildings or projects as successful models to replicate when the actual performance is not as good at it seems. This is also linked with one of the detected barriers in the survey, Low level of uptake of verification of energy savings from completed projects.

The energy performance measurement is essential as part of the decarbonisation process. The decarbonisation strategy needs to prioritise absolute decrease in GHG emissions, through different key actions: Energy efficiency, energy management, renewables. It is very simple to measure the impact of renewable energy in the carbon footprint, but the only way of evaluating if we are also in the right direction in terms of energy efficiency or energy management it to evaluate that through normalised indicators. Reducing carbon footprint is the main objective, and improving energy performance should be one specific target to help to meet the main objective.

Annex II – Energy metering and data collection

Data availability and data processing capabilities are changing the world at a high level. Concepts as, Internet of things or artificial intelligence are very common nowadays, when they seemed very far from reality only a few years ago. The development of this new technology is pushing all the metering and data collection technology, which is becoming easily accessible, affordable, and secure. As part of this study, the lack of energy metering and data to enable analysis has been addressed as one of the main barriers during the survey. The purpose of this annex is to show the main steps of this process in order to plan it efficiently and adapted to each system.

These are all the steps that should be covered in a good data collection plan:

1. List the existing meters, describing the meter characteristics, model, etc. This includes energy data and variable data used in the energy performance monitoring (see previous annex).
2. Describe the current data collection system. This could be a manual system or an automatic system where a datalogger or a similar device collects the data and send it to the storage system.
3. Describe where the data is stored. This could be an on-site server or an on-line server.
4. Describe how the data is used or shown (BMS, SCADA, excel tool, on-site software, on-line software, etc.)
5. Repeat steps 2 to 5, analysing in this case the potential improvements that would improve the data collection system and the performance monitoring capabilities.
6. Analyse additional meter requirements. ISO 50001:2018 points to the importance of monitoring performance in the significant energy uses. In each site, there will be systems that are especially important from the energy consumption point of view.

In the defence sector specifically, there are many low-cost actions that can be implemented in order to improve metering and data collection systems:

- As the starting point, all the sites should have access to the energy bills. This is all what an organisation needs to calculate their energy-related carbon footprint, and it can also be the basis of an initial energy performance monitoring system. During the DEMC program we had the opportunity to see that bill data collection is not always easy, due to delays in bill availability. This can be solved in different ways:
    - Solving any internal use that could be causing this delay. In some cases, the barrier can be internal, between departments. This needs to be solved showing the importance of getting the data on time.
    - Contacting the distribution and/or supplier company to check if they have an on-line platform where the 15-minute data or daily data is available in real time. This is very common nowadays in most European countries. In some countries, there are national platforms concentrating all the data from the different distribution companies that are accessible by organisations at no cost.
    - Installing a device to collect the reading from the company meter or to install an additional meter next to it to collect the information in a data logger to send the information.

- For those cases where a site has multiple buildings, energy meters can be installed in each one and can be connected with one single data logger through radio-frequency, reducing the hardware requirements and the implementation cost. The same solution applies to those cases where significant energy uses will be metered.

- Overcome barriers related to security issues. During the DEMC program, this was addressed as a major barrier in order to automate systems.
    - It is important to analyse in each case which information is confidential and/or cannot be shared. In general, with some exceptions, energy consumption will not be sensible information.
    - In some cases, occupancy data is confidential and cannot be used, even when it is collected by the security department. In those cases, level of activity will need to be measured somehow if it is relevant variable. This can be done using a calendar schedule (if any), number menus at the cantina, number of hours used by certain systems or equipment that depend on occupancy (lifts, training spaces, etc.)
    - If due to potential hacking risk it is dangerous to use existing on-site networks to communicate metering devices with external tools (on-line servers or software, for example) it is possible to create an independent system that uses GPRS or similar to send the information and is not connected with the site systems at any point.
    - If there are any confidential issues, on-site servers will need to be used. This usually requires customised solutions and internal resources that are sometimes more expensive to maintain than the on-line systems.

- Use available information from the outside. Weather data is widely available on the internet. Information from a long list of weather stations can be downloaded, including degree-days (with different base-temperatures), humidity data, etc. This can be automatically or manually collected.

- Be aware of the existing tools that can help to analyse and represent large amounts of data. This includes a wide range of solutions, including:
    - Advanced use of Excel. Excel allows programming, creating dashboards, menus, automating links, etc.
    - Business Intelligence tools as Power BI, Data Studio, or similar tools.
    - Specialised on-line software. The advantage of these ones is that they have been designed to monitor energy data. The disadvantages are that they tend to be rigid (not easy to adapt if needed) and that only a few include normalised indicators.

- Improve transport data. Energy consumption in transport is not always well-documented, even when, in some organisations it could represent a big portion of their GHG emissions. In the defence sector, sometimes it can be significant, even more than energy in buildings. As a starting point, it would be beneficial to collect daily consumption and daily distance in each unit. In some cases (trucks, ships, air transport) additional variables might be required in order to evaluate energy performance properly (load, duration of flights, etc).

The purpose of improving metering and data collection is multiple:

- It allows to monitor energy related GHG emissions in a systematic way.
- It improves energy performance monitoring, which will lead to detect saving opportunities and deviations.
- It permits better estimating the impact of potential energy efficiency measures, through the submetering data, or better evaluating the optimal size of potential renewable energy systems in each installation.
- It allows to have the detail hourly energy demand, which can help to optimise power demand in energy contracts (reducing energy costs).

Annex III – Some practical tips on improving operational control and implementing energy conservation measures

The experience of visiting military installations during the DEMC program and other buildings across Europe over many years is that there are significant energy savings to be made through improved operational control. By operational control, we mean how existing equipment and systems are operated and maintained. The concept of saving energy through operational control improvement is the same as mentioned earlier in this report under the title of energy conservation. These are savings with no cost or low cost to implement. Many of the barriers referred to earlier in this report are also barriers to improving operational control including giving priority to these activities and technical knowledge related to operational control.

An easy technique to get on overview on whether building heating or cooling system are being operated efficiently is to compare monthly heating and cooling energy consumption with the external temperature. It is to be expected that heating energy consumption will be higher in colder months than warmer ones. This comparison can easily be checked using a scatter diagram of fuel consumption with heating degree days (Bizee, 2008). In buildings with significant cooling demand the same process can be carried out comparing electricity consumption with cooling degree days. Steps to investigate operational control in a building:

1. Space operating conditions

Ensure that you know the required indoor conditions including temperature, light levels, humidity if applicable and challenge then if they seem excessively wasteful of energy. Different types of spaces require different temperature, humidity, and light levels. Compare the indoor temperature with that required. Is the building being overheated. A one-degree Celsius reduction in temperature of a heated building will result in up to a 10% heating energy saving. If some or all spaces in a building are being overheated, check why this is happening. It is common to find that radiators are set at too high a temperature. This occurs even when thermo-static radiator valves (TRVs) are used and when automated building management systems are in place. Ensure that occupants understand how TRVs work and how they should be set to achieve a consistent and comfortable temperature. They should be set at lower temperatures in corridors and toilets for example. Similarly check lux levels in different spaces compared with required light levels. If humidity control is in operation, firstly challenge the setting and requirements and then check that required levels are being met and that spaces are not overly humidified or dehumidified.

2. Heating and cooling distribution

Once the space conditions are under control, check how the energy is being distributed. This includes heating and cooling circulation pumps. These pumps should typically be fitted with variable speed motors which respond to heating and cooling requirements. For example, check that at times of low heat demand the heating pumps are running at low speed. Check insulation of heating and cooling pipes. Hot surfaces should be insulated and if adequately insulated they will not feel very hot to the touch. Exercise caution when touching hot surfaces! Adequately specified and maintained insulation will be at a temperature close to the ambient temperature of the space where they are located. If a heating system has different zones supplied by separate distribution pumps, ensure that out if service zones have their pumps stopped.

Note: avoid the use of three port control valves, use 2 port valves in conjunction with variable speed pumps. Investigate the possibility of shutting off the recirculation port.

3. Heating and cooling generation

Once space conditions are under control and energy distribution systems are operating efficiently and effectively, then examine the heating and cooling generation systems. This includes heating boilers, heat pumps, and chillers.

- Boilers
    1. Is the boiler house very warm? If it is, then this is an indication of heat loss through inadequate insulation. Check and maintain as appropriate.
    2. Test boiler exhaust oxygen levels at the beginning of the heating season annually. Compare the actual values with the minimum value recommended by the manufacturer and adjust as necessary. This should be part of the annual maintenance of the boiler.
    3. Observe the starting and stopping sequence in installations with multiple boilers and ensure that the minimum number of boilers to meet the heating demand are in operation.
    4. Ensure that hot water is not being pumped through stopped boilers resulting in heat loss through the insulation and exhaust, and excessive pumping energy. Stop and isolate backup boilers.
    5. For condensing boilers, check for condensation from the drain. If there is none, consider reducing the supply temperature.

- Chillers
    1. Ensure chillers are not running when not required. Check time schedules and ambient conditions.
    2. One of the most important parameters for a refrigeration system is temperature-lift. This is the difference between the condensing temperature and the evaporating temperature. Each degree reduction in temperature-lift will reduce energy consumption by about 3% with a corresponding increase in cooling capacity. Checks related to temperature-lift include:
        a. Ensure chiller cooling setpoints are as high as possible to meet operational requirements.
        b. Check evaporating temperature to ensure it is as high as possible to meet operational requirements.
        c. Ensure that condenser fins are clean so that condensing temperatures are as low as possible.
        d. Ensure that condenser temperature settings are correct, and that condenser control is operating correctly and responding to outside air temperature and load conditions.

All the items above apply to space cooling, cold rooms, heat pumps, and data centres.

- Building Management Systems checking
  1. Ensure that documentation is available to understand the design intent of the building management system.
  2. Check available graphics for unexpected conditions, for example heating when outside air temperature is not cold or cooling during cool conditions.
  3. Check that all temperature and pressures correspond to what would be expected under current operating conditions.
  4. Check that time schedules are correctly set for current operating conditions.

Annex IV – Building Management Systems (BMS)

BMSs are an excellent tool to optimise the control and operation of building energy systems. They are sometimes referred to as building energy management systems (BEMS) or building automation systems (BAS). They typically have the functionality to monitor and control the operation of building systems, specifically heating, ventilation and air conditioning (HVAC) systems or in some case heating systems only. They are most beneficial in more complex systems where both analogue and digital control are required. They are not typically required when the only required functionality is time schedules. There are lower cost, more effective, and less complex solutions available in those cases using networked discrete controllers including Internet of Things (IoT) solutions. If specified, configured, and operated correctly they will increase occupant comfort and productivity and additionally will minimise energy consumption and related GHG emissions.

Common functionality with energy saving benefits include:

Optimisers v time schedules

A time scheduler is something that will switch equipment on and off at specified times. Options include different times for different days of the week and for holiday periods. Where time schedules are used ensure that equipment is switch of when not required. An optimiser is similar to a time scheduler but is automatically variable depending on ambient conditions. For example, an office may be occupied from 09:00 every weekday. An optimiser would start the heating system at different times each day depending on outside temperature and would learn heat up rates to adjust these times. Similarly, it would stop heating systems in advance of unoccupied times depending on outside temperature and learned cool down rates.

Weather compensation

Weather compensation automatically changes setpoints in heating and cooling settings depending on ambient conditions. For example, boiler temperature and chiller temperature can be higher or lower depending on outside air temperature. Corresponding changes to distribution pumps settings can also be implemented, reducing pumping pressure when loads are low. This automatic resetting of setpoints is often based on monitoring the positions of control elements rather than monitoring the outside temperature. An example would be reducing the temperature from a boiler until the most open heating valve is 95% open. If the valve approaches 100% then the temperature should be increased a little. There are also weather compensation curves built into most BMSs. For example, the supply temperature might be 80°C at outside air temperature (OAT) of -5°C and 50°C at OAT of 15°C with a linear relationship in between.

Variable duct temperature

This is a similar concept to weather compensation. It involves changing the supply air temperature from air handling units automatically based on ambient conditions. In colder weather the supply duct will be warmer than in warmer weather.

Dead bands

This concept is used in air handling systems which employ both heating and cooling services. For example, heating might be in operation at OAT less than 14°C and cooling at OAT greater than 25°C. In between those temperatures neither heating nor cooling would be in operation. In between those temperatures temperature control could be achieved by mixing return air with fresh air.

CO_2 control of fresh air

The freshness of indoor air can be measured using a CO_2 sensor. The optimum level might be a value of, for example, 900 ppm of CO_2. Fresh air supply can be modulated to achieve this setting. It can be modulated by having a variable speed motor on the supply air fan. It is particularly effective in large spaces with variable occupancy. In the military context these can include gymnasiums, dining halls, open plan offices, sleeping quarters, etc. Very significant savings can be achieved in terms of fan energy and heating and/or cooling energy. Small amounts of ventilation are required in these areas until there are more people present. Then the CO_2 sensor will detect the increase and modulate the fan speed to achieve a healthy and energy efficient atmosphere in the space.

Sequencing of multiple boilers, pumps, etc.

It is common to see multiple boilers, chillers or pumps operating in parallel when the load does not require them. If the second unit is routinely required, then it should be automated to start and stop to meet demand. If the second unit is a backup for periods when the primary unit is out of operation, then perhaps it can be manually switched off and started manually when the primary unit is out of operation.

Annex V – Overview of a potential Decarbonisation Management System (DMS)

The Defence Energy Manager's Course (DEMC) contains all the materials and steps needed to develop an effective energy management system (EnMS). The results in terms of energy, cost and carbon emission reductions were very impressive in those installations where there was a high level of commitment to improving energy performance. Many of the barriers identified in this report also applied to many installations where success levels were low or negligible.

The DEMC was based on the requirements of ISO 50001, the international standard for energy management systems. An effective EnMS includes about 90% of the requirements of an effective DMS. The context, leadership, and support, and improvement elements are very similar with the added importance and driver of the need to decarbonise.

The areas where there are differences include the following:

- Performance improvement activities need to go beyond energy savings and energy efficiency. They need to build on energy conservation and energy efficiency measures and include heat recovery and refuelling opportunities as mentioned in the 4R's above. Refuelling includes electrification, bioenergy, renewable energy sources and probably power purchase agreements.
- Target setting will be in terms of decarbonisation targets rather than energy saving. A common decarbonisation target will be to achieve net zero carbon by a particular year. The Science Based Target (2022) Initiative's interpretation of net zero targets for corporations is at least a 90% reduction in scope 1 and scope 2 emissions.
- Performance indicators are much simpler as only absolute emissions need to be monitored. Statistical analysis including normalisation as used in energy management are not required. However, normalised indicators support decarbonisation work in understanding energy performance and where improvements are being achieved or not achieved.
- Design activities need to go beyond energy efficient design as described in an earlier annex to this report. These considerations also need to include procurement activities which are typically linked to design work for most major activities.

Similarities and difference between energy management and decarbonisation management

The list below is based on the structure of the DEMC and of ISO 50001:2018.

Context

The elements of the external and internal context of both types of system are fundamentally the same. See the next Annex for more detail on identifying the context for a decarbonisation management system.

Leadership

The leadership elements are very similar. It is a common requirement that senior leaders provide direction and support for the activities of both energy and decarbonisation management. As outlined earlier in this report, lack of leadership and lack of priority for energy efficiency is a common barrier in the military and other contexts.

Planning

Planning is an area of difference between both systems. The concept of continually identifying opportunities for improvement, evaluating them, prioritising their implementation, and verifying their results apply in both cases. The concept of establishing baselines and performance indicators apply to both. One of the big differences is in the methodology of setting baselines and performance indicators. In an energy management system these will be normalised, taking account of relevant variables affecting energy consumption. However, in the case of carbon footprints and reduction targets, absolute values are required. Improvement opportunities in decarbonisation will include renewable energy opportunities and fuel switching opportunities such as electrification. These are not typically part of energy management systems.

Support

The support activities, competence, training, awareness, communication, etc. are very similar. There will be additional knowledge requirements for decarbonisation including carbon foot printing, target setting, decarbonisation actions and monitoring of progress. These competences are not arduous for personnel already familiar with the principles of energy management and energy engineering.

Operations

Operations include operational control, procurement, and design. Design and operation control are detailed in other Annexes of this document.

All three of these activities are similar for decarbonisation and energy management with the additional need to eliminate fossil fuels from design projects and from procurement activities.

Performance evaluation

Performance evaluation of the management systems is identical including the internal audit and management review and differ somewhat in the area of monitoring as mentioned in planning above regarding baselines and performance indicators.

Improvement

The concept of continual improvement of the management system and of energy performance improvement are the same for decarbonisation management. They both need to be centred on the concept of continual improvement.

Context of a Decarbonisation Management System (DMS)

One of the initial steps in developing an EnMS or a DMS is to establish the context. The context includes both the internal and external contexts of the entity. One of the main benefits in understanding the context and sharing it among decision makers is to increase support for the decarbonisation efforts.

1. External context

The external context is often evaluated using PESTLE analysis. In the case of a decarbonisation management system, this means considering the Political, Economic, Societal, Technological, Legal and Environmental context of its energy using operations and greenhouse gas emissions. A brief outline of a PESTLE analysis related to military buildings could be as follows:

- **Political:** Politicians in the EU are becoming more and more aware of the need for decarbonisation. Decarbonisation targets are increasing regularly. Currently there is a target to reduce GHG emissions by 55% by 2030 and to achieve net zero emissions by 2050. Some individual member states also have national targets that may not be the same. It is important to take account of your national and sectoral targets where they exist, when setting targets for the defence sector. The other current political context is the war in Ukraine, which in addition to many other impacts has also caused an energy crisis in relation to energy supplies from the Russian Federation.
- **Economic:** The economic impacts of climate change include the cost of taking action to mitigate its effects, action to adapt to its effects and the very high costs of inaction and delayed action. Many of the actions required to decarbonise have good financial returns and make economic sense in addition to their environmental benefits.
- **Societal:** Society is starting to become more concerned about the impacts of climate change. Examples of this awareness include activism in the form of Fridays for Future (started by Greta Thunberg), Extinction Rebellion, and others. More and more members of the defence forces will be aware of this through the news and through interaction with family and friends.
- **Technological:** There are an ever-increasing set of technological solutions to support the decarbonisation of military buildings. These include insulation materials, heat recovery systems, automation systems, heat pumps, increased efficiency electric motors, high efficiency refrigeration equipment, variable speed pumps, alternative fuels, etc.

- **Legal:** The EU is publishing ever increasing number of pieces of legislation related to energy efficiency, decarbonisation, and sustainability. Defence Forces can often be exempt from this legislation but in many cases choose to implement their requirements as they represent best practice. There are increasing legal actions being taken against governments globally for inaction on environmental matters including climate change. Recent changes to EU legislation include the recast Energy Efficiency Directive (EED) and the Corporate Sustainability Reporting Directive (CSRD). These impose energy efficiency targets, energy management systems implementation, greenhouse gas emission reporting and mitigation plans on organisations in the EU.
- **Environmental:** The primary environmental impacts of the operation of military buildings are greenhouse gas emissions from the use of energy. These include both direct emissions from the combustion of fossil fuels and indirect emissions from the consumption of electricity. Localised air pollution is another environmental impact.

There is a significant benefit and motivator in having clear ideas about the external context. It can significantly increase support and leadership form senior personnel if communicated effectively and clearly to them.

2. Internal context

The internal context can be effectively evaluated using SWOT analysis. This means establishing the Strengths, Weaknesses, Opportunities and Threats related to its operations. A brief outline of a SWOT analysis related by military buildings could be as follows:

- **Strengths:** Defence forces often want to be seen as leaders around energy efficiency and decarbonisation efforts. This is an important strength. Given enough priority and commitment, many military units can become case studies in effectiveness in these areas. There were numerous good examples among the participants in the EDA DEMC.
- **Weaknesses:** Review the barriers identified in this document. Many of those barriers are common in the defence forces and should be considered. It is important to be open and honest in identifying weaknesses and in developing plans to address them. Try not to underestimate the weaknesses as addressing them is critical to developing an effective approach to energy efficiency and to decarbonisation.
- **Opportunities:** A common opportunity at the moment is the availability of significant funding for investment in energy efficiency and in decarbonisation. Another important opportunity for the EDA members is collaboration and learning from each other through knowledge sharing.
- **Threats:** A common threat is the rotation of important personnel and the loss of knowledge and sometimes loss of enthusiasm when someone moves to a new role. This threat needs to be planned for.

The weaknesses and threats identified should be given particular attention and measures taken to minimise or eliminate them.

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4. Defining the key requirements for an energy storage selection decision support tool for homeland defence installations

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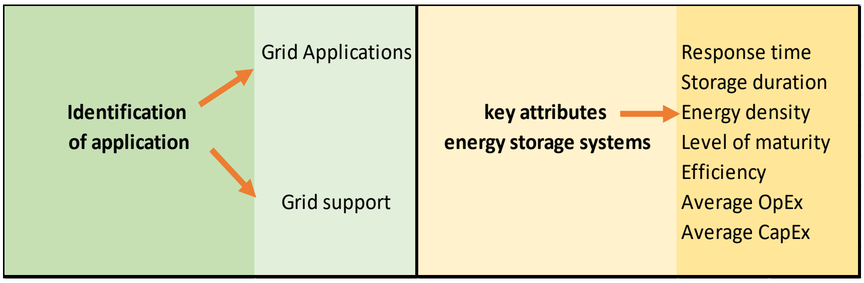
Abstract

The global commitment to achieving zero carbon dioxide emissions by 2050, as part of the European Union's decarbonisation efforts, necessitates a shift away from fossil fuels towards renewable energy sources. The evolving renewable energy generation market faces challenges due to the variable nature of renewable sources and the need for effective energy storage systems. This study explores the key requirements for an energy storage selection decision support tool to assist users in matching suitable storage systems with their applications. The investigation involves a comprehensive review of energy generation technologies (wind, solar, biomass, hydro, geothermal) and storage systems (thermodynamic, mechanical, electrochemical, electromagnetic). Qualitative factors are categorised in a Microsoft Access database, forming the basis for the decision support tool's main factors and key requirements. Future work involves the development of technical specifications, software tools, and physical protection requirements for energy storage systems, with a specific focus on Ministry of Defence (MoD) environments. Additionally, financial evaluation tools, studies on alternative fuels like ammonia, and pilot projects for hydrogen storage and generation are proposed. The collaboration between the European Defence Agency's (EDA) Consultation Forum for Sustainable Energy in the Defence and Security Sector (CFSEDSS) and the energy industry holds significant potential for leading advancements in hydrogen storage development.

Executive summary

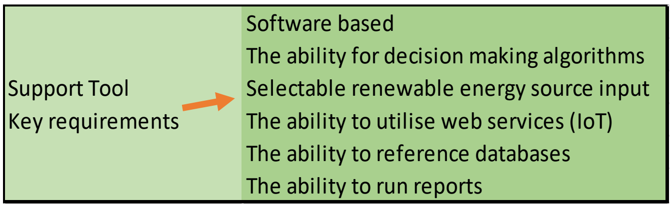
Global decarbonisation and the pledge to achieve zero carbon dioxide emissions by the year 2050 in the European Union is a challenging target to meet. In order to meet this goal, the burning of fossil fuels as an energy source will cease. Thus, the renewable energy generation market is transforming and rapidly growing as the demand rises for clean energy. Renewable energy generation is a variable energy source with unpredictable long-range forecasting. Intermittent energy generation from renewable energy sources require an energy storage system to store energy during times of low demand and release energy at times of high demand with low production. Energy storage systems are vital in enabling successful renewable energy production and building resilience in energy supply networks. This study investigates the key requirements for an energy storage selection decision support tool. The tool should enable the user to select an appropriate energy storage system and match it to their application. To define the key requirements of a energy storage selection tool, it was necessary to review energy generation technologies under the following five categories: 1. Wind, 2. Solar, 3. Biomass, 4. Hydro, and 5. Geothermal. It was also necessary to review energy storage systems under the following four categories: 1. Thermodynamic, 2. Mechanical, 3. Electrochemical, and 4. Electro-magnetic. The output from the reviewed energy generation and storage technologies is broken out and categorised into the main qualitative factors recorded in a Microsoft access database. The main factors are illustrated in **Figure 4.1.**

Figure 4.1. Main factors



The key requirements for a decision support tool are illustrated in **Figure 4.2.**

Figure 4.2. Requirements decision support tool



Future work identified from this study should include the following:

- Development of technical specification and functional requirement documents for a decision support tool.
- Development of a software tool for the selection of energy storage systems.
- Development of a technical specification for the physical protection requirement of an energy storage system used in a Ministry of Defence (MoD) environment.
- Development of an updated financial evaluation tool for energy projects.
- Performance of a visibility study on the potential use of ammonia as a fuel or storage medium for hydrogen.
- Creation of pilot hydrogen storage and generation projects.

Implementing the future works listed above could put MoDs in a position to match a suitable storage system with a renewable generation energy source. The collaboration of the European Defence Agency's (EDA) Consultation Forum for Sustainable Energy in the Defence and Security Sector (CFSEDSS) and the energy industrial community are a resource like no other and have considerable potential to lead the way in hydrogen storage development.

4.1. Introduction

The unpredictability of renewable energy generation makes it challenging to implement a reliable and resilient generation system that will deliver and meet the demand of a modern energy consumer's profile. Energy storage systems (ESS) link intermittent renewable energy production and variable demand profiles. The correct application of ESS could enhance the effectiveness of a renewable energy source (RES) by storing surplus energy from production and releasing it when production is low, during the night for solar and windless days for wind turbines or when demand increases during peak usage times.

Resilience and efficiency can be increased within the EUMoDs and armed forces energy networks while contributing to the EU climate neutrality 2050 targets with the use of energy storage. This contracting study examines energy storage systems and their suitability, readiness, and practicality for implementation within a homeland defence installation. Techno-economic analysis, environmental conditions, and other critical attributes of the technologies are carved out defining factors with functional analysis for developing a decision support tool. The overarching aim of this study is to define the key requirements for an energy storage selection decision support tool for homeland defence installations. Many technologies, concepts, and ideas exist and have informed many academic papers. The focus of this study is practical, and will also include a non-exhaustive list of relevant technologies in the discovery work.

4.2. Context

The CF SEDSS II Working Group 2 on Renewable Energy Sources (WG-2 RES) developed an initial project idea on the "Energy Storage Selection Tool". The tool should aid in selecting an appropriate storage technology to inform the EU MoDs and relevant stakeholders on the most appropriate storage systems for different military installations, as defined by the characteristics of the application. The scope of this study is to provide a brief analysis of the most suitable energy storage solutions based on the energy systems that can help MoDs and relevant stakeholders increase their energy resilience and autonomy.

The objective of this study requires two main parts:

- **Part A**
  - Assess which energy systems and RES are suitable for implementation in homeland defence installations.
  - Examine the current availability of RES and storage technologies and identify those most appropriate for use in homeland defence installations.

- **Part B**
  - Define the key requirements for developing a decision support tool.
  - Perform functional analysis to define the key attributes of a decision support tool.
  - Outline how the support tool will consider both short-term and long-term storage aspects aimed at selecting and integrating an optimised storage solution.

4.3. Problem analysis

"At the grid-scale level, energy storage is needed to efficiently manage the dynamics of demand and supply. This includes managing the short duration peak power requirement and maintaining the frequency when the grid is under stress," says Dr Ganesh Das, Chief of Strategy, Collaboration, Innovation, and R&D at Tata Power Delhi Distribution Limited.

Energy storage systems will play a critical role in decarbonising and breaking the reliance on fossil fuels. All European countries are reducing their reliance on fossil fuels by boosting renewable-energy outputs, whether this is through wind or solar. The intermittent nature of these renewable energy sources makes energy storage systems vital to the success of green energy generation. However, during times of low renewable energy generation, previously stored excess energy should be called upon to meet the energy demand.

This study is the initial step in building an energy storage selection tool. This tool will give the user a clear indication of what energy system would best suit their application and requirements. This study will define the key requirements for selecting an energy storage system. Choosing the most appropriate energy storage solution could help reduce carbon emissions and dependence on civilian power grids and increase resilience and business continuity.

There is **no singular energy storage system that suits all applications a successful solution is likely to be a hybrid of technologies lending on the response dynamics of the system**. Applications vary from low-energy applications to energy-intensive applications. Those with higher energy demands which require more energy-dense storage systems may be better suited to hybrid storage.

Combinations of energy storage systems should combine lower energy-dense systems with high response times with high energy-dense systems with lower response times. For example, the pairing of flywheel and gas storage with power systems is not uncommon, and they work quite well together. The flywheel has the ability to deliver energy instantly, but has a very low energy density, whereas the gas storage has a higher energy density and a longer response time. The flywheel stabilises the energy demand from the energy user and gives time for the gas storage system to come online, take over and deliver the required energy.

4.4. Methodology

1. A literary review of academic papers, scientific journals and published works of creditable data will provide the sources of information.
2. Energy storage systems are analysed under the following categories:
   - Thermodynamic.
   - Mechanical.
   - Electrochemical.
   - Electro-magnetic.
3. Conduct a brief analysis of renewable energy generation systems. Since some storage systems may perform differently depending on the source of renewable energy input, this factor will need to become part of the selection process.
4. A questionnaire has been sent to the members of the WG-2 RES. Its results have aided in this study's final direction. The answers to the questionnaire allude to the level of renewable energy generation and storage, either already existing or planned within the community. They also provide an understanding of the load profile of the significant energy users (SEU), time of use, and geographical constraints or attributes that can affect energy production and storage, e.g. rivers, mountains, valleys, the height of installation, atmospheric pressure, and peak summer/winter temperatures.
5. The collected data has been categorised into qualitative properties, which form the basis of a functional analysis. Categorical data in a matrix form or a more straightforward lookup table will become the building blocks for a decision-making tool.
6. A process logic map has also been developed to include the key questions that need to be answered when selecting an energy storage technology.

4.5. Solution implementation

4.5.1. Energy generation system review

By definition, renewable energy generation is a recyclable energy source. Renewable energy generation is linked to green energy and clean energy. While there is a lot of cross-over in the terminology, subtle differences exist. Renewable energy is a recyclable energy source; green energy is an energy source that comes from a natural source; and clean energy is an energy source that emits no pollutants such as carbon dioxide. Becoming net zero refers to balancing harmful emissions by removing emissions from the atmosphere to achieve carbon neutrality. The underpinning goal of net zero across Europe strives to balance the number of emissions produced and those removed from the atmosphere to reduce global warming. With this goal in place, consideration should only be given to renewable, green, and clean energy generation systems.

a) Renewable, green and clean energy generation systems

Renewable energy technologies harness the power of the sun, wind, and heat from the Earth's core and transform this power into usable forms of energy.

Table 4.1 below outlines the five key types of renewable energy, their global generation, and the normalised energy cost per MWh.

Table 4.1. World energy share (IEA, 2019)

Energy Source	% of 2021 Global Electricity Generation	Normalised Euro cost of Energy per MWh (LCOE)
Wind	6.6%	€38
Solar	3.7%	€35
Biomass	2.3%	€113
Hydro	15.3%	€63
Geothermal	<1%	€74

The normalised cost of energy (LCOE) measures the lifetime costs of a new utility-scale plant divided by total electricity generation.

b) Solar Power

The renewable aspect of solar energy generally falls under two categories: photovoltaic (PV) and solar thermal collectors.

PV devices generate electricity directly from sunlight via an electronic process that occurs naturally in certain types of materials called semiconductors. Electrons in these materials are released by solar energy and can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid.

Solar thermal collectors are categorised into two groups: flat plate and evacuated tube. Both categories perform the same job, although they have minor differences. They are a range of technologies which transform energy from the sun into hot water. Unlike solar PV, solar thermal has no electrical generation and is purely thermal. The current trends in PV deployments worldwide clearly indicate that PV energy will play a significant role in the near future energy mix. For example, the global solar PV capacity is projected to increase by 37.5% from 2019 to 2030 (i.e., from 593.9 GW in 2019 to 1,582.9 GW in 2030) (GlobalData, 2019). Solar PV technologies are commercialised under three main construction types: monocrystalline, polycrystalline, and thin film.

Monocrystalline solar panels

Monocrystalline solar panels, also called single-crystalline cells, are manufactured from the purest silicon materials. The rounded edge and the dark colour distinguish monocrystalline panels. Monocrystalline solar panels deliver the highest efficiency in standard test conditions compared to the other two types of solar cells. The current delivered monocrystalline solar panel efficiency stands at approximately 22-27%.

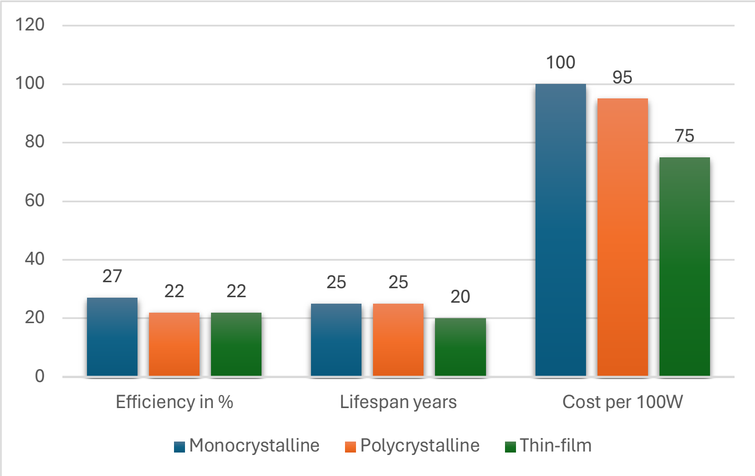
Polycrystalline solar panels

Polycrystalline solar panels, also called multi-crystalline cells, are slightly less efficient than those comprised of monocrystalline solar cells due to the nature of production. The silicon is not grown as a single cell but as a block of crystals. These blocks are then cut into wafers to produce individual solar cells. Polycrystalline panels are recognised by their square cut and blue-speckled colour. The current delivered polycrystalline solar panel efficiency stands at approximately 15-22%.

Thin film solar panels

Thin film solar panels cover a glass, plastic or metal substrate with one or more thin layers of photovoltaic material. Thin film solar panels are usually flexible and low in weight. However, it is recognised that such panels degrade somewhat faster than mono and polycrystalline solar panels. Production of this kind of panel is less complex; however, their output is 5% less than monocrystalline solar panel efficiency. Typically, thin film cells deliver between 15-22% solar panel efficiency. Solar panel efficiency panels are tested under Standard Test Conditions (STC). STC specifies a temperature of 25°C and an irradiance of 1,000 W/m^2, which is the equivalent of a sunny day with the incident light hitting a sun-facing 37°-tilted surface. Under these test conditions, a solar panel efficiency of 15% with a 1 m^2 surface area would produce 150 Watts (**Figure 4.3**).

Figure 4.3. Solar PV comparison (IRENE, 2019)



c) *Wind power*

Wind power is a clean and renewable energy source. Wind turbines harness energy from the wind using mechanical power to spin a generator and create electricity. Wind energy is the energy obtained from the force of the wind transforming the kinetic energy of air currents into electrical energy. The energy is mainly extracted from the rotor, which transforms the kinetic energy into mechanical energy, and from the generator, which transforms this mechanical energy into electrical energy.

Wind energy is renewable, efficient, matured technology, and secure energy that is key to the energy transition and the decarbonisation of the economy. The optimal height of a turbine is usually 80 to 120 metres high, depending on wind strength and whether the turbine is located onshore or offshore.

Onshore wind turbines

Onshore wind power refers to turbines located on land rather than over water. They are typically located in sparsely-populated areas with low conservation value. Onshore wind electricity generation increased by 12% in 2019. Capacity additions also grew by 22% after stagnating for a few years.

- **Advantages:**
  - The infrastructure required for onshore wind power is less expensive than for offshore wind turbines.
  - Cabling: shorter cables, and above-ground installations reduce costs significantly giving onshore an advantage over offshore.

- **Disadvantages:**
  - With varying wind speeds, the speed of onshore wind turbines is somewhat unpredictable. Because wind speed and direction can vary significantly on land, achieving consistent power generation can be challenging.
  - Potential wind blockages, such as physical blockages from buildings and surrounding landscapes such as hills or mountains, can cause production inconsistencies.

Visual and sound factors must be considered since onshore wind farms can be an eyesore on the landscape. Wind turbines built on high ground to generate more power can impose on surrounding residential areas. Wind turbines are also not silent, meaning they can cause noise pollution if located near a residential area.

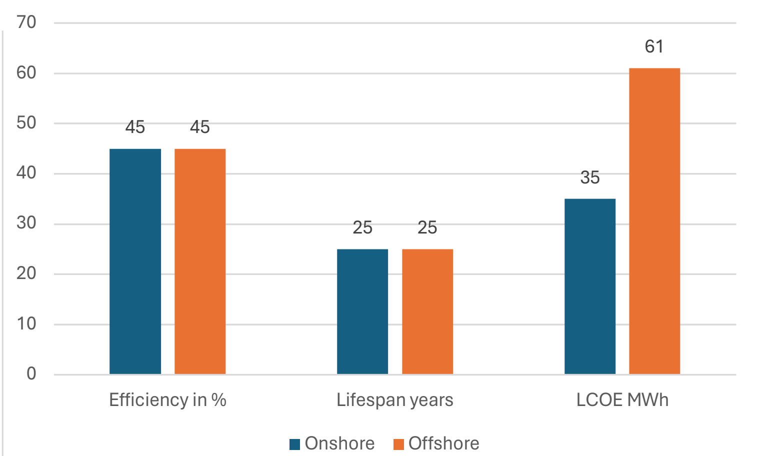
Offshore wind turbines

Offshore wind power refers to wind farms located over shallow open water, usually in the ocean, with higher wind speeds. The term 'offshore wind' can also refer to inshore water areas such as lakes (**Figure 4.4.**).

- **Advantages:**
  - Offshore wind speeds are typically faster than on land; even small speed increases can significantly increase energy generation. As such, fewer turbines are needed to produce the same amount of energy as an onshore turbine.
  - Visually, offshore turbines do not have as much visual impact as those on land. They do not interfere with land usage, and no physical obstacles can interrupt the wind flow. For this reason, offshore wind farms can be made larger and generate more energy than those onshore, with less physical impact.
  - Larger turbines mean that offshore turbines can also be built taller than those onshore.

- **Disadvantages:**
  - Higher costs are involved with creating the infrastructure for offshore wind farms, which can be expensive and complex, especially over deeper waters.
  - Maintenance can be difficult. Offshore turbines often require more maintenance than their onshore counterparts due to the harsh enjoinments they are installed in.
  - Offshore wind farms are also difficult to access, which means longer wait times for repairs.
  - The majority of wind turbine generators are asynchronous meaning the rotor must turn at a speed above the slip speed limiting the production of energy through a variety of wind conditions (IRENA, 2019).

Figure 4.4. Onshore Vs offshore wind (IEA, 2019)



When comparing a life cycle assessment of onshore and offshore wind farms, evidence demonstrates that onshore wind farms tend to lead to an overall more adverse environmental impact (in terms of the materials used to construct them, installation and operation processes, and maintenance) than offshore wind farms (Piasecka et al., 2020).

d) Biomass

Biomass is renewable organic material that comes from plants and animals. Biomass can be any material derived directly or indirectly from organic matter, animal matter, fungi, or algae. This includes wood, straw, energy crops, sewage sludge, organic waste materials, and animal litter (**Figure 4.5**).

Biomass gets converted to energy through processes that include:

- Direct combustion (burning) to produce heat.
- Thermochemical conversion to produce solid, gaseous, and liquid fuels.
- Chemical conversion to produce liquid fuels.
- Biological conversion to produce liquid and gaseous fuels.

Direct combustion is the most common method for converting biomass to usable energy. All biomasses can be burned directly for heating buildings and water. Thermochemical conversion of biomass includes pyrolysis and gasification, both of which are thermal decomposition processes in which biomass feedstock materials are heated in closed, pressurised vessels called gasifiers at high temperatures. They mainly differ in terms of processing temperatures and the amount of oxygen present during the conversion process.

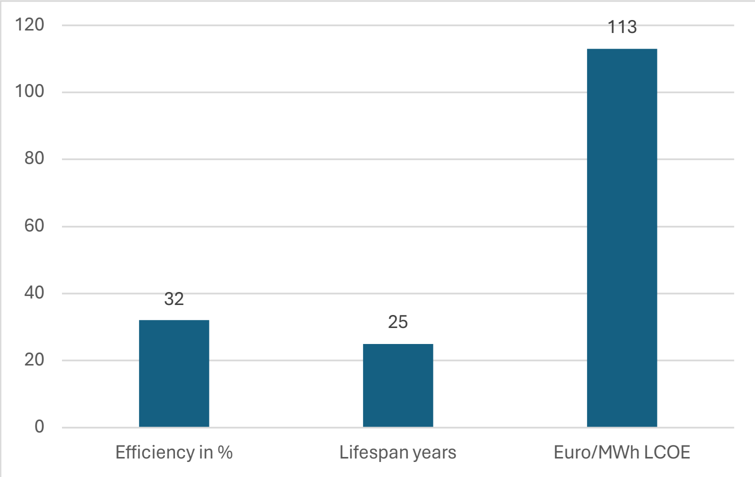
Pyrolysis is one of the technologies available to convert biomass into an intermediate liquid product that can be refined to drop-in hydrocarbon biofuels, oxygenated fuel additives, and petrochemical replacements. Pyrolysis is a method of heating organic materials, such as biomass, in the absence of oxygen. Hydrotreating is used to process bio-oil (produced by fast pyrolysis) with hydrogen under elevated temperatures and pressures in the presence of a catalyst to produce renewable diesel, gasoline, and even jet fuel.

Gasification entails heating organic materials to 800–900°C with controlled amounts of free oxygen and steam into the vessel, producing a carbon monoxide and hydrogen-rich gas called synthesis gas or syngas. Syngas can be used as fuel for diesel engines, heating, and generating electricity in gas turbines.

- **Advantages:**
  - Biomass energy is a renewable form of energy. As we utilise biomass materials, the supply of organic matter is diminishing. However, biomass can be regenerated.
  - Biomass is a reliable resource that can produce energy at any time. This offers an advantage over other renewable energy resources, such as wind and solar energy, which are intermittent.
  - Biomass is widely available for waste reduction since the planet produces a lot of waste. Much of our waste is biodegradable, such as food and plant waste. Biomass energy takes waste that would otherwise sit in a landfill and makes it into a worthwhile energy product.
  - Carbon dioxide emissions are driving forces of climate change. Biomass is considered a carbon-neutral energy source because it fits into the natural carbon cycle. Biomass combustion emits carbon that is already part of the biogenic carbon cycle. It operates in a continuous flow of carbon between the biosphere and the atmosphere. Bioenergy does not generate any net additional biogenic carbon in the atmosphere.

- **Disadvantages:**
  - The production of biomass energy can come with a high price tag. First, constructing biomass energy plants requires a significant upfront investment. Then, the cost of harvesting and transporting biomass materials needs to be considered.
  - Biomass energy is carbon-neutral; however, biomass still releases carbon dioxide into the atmosphere. By contrast, other renewable sources are carbon-zero. Carbon neutral or carbon neutrality is the balance between emitting carbon and absorbing carbon emissions from carbon sinks. Carbon sinks are any systems that absorb more carbon than they emit, such as forests, soils and oceans. Net-zero carbon means no carbon was emitted from the get-go, so no carbon needs to be captured or offset. For example, a company's building running entirely on solar, and using zero fossil fuels can label its energy as "zero carbon." Biomass energy is not as efficient as other energy sources. In many cases, it takes more energy to burn the organic material than the process actually produces.

Figure 4.5. Biomass comparison (IEA, 2019)



e) Geothermal

Geothermal energy is a type of renewable energy that is taken from the Earth's core. It comes from the heat generated during the planet's original formation and materials' radioactive decay. This thermal energy is stored in rocks and fluids in the Earth's centre. Depending on its characteristics, geothermal energy can be used for heating and cooling purposes or be harnessed to generate clean electricity.

However, high or medium-temperature resources are needed for electricity generation, which are usually located close to tectonically active regions. There are also several different geothermal technologies with distinct levels of maturity. Technologies for direct uses, such as district heating, geothermal heat pumps, greenhouses, and other applications, are widely used and can be considered mature.

Geothermal energy use can be divided into three categories: direct-use applications, geothermal heat pumps (GHPs), and electric power generation. Direct uses are probably the most widely used set of applications, involving the direct use of heated water from the ground without requiring specialised equipment. All direct-use applications make use of low-temperature geothermal resources, which range between about 50 and 150 °C.

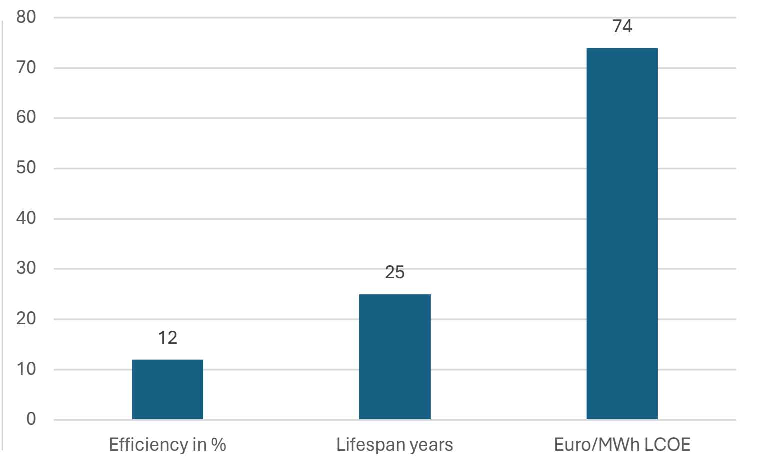
Geothermal heat pumps (GHPs) rely on the relatively stable moderate temperature conditions that occur within the first 300 metres of the surface to heat buildings in the winter and cool them in the summer. In that part of the lithosphere, rocks and groundwater occur at temperatures between 5 and 30 °C. At shallower depths, where most GHPs are found (such as within 6 metres of Earth's surface), the temperature of the ground maintains a near-constant temperature of 10 to 16 °C. Consequently, that heat can be used to help warm buildings during the colder months of the year when the air temperature falls below that of the ground.

Electric power generation depends upon the temperature and the fluid (steam) flow; geothermal energy can be used to generate electricity. Geothermal power plants can produce electricity in three ways. Despite their differences in design, all three control the behaviour of steam and use it to drive electrical generators. Given that the excess water vapour at the end of each process is condensed and returned to the ground, where it is reheated for later use, geothermal power is considered a form of renewable energy (**Figure 4.6**).

- **Advantages:**
  - Geothermal energy is generally considered environmentally friendly. The carbon footprint of a geothermal power plant is minimal. An average geothermal power plant releases 99% less carbon dioxide (CO_2) than a fossil fuel plant for every megawatt-hour (MWh) of electricity it generates, according to the Environmental Impact Assessment. Renewable and sustainable, geothermal reservoirs come from natural resources and are naturally replenished. Geothermal energy is, therefore, a renewable energy source.
  - Geothermal energy is a reliable source of energy; we can predict the power output of a geothermal power plant with remarkable accuracy. This is often not the case with solar and wind, where changeable weather systems play a huge role in power production.

- **Disadvantages:**
  - There is an abundance of greenhouse gases below the surface of the Earth. When geothermal energy is used, some gases may escape towards the surface and into the atmosphere. These emissions tend to be higher near geothermal power plants.
  - Surface instability (earthquakes) and the construction of geothermal power plants can impact the stability of the land, directly leading to subsidence.
  - Commercial geothermal power projects are expensive.

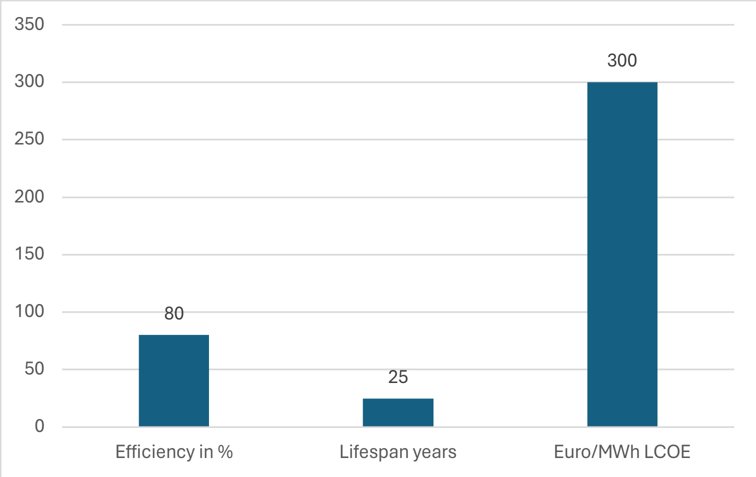
Figure 4.6. Geothermal comparison



f) Tidal

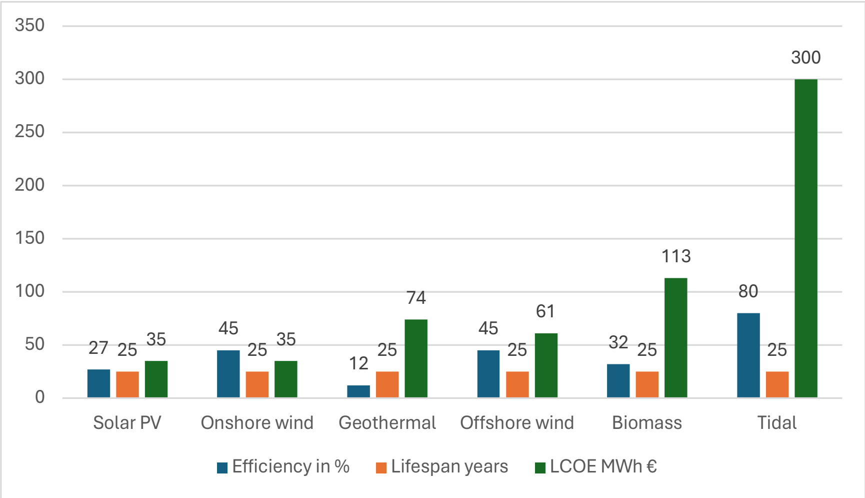
Tidal energy is a form of power produced by the natural rise and fall of tides caused by the gravitational interaction between the Earth, the Sun, and the moon. The potential or kinetic energy of tide movement is captured and converted into electricity. There are currently three ways to get tidal energy: tidal streams, barrages, and tidal lagoons. Tidal streams are fast-flowing bodies of water created by tides. A turbine is a machine that extracts energy from a flow of fluid. Because water is much denser than air, tidal energy is more powerful than wind energy. Moreover, unlike wind, tides are predictable and stable. Where tidal generators are used, they produce a steady, reliable stream of electricity. Barrage turbines inside barrages harness the power of tides the same way a river dam harnesses the power of a river. The barrage gates are opened as the tide rises. At high tide, the barrage gates close, creating a pool or tidal lagoon. The water is then released through the barrage's turbines (**Figure 4.7**). Finally, a tidal lagoon is a body of ocean water that is partly enclosed by a natural or man-made barrier. Tidal lagoons might also be estuaries and have freshwater emptying into them. A tidal energy generator using tidal lagoons functions much like a barrage.

Figure 4.7. Tidal comparison



To conclude renewable energy generation technologies, **Figure 4.8** below contrasts all the currently available technologies and has ranked the best performing on average from left to right, with solar PV being the best performing on average and tidal being the worst performing on average.

Figure 4.8. Renewable generation comparison[99]



4.5.2. Energy Storage system review

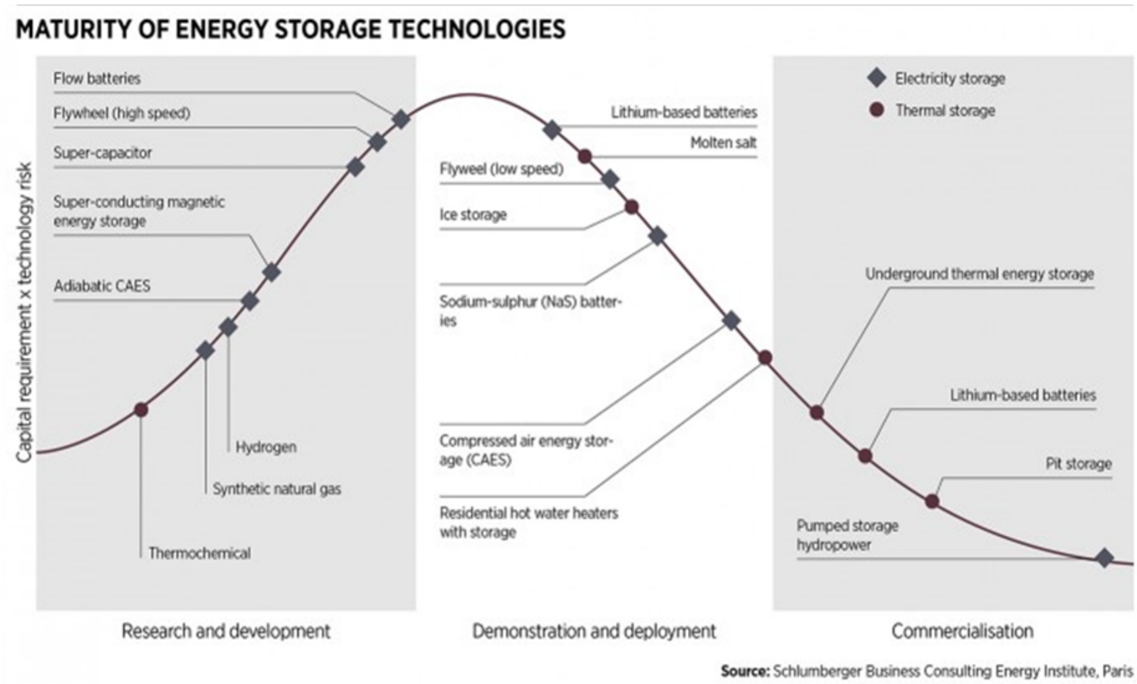
Energy storage systems are the methods and technologies used to store energy. The stored energy can be drawn upon at a later time to perform useful operations. There are various methods and technologies available to store energy in various forms. Applications, economics, integration within the system, and availability of resources typically dictate the choice of energy storage technology. Energy storage technologies exist at different levels of maturity, ranging from level 1 to 3:

99. Figure 4.8 is the compiled information of the renewable energy generation technologies review the information can be referenced in the International Energy Agency 2019 Renewable report.

- Level 1 (Research and development).
- Level 2 (Demonstration and deployment).
- Level 3 (Commercialisation).

This report takes a practical approach to energy storage systems and will exclude novel concepts of energy storage systems that are still in the research and development stage from full evaluation (**Figure 4.9**).

Figure 4.9. Maturity of energy storage (Lott et al., 2014)



Energy storage systems can be categorised by their defining technologies as follows (**Figure 4.10**):

Thermodynamic

Thermal energy storage (TES) is a common form of energy storage. A material gains energy when increasing its temperature and loses it when decreasing; this feature makes it possible to use different materials with different thermal properties to achieve various results, leading to different thermal energy storage applications.

Mechanical

Mechanical energy storage systems take advantage of kinetic or gravitational forces to store inputted energy. While the physics of mechanical systems are often quite simple (e.g. spinning a flywheel or lifting weights up a hill). The technologies enabling efficient and effective use of these forces are particularly advanced.

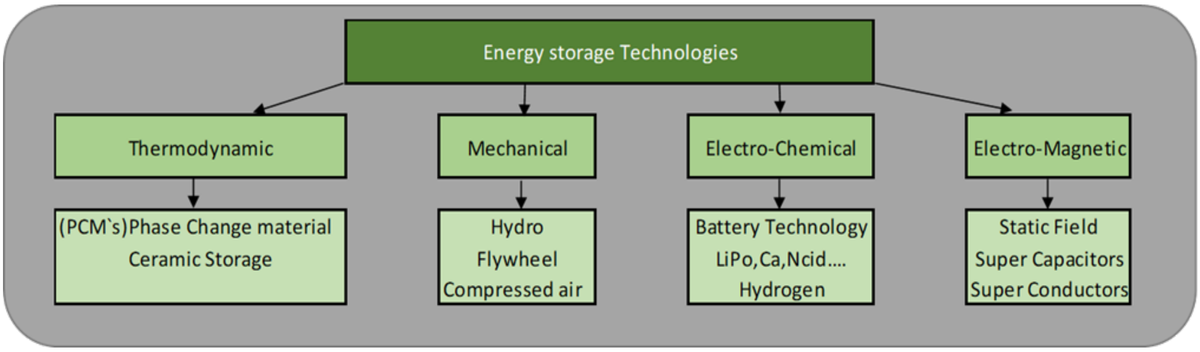
Electrochemical

Electrochemical energy is the conversion of chemical energy into electrical energy, and vice versa. This includes reactions transferring electrons and redox (reduction-oxidation) reactions.

Electro-magnetic

Superconducting magnetic energy storage (SMES) is a method of energy storage based on the fact that a current will continue to flow in a superconductor even after the voltage across it has been removed. When the superconductor coil is cooled below its superconducting critical temperature, it has negligible resistance; hence, the current will continue to flow even after a voltage source is disconnected. Energy is stored in the form of a magnetic field generated by the current in the superconducting coil. It can be released by discharging the coil.

Figure 4.10. Categorised storage technologies



a) *Suitability Index*

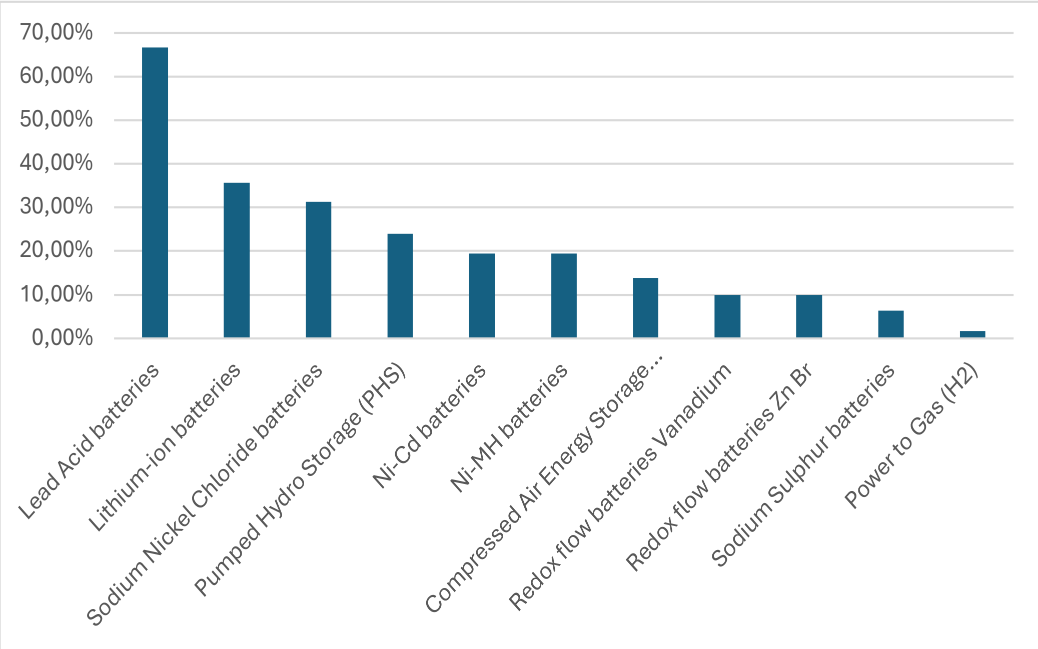
This review of the available energy storage systems excluded novel ideas and focused more on commercialised technologies or technologies that have the potential to be commercialised shortly (**Figure 4.11**). The suitability index is a method of shortlisting the current technologies selection at the present state of the art. It should be noted that the suitability index should be dynamic, and its own suitability can change as technology develops or the user's requirements become more specific. Not all reviewed technologies in this document are listed in the suitability index due to the lack of information available (Equation 1).

$$\text{Suitability Index } \frac{Level\ of\ maturity * Average\ efficiency}{Average\ Capex/kW} \quad \text{[Eq.1]}$$

Figure 4.11. Suitability index table

ID	Categories	Technologies	Avg Capex€/kW	Avg Eff (%)	Level of maturity, Level 1,2,3	Suitability Index
8	ElectroChemical	Lead Acid batteries	300	80	2.5	66.67%
10	ElectroChemical	Lithium-ion batteries	725	86	3	35.59%
9	ElectroChemical	Sodium Nickel Chloride batteries	575	90	2	31.30%
1	Mechanical	Pumped Hydro Storage (PHS)	1000	80	3	24.00%
14	ElectroChemical	Ni-Cd batteries	1000	65	3	19.50%
15	ElectroChemical	Ni-MH batteries	1000	65	3	19.50%
4	Mechanical	Compressed Air Energy Storage (CAES)	800	55.2	2	13.80%
18	ElectroChemical	Redox flow batteries Vanadium	1400	70	2	10.00%
19	ElectroChemical	Redox flow batteries Zn Br	1400	70	2	10.00%
7	ElectroChemical	Sodium Sulphur batteries	2500	80	2	6.40%
22	Chemical	Power to Gas (H2)	3500	30	2	1.71%

Figure 4.12. Suitability index graph

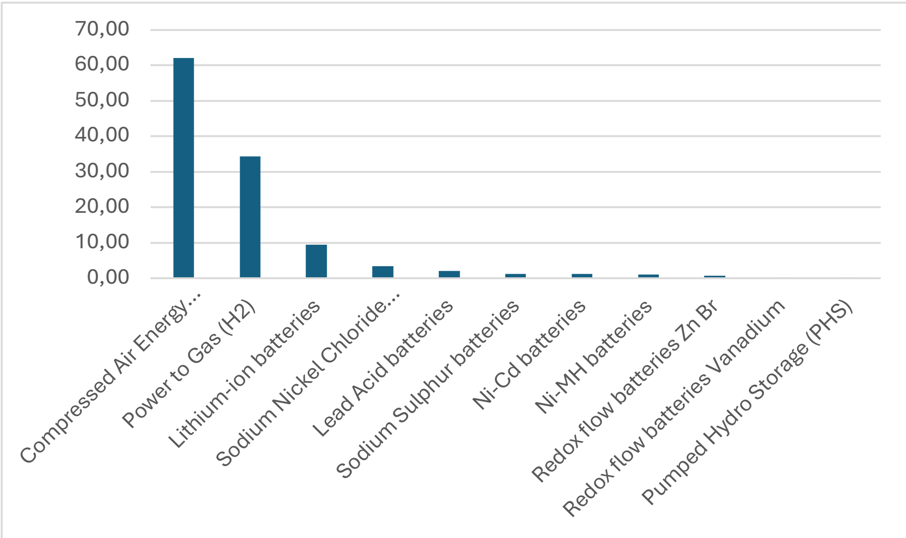


The suitability index should form part of the evaluation tool. The suitability index should rank the selected energy storage technologies that form the function of the application definition. The suitability index, while not necessary, can aid in the final selection where multiple technologies are presented as a solution. **Figure 4.12** above ranks the technologies from left to right, from the most to the least suitable. The index above ranks lead acid batteries as being the highest suitability. If this index were being performed for a grid service, where the storage system was confined by physical space, the suitability index would need to include information about the energy density of the storage solution. Thus, the suitability index formula would be expressed by equation 2.

$$\text{Suitability Index } \left(\frac{Level\ of\ maturity * Average\ efficiency * Energy\ density}{Average\ Capex/kW}\right) /10\% \qquad \text{[Eq.2]}$$

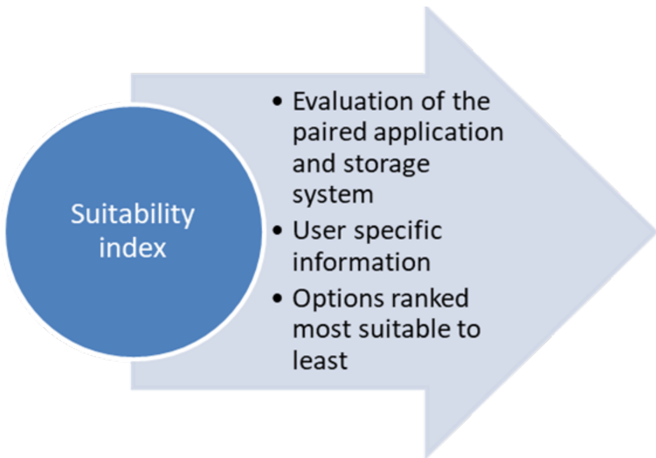
This would then produce the graph shown in **Figure 4.13**

Figure 4.13. Suitability index graph



While the results of the initial pairing of technology to the application, as referred to in the section 8, the ranking is slightly different and is thus a function of the user-defined suitability index formula (**Figure 4.14**).

Figure 4.14. Suitability index informatics



b) Sensible heat storage (SHS)

Sensible heat storage (SHS) is the most straightforward method. It simply means the temperature of some medium is either increased or decreased. This type of storage is the most commercially available of the three; other techniques are less developed. The materials are generally inexpensive and safe. One of the cheapest, most commonly used options is a water tank, but materials such as molten salts or metals can be heated to higher temperatures and therefore offer a significantly higher storage capacity. Energy can also be stored underground (UTES), either in an underground tank or in some kind of heat-transfer fluid (HTF) flowing through a system of pipes, either placed vertically in U-shapes (boreholes) or horizontally in trenches.

Another system is known as a packed-bed (or pebble-bed) storage unit, in which some fluid, usually air, flows through a bed of loosely packed material (usually rock, pebbles or ceramic brick) to add or extract heat. A disadvantage of SHS is its dependence on the properties of the storage medium. Storage capacities are limited by the specific heat capacity of the storage material, and the system needs to be properly designed to ensure energy extraction at a constant temperature (**Figure 4.15, Table 4.2**) (Sarbu and Sebarchievici, 2018).

Figure 4.15. Sensible heat storage (Bespalko et al., 2018)

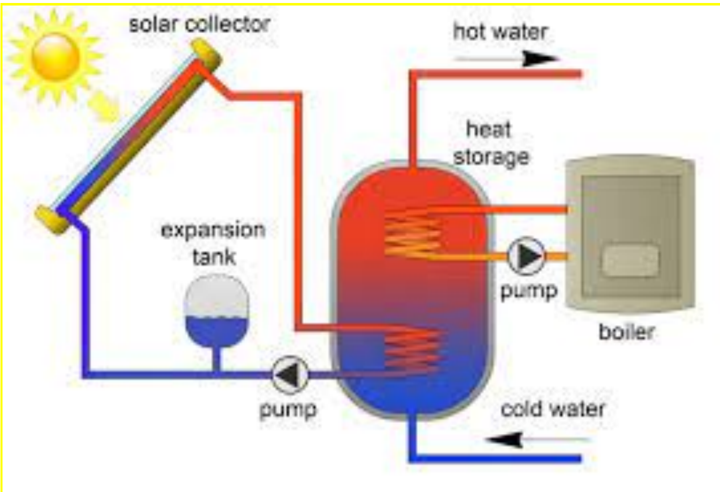


Table 4.2. Annex 1 Extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
27	Thermal	Sensible Thermal Energy Storage (STES)	1-12 hours	3000-4000	50-90	Min	3	10-50 kWh/t	0,001-10 MW

c) molten salts

Molten salts have high boiling points, low viscosity, low vapor pressure, and high volumetric heat capacities. A higher heat capacity corresponds to a smaller storage tank volume. In choosing an appropriate chemical mixture, having the lowest possible melting point (and highest boiling point) is advantageous to maximise the available temperature range for the molten salt. If the melting point is too high, additional heating may be required to prevent freezing. Salts used for storage (such as sodium nitrate $NaNO_3$ and potassium nitrate KNO3) have melting points between 300-500°C and volumetric heat capacities between 1670 – 3770 kJ/m3°C. The salts are heated and stored in an insulating container during off-peak hours. When energy is needed, the salt is pumped into a steam generator that boils water, spins a turbine, and generates electricity. The conversion of thermal energy to electricity can proceed by several different cycles, such as the Rankine, Brayton, and Air-Brayton cycles. The Brayton gas cycle, for example, involves an adiabatic expansion of the high-pressure and high-temperature gas across a turbine to do mechanical work, isobaric cooling, adiabatic compression to high pressure, and isobaric heating, whereupon the cycle is repeated. Other applications include using the stored heat directly for high-temperature processes (such as H2 production and coal-to-liquid conversion), which avoids the thermodynamic cost incurred from converting to electricity. The cooled salt is pumped back into the storage tank to be heated and reused (**Figure 4.16, Table 4.3**) (Dodaro, 2015).

Figure 4.16. Solar salt storage (Bonk et al., 2020)

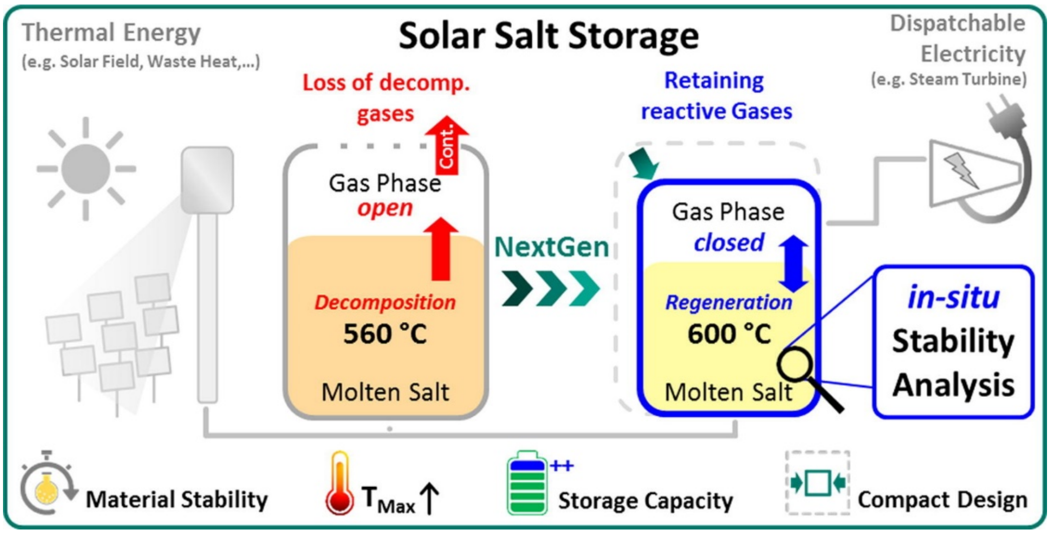


Table 4.3. Annex 1 extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
26	Thermal	Molten salts	6-10 hours	100-300	40	Mins	2	3 GWh	300 MW

d) Phase Change Material (PCM)

Phase Change Materials (PCM) or latent heat storage materials use a physical effect to store large amounts of energy in either a hot or cold form with nearly no loss and rerelease them later. When a PCM is heated and reaches its melting temperature, the temperature stays nearly constant until the melting process is completed. The temperature only rises again afterwards. Perhaps the best-known example of this process is water, which has its phase transition from solid to liquid state at 0°C and has been used as cold storage in the form of ice and snow to keep food cool for centuries. Melting 1 kg of ice requires the same amount of energy as heating the water from 0°C to 80°C.

PCMs are particularly interesting for several applications because of their high storage capacity and extremely low losses compared to other storage technologies. The term 'latent heat storage material' is commonly used as an alternative for Phase Change Material (PCM). PCMs are materials which change their state from solid to liquid or change between two different solid crystallisation states over a defined temperature range (phase transition). This process is reversible (reproducible phase transition) and can be used for thermomechanical purposes (**Figure 4.17, Table 4.4**). The advantage of PCMs over other storage materials is that they can absorb larger amounts of energy by storage volume/mass with a small temperature difference between the storage medium and its surroundings. They can also store the energy over time with minimal energy losses, and, finally, they can rerelease the energy when needed (RAL Quality Association, n.d.).

Figure 4.17. Phase change materials (Thermtest Instruments, 2020)

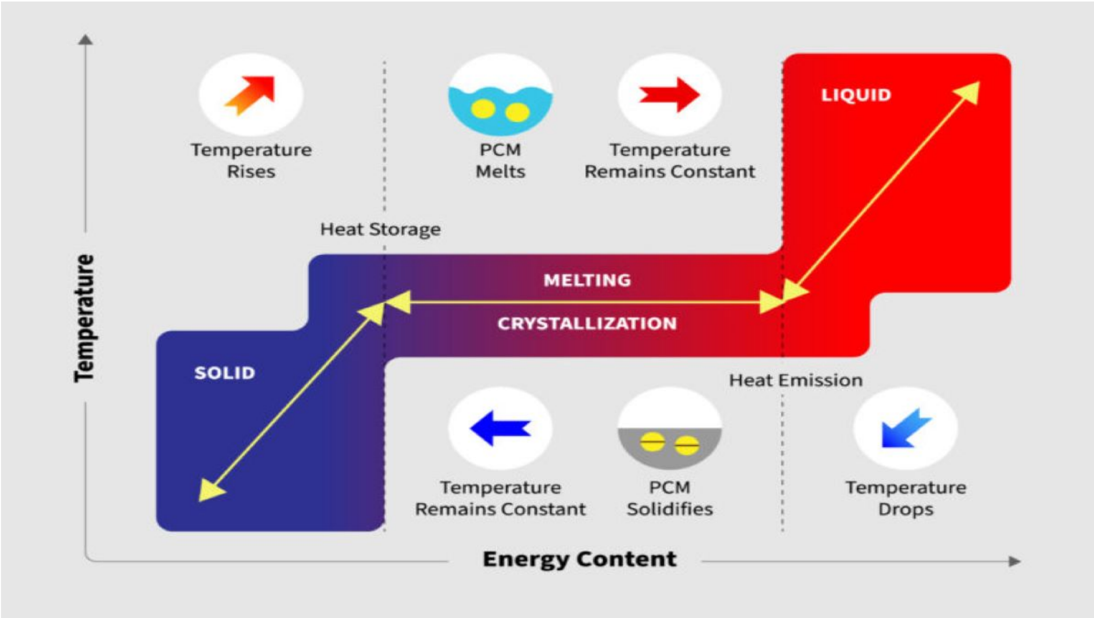


Table 4.4. Annex 1 extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/ kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
28	Thermal	Phase Change Material (PCM)	Weeks	5500-15000	75-90	min	1	50-150 kWh/t	0,001-1 MW

e) *Pumped Hydro Storage (PHS)*

Pumped hydro storage plants store energy using a system of two interconnected reservoirs, with one at a higher elevation than the other. Water is pumped to the upper reservoir in times of surplus energy, and in times of excess demand, water from the upper reservoir is released, generating electricity as the water passes through reversible Francis turbines on its way to the lower reservoir. The process is then repeated with an overall cycle efficiency of about 80% (**Figure 4.18, Table 4.5**).

Figure 4.18. Pumped hydro storage (Office of Energy Efficiency and Renewable Energy, 2022)

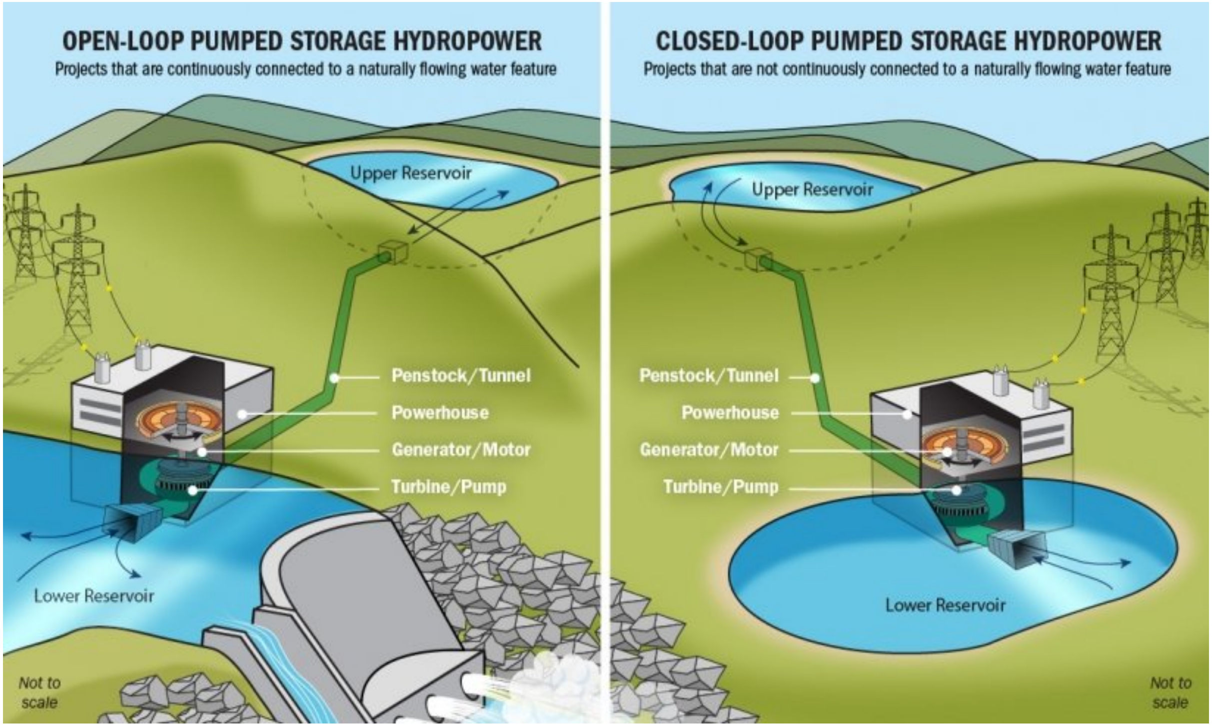


Table 4.5. Annex 1 extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/ kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
1	Mechanical	Pumped Hydro Storage (PHS)	Hours	500-1500	80	Seconds – Minutes	3	1-100 GWh	100 MW-1 GW

f) Pumped Heat Electrical Storage (PHES)

In pumped heat electrical storage systems, electricity is used to drive a storage engine connected to two large thermal stores. The engine takes heat from the hot store, and delivers waste heat to the cold store. Electrical energy drives a heat pump, which pumps heat from the "cold store" into the "hot store" (similar to the operation of a refrigerator). The heat pump is then reversed to become a heat engine to recover the expelled energy. When recovering electricity, the heat engine drives a generator. Pumped heat electrical storage (PHES) is analogous to pumped hydro storage, but rather than pumping water uphill, heat is pumped from one thermal store (-160°C) to another (+500°C) using a reversible heat pump/heat engine. Reversing the process drives the heat engine and generates electricity. The heat storage material is crushed rock. A closed circuit filled with the working gas connects the two stores, the compressor, and the expander. A monatomic gas such as argon is ideal as the working gas as it heats up and cools down much more easily than air for the same pressure increase/decrease (**Figure 4.19, Table 4.6**).

Figure 4.19. Pumped heat electrical storage (EASE, 2016b)

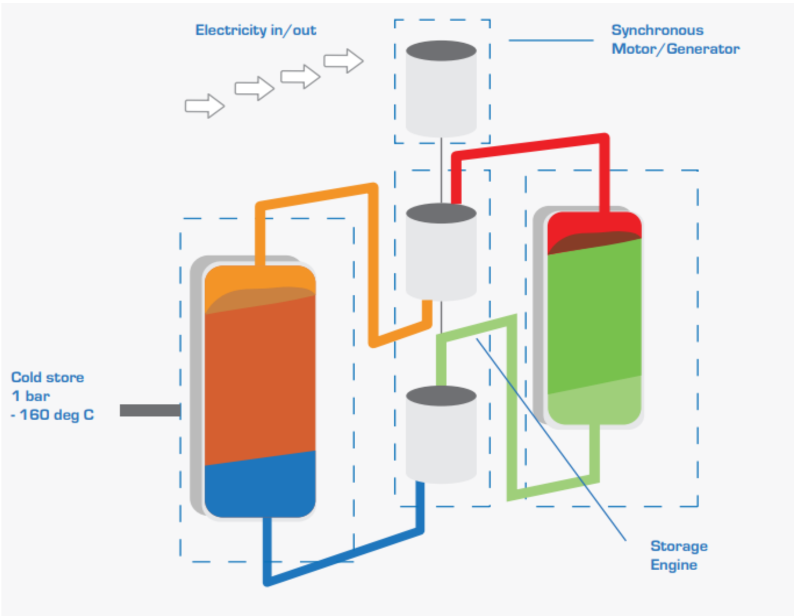


Table 4.6. Annex 1 extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
2	Mechanical	Pumped Heat Electrical Storage (PHES)	3-6 hours	350	70-75	Seconds – Minutes	1	500 kWh-1 GWh	100 kW-200 MW

g) Adiabatic Compressed Air Energy Storage (ACAES)

An adiabatic compressed air energy storage (A-CAES) system is based on air compression and air storage in underground geological voids. During operation, available electricity is used to compress air into a cavern at depths of hundreds of meters and pressures up to 100 bar. The heat produced during the compression cycle is stored using thermal energy storage (TES) while the air is pressed into underground caverns. When the stored energy is needed, this compressed air is used to generate power in a turbine while simultaneously recovering the heat from the thermal storage.

In periods with a surplus of electrical power, an electrically driven compression train compresses ambient air from atmospheric pressure up to 70 bars. The compressor discharge temperature can exceed 600 °C. Downstream, at the compression train, the hot air is sent to a TES, which is designed for the applied internal pressure and sufficiently insulated to minimise heat energy losses. In a regenerator type TES, hot air passes ceramic, concrete, or natural rock materials while its heat is transferred to the store inventory. Alternatively, TES systems can also be applied based on thermo-oil, molten salt, etc. The cooled air is then injected under pressure into the cavern (**Figure 4.20, Table 4.7**).

In discharge operations, the air leaves the cavern and passes through the TES before being applied to an expansion turbine coupled to a generator without co-firing any fuel.

Figure 4.20. Adiabatic compressed air energy storage (EASE, 2016)

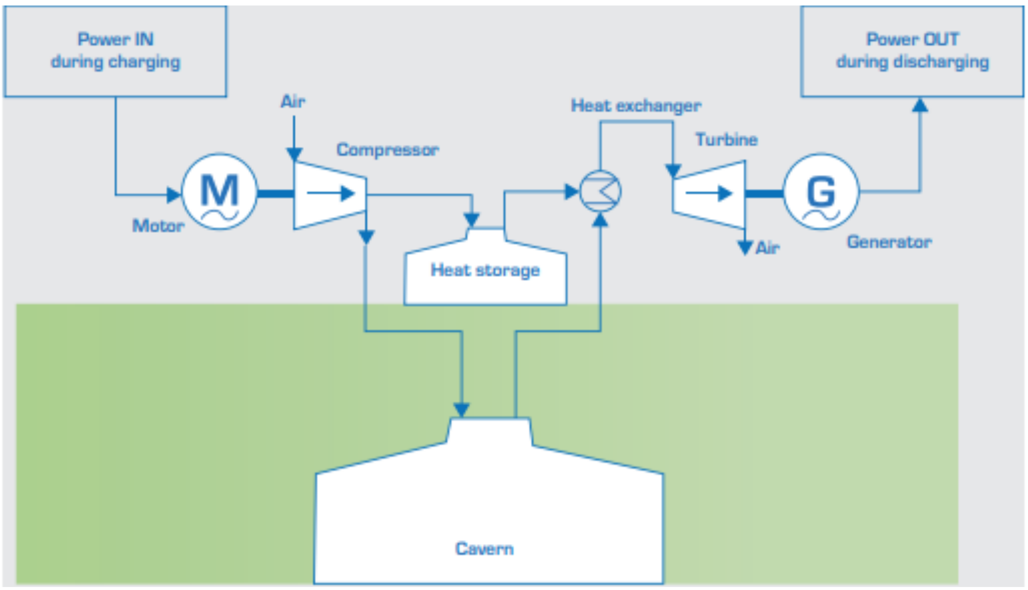


Table 4.7. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
3	Mechanical	Adiabatic Compressed Air Energy Storage (ACAES)	Hours	1200-2000	>70	min	1	10 MWh-10 GWh	10-300 MW

h) Compressed Air Energy Storage (CAES)

Compressed air energy storage (CAES) is based on the gas turbine cycle. Surplus power is used to compress air using a rotary compressor and then store it, often in an underground chamber. When the power is required, it is released from the chamber and passed through an air turbine that generates electricity from the high-pressure airflow. Output from the plant can be boosted by burning natural gas in the high-pressure air before it enters the air turbine, as would happen in a conventional gas turbine. However, this has the penalty of producing carbon dioxide emissions, which the regular storage plant does not. More advanced plants can store heat during air compression and release it during the expansion phase. However, only two commercial CAES plants have ever been built (**Figure 4.21, Table 4.8)** (Breeze, 2014).

Figure 4.21. Compressed air energy storage (CAES) (OilFree Air, n.d.)

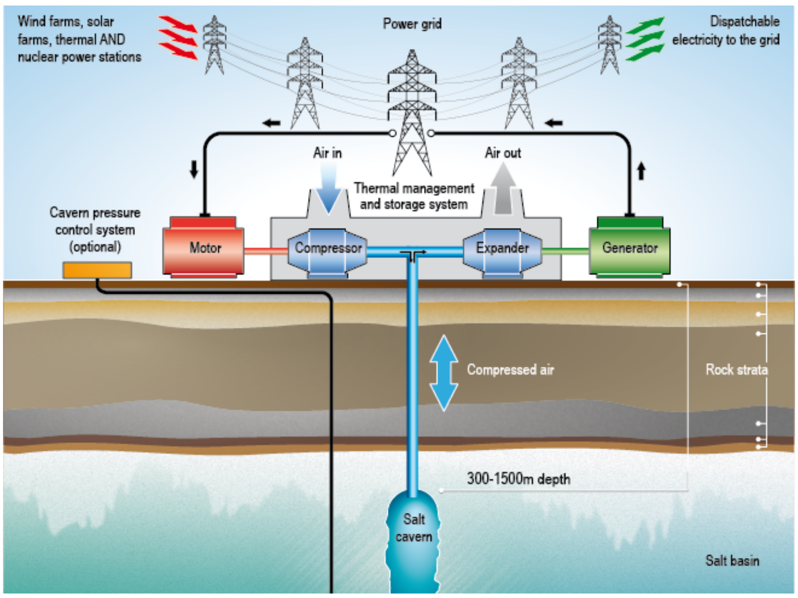


Table 4.8. Annex 1 extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
4	Mechanical	Compressed Air Energy Storage (CAES)	Hours	400-1200	45-60	Minutes	2	10 MWh-10 GWh	10-300 MWI

i) Liquid Air Energy Storage (LAES)

Liquid Air Energy Storage (LAES) technology uses a freely available resource: air that has been cooled and stored as a liquid. When energy is needed, the liquefied air is converted back into a pressurised gas which drives turbines to produce electricity. LAES is ideal for replacing fossil fuel-based power plants by providing long-duration storage in renewable power systems. It offers cost-effective supply-demand balancing besides ancillary services, such as grid stability, inertia, and reactive power (**Figure 4.22, Table 4.9**).

Figure 4.22. Liquid air energy storage (Legrand et al., 2019)

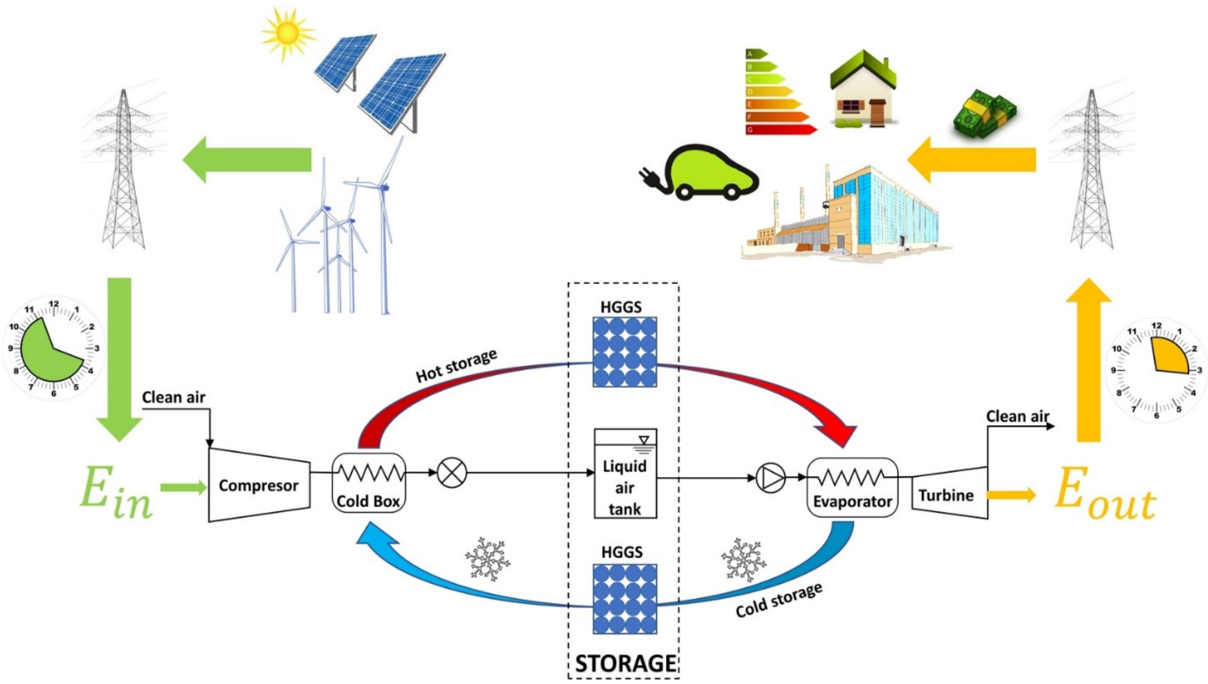


Table 4.9. Annex 1 extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
5	Mechanical	Liquid Air Energy Storage (LAES)	2-24 hours	500-3500	50-100	Min	1	10 MWh-8 GWh	5-650 MW

j) Flywheel

Flywheel energy storage systems (FESS) use an electric energy input stored as kinetic energy. Kinetic energy can be described as the "energy of motion." In this case, it refers to the motion of a spinning mass called a rotor. The rotor spins in a nearly frictionless enclosure. When short-term backup power is required because utility power fluctuates or is lost, the inertia allows the rotor to continue spinning, and the resulting kinetic energy is converted to electricity. Most modern high-speed flywheel energy storage systems consist of a very large rotating cylinder (a rim attached to a shaft) that is supported on a stator the stationary part of an electric generator by magnetically levitated bearings. Efficiency is maintained by the flywheel system operating in a vacuum to reduce drag. The flywheel is connected to a motor generator that interacts with the utility grid through advanced power electronics (**Figure 4.23, Table 4.10**) (Xu et al., 2023).

Figure 4.23. Flywheel storage (Olabi et al., 2021)

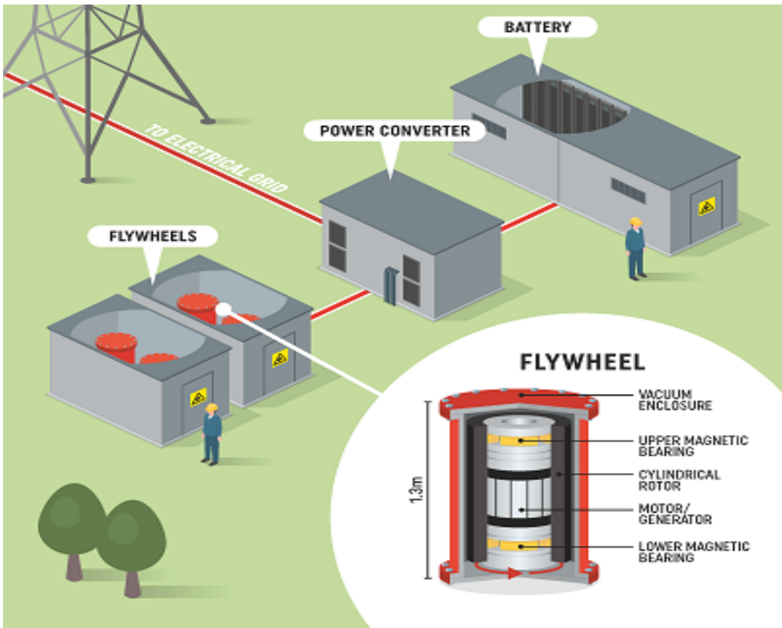


Table 4.10. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
6	Mechanical	Flywheel	5-30 minutes	500-2000	85	Minutes	1.5	5-10 kWh	1-20 MW

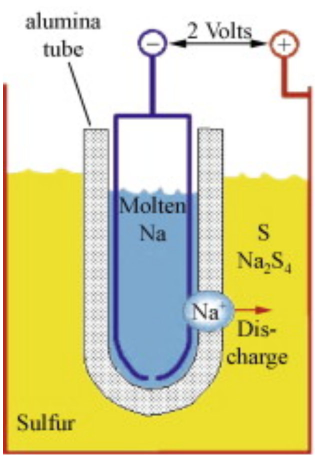
k) Liquid Sodium (Na) and Sulfur (S) (NaS)

The active materials in a NaS battery are molten sulfur as the positive electrode and molten sodium as the negative electrode. The electrodes are separated by a solid ceramic, sodium alumina, which also serves as the electrolyte. This ceramic allows only positively charged sodium ions to pass through.

During discharge, electrons are removed from the sodium metal (one negatively charged electron for every sodium atom), forming the sodium ions that then move through the electrolyte to the positive electrode compartment. The electrons stripped from the sodium metal move through the circuit and back into the battery at the positive electrode, where the molten sulfur takes them up to form polysulfide. The positively charged sodium ions move into the positive electrode compartment to balance the electron charge flow.

During the charging phase, this process is reversed. The battery must be kept hot (typically >300°C) to facilitate the process (i.e., independent heaters are part of the battery system). In general, Na/S cells are highly efficient (typically operating at 89% efficiency). NaS battery technology has been demonstrated at over 190 sites in Japan. More than 270 MW of stored energy, suitable for 6 hours of daily peak saving, have been installed. In Abu Dhabi, fifteen NaS systems, acting in coordination, provide 108 MW / 648 MWh to defer fossil fuel generation investment and provide frequency response and voltage control services (**Figure 4.24, Table 4.11**) (Energy Storage, 2023).

Figure 4.24. Sodium Sulphur batteries (https://www.energy-storage.news/nas-batteries-long-duration-energy-storage-proven-at-5gwh-of-deployments-worldwide/)



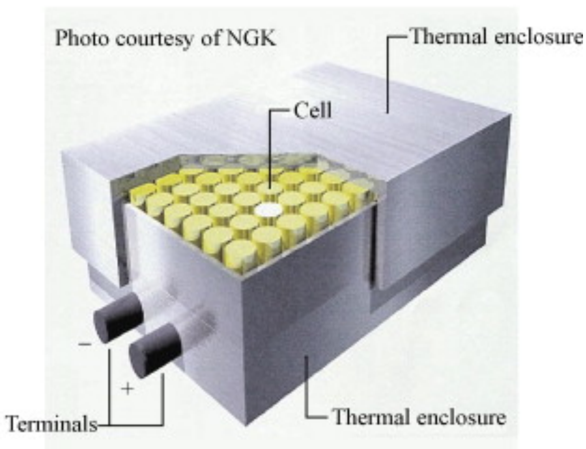


Table 4.11. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
7	Electrochemical	Sodium Sulphur batteries	6 hours	2000-3000	75-85	Milliseconds	1	< 100 MWh	< 10 MW

I) Lead-acid batteries

The lead–acid battery is a type of rechargeable battery. Compared to modern rechargeable batteries, lead–acid batteries have relatively low energy density. Despite this, their ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio. These features, along with their low cost, make them attractive for use in motor vehicles to provide the high current required by starter motors during ignition processes.

Lead-acid batteries are inexpensive compared to newer technologies and are widely used even when surge current is not important. Accordingly, other designs could provide higher energy densities. Large-format lead-acid designs are widely used for storage in backup power supplies in cell phone towers, high-availability emergency power systems (such as hospitals), and stand-alone power systems (**Figure 4.25, Table 4.12**).

Figure 4.25. Lead-acid batteries (Ibraheem, 2018)

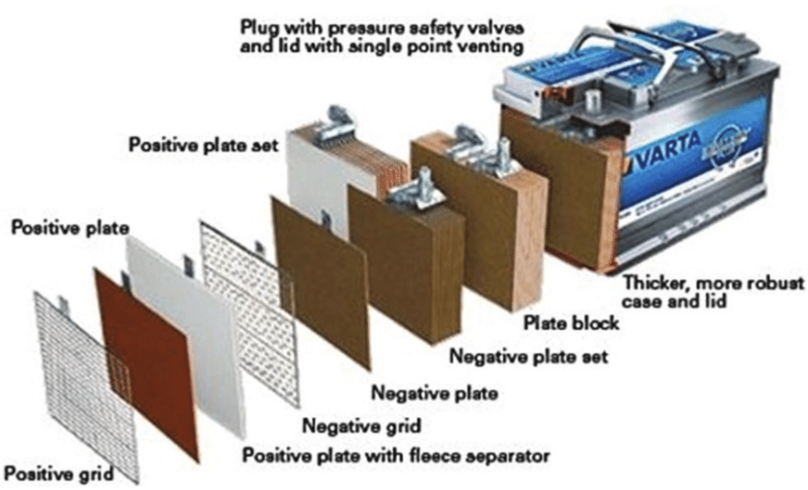


Table 4.12. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
8	Electrochemical	Lead Acid batteries	Hours	100-500	75-85	Milliseconds	3	Up to 10 MWh	Some MW

m) Sodium nickel chloride batteries

A $Na/NiCl_2$ secondary battery is an energy storage system based on electrochemical charge/discharge reactions that occur between a positive electrode (cathode) consisting mainly of nickel (Ni), sodium chloride (NaCl), and a negative electrode (anode) that is typically made of sodium (Na). The electrodes are separated by a beta-alumina ceramic wall that is conducive for sodium ions but an isolator for electrons. This beta-alumina ceramic acts as an electrolyte, enabling the conduction of sodium ions between the anode and cathode of the cells. The battery temperature is kept between 270° C and 350° C to keep the electrodes in a molten state (i.e., independent heaters are part of the battery system) (**Figure 4.26, Table 4.13**).

Figure 4.26. Sodium nickel chloride batteries (EASE, 2016C)

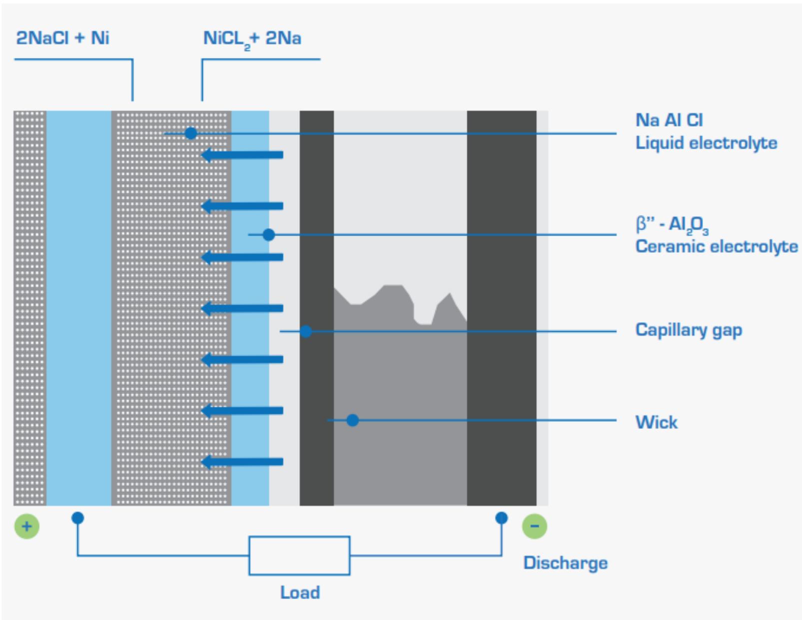


Table 4.13. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
9	Electrochemical	Sodium Nickel Chloride batteries	2- to several hours	150-1000	85-95	Milliseconds	3	4 kWh-10 MWh	Several MW

n) Lithium-ion batteries

In lithium-ion batteries, the anode and cathode store lithium. The electrolyte carries positively charged lithium ions from the anode to the cathode and vice versa through the separator. The movement of the lithium ions creates free electrons in the anode, which creates a charge at the positive current collector. An electrical current then flows from the current collector through the device (e.g., cell phone, computer, etc.) to the negative current collector. The separator blocks the flow of electrons inside the battery. Lithium-ion batteries offer good energy storage and density for their size and can be charged/discharged many times in their lifetime (**Figure 4.27, Table 4.14**).

Figure 4.27. Lithium-ion batteries (https://energystorage.org/why-energy-storage/technologies/lithium-ion-li-ion-batteries/)

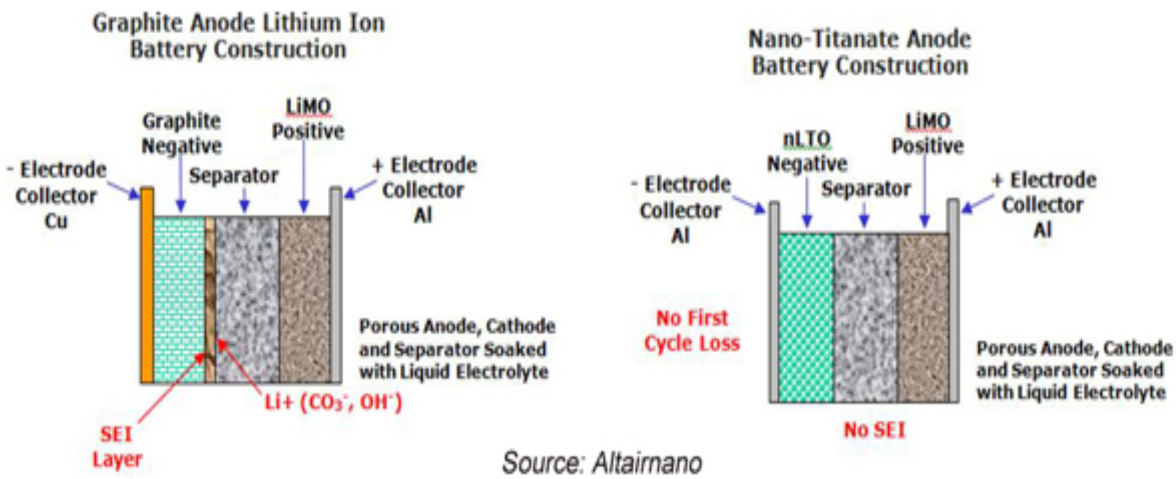


Table 4.14. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
10	Electrochemical	Lithium-ion batteries	10 min to 4 hours	150-1300	86	Milliseconds	2	< 10 MWh	< 50 MW

o) Lithium-S batteries R&D

Li-S battery technology, water-based Lithium-Sulphur (Li-S) offers the lightest high-energy batteries that are completely self-contained. The design could achieve energy densities between 400-600 Wh/kg, a substantial improvement from today's state-of-the-art Li-Ion batteries that can hold only 150 Wh/kg. Vehicle transportation and grid storage applications would be able to transition to a widespread commercial and military market. Lithium-sulphur batteries may displace lithium-ion cells because of their higher energy density and reduced cost. This is due to the use of sulphur instead of cobalt, a common element in lithium-ion batteries. Li–S batteries offer specific energies on the order of 550 Wh/kg, while lithium-ion batteries are in the range of 150–260 Wh/kg (**Figure 4.28, Table 4.15**) (Manthiram et al., 2013).

Figure 4.28. Lithium-S batteries R&D (He and Manthiram, 2019)

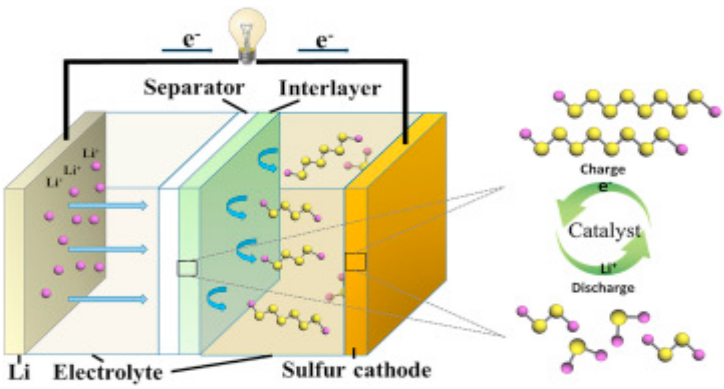


Table 4.15. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
11	Electrochemical	Lithium-S batteries R&D	Not available	Not available	Not available	Milliseconds	1		

p) *Lithium-metal-polymer batteries*

A lithium-metal-polymer (LMP) battery system is an energy storage system based on electrochemical charge/ discharge reactions occurring between a positive electrode (cathode), based on a metal oxide intercalation compound, and a negative electrode (anode), typically made of lithium metal. The cell reaction is the intercalation of lithium ions into the structure of the cathode during the discharge cycle and a de-intercalation of lithium ions from the charged cathode and its plating onto the anode during the charge cycle. The cell operation needs to run at an internal temperature of 70-80 °C (**Figure 4.29, Table 4.16**).

Figure 4.29. Lithium-metal-polymer batteries (EASE, 2016a)

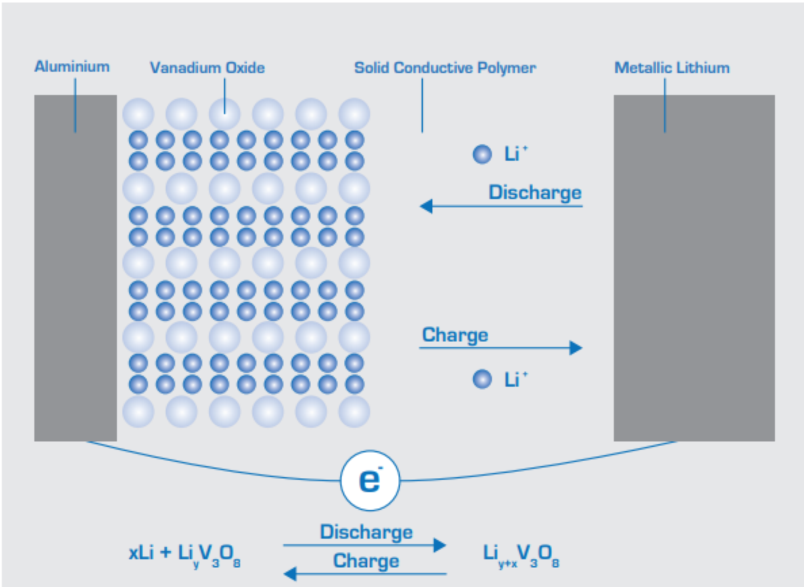


Table 4.16. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
12	Electrochemical	Lithium-Metal-Polymer batteries	years	Unknown	88%	Milliseconds	1	2600 Wh/kg-1	

q) Ni-Cd batteries

Nickel-cadmium (Ni-Cd) batteries have high power and energy density and high efficiency of charge/discharge but typically struggle with short cycle life. The primary demerit of Ni-Cd batteries is their relatively high cost due to the expensive manufacturing process required. Moreover, cadmium is a toxic heavy metal, posing issues associated with the disposal of Ni-Cd batteries. Ni-Cd batteries also suffer from the "memory effect," where the batteries can only take a full charge after a series of full discharges electronics (**Figure 4.30, Table 4.17**).

Figure 4.30. Ni-Cd batteries (Abdin and Khalilpour, 2019)

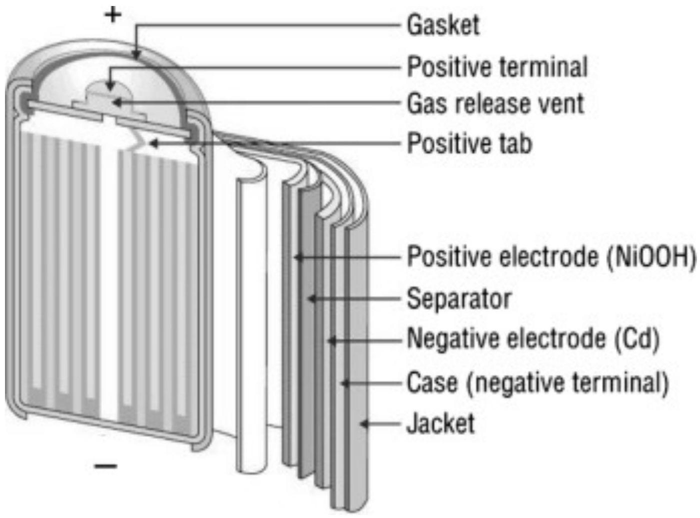


Table 4.17. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
14	Electrochemical	Ni-Cd batteries	hours	500-1500	60-70	Milliseconds	3	some MWh	some MW

r) Ni-MH batteries

A nickel metal hydride battery (NiMH or Ni–MH) is a rechargeable battery. The chemical reaction at the positive electrode is similar to that of the nickel-cadmium cell (NiCd), using nickel oxide hydroxide (NiOOH). However, the negative electrodes use a hydrogen-absorbing alloy instead of Cadmium. NiMH batteries can have two to three times the capacity of NiCd batteries of the same size and with significantly higher energy density, although this is much less than lithium-ion batteries. They are typically used as a substitute for similarly shaped non-rechargeable alkaline batteries. Generally, they have a compatible cell voltage and are less prone to leaking and explosion electronics (**Figure 4.31, Table 4.18**) (University of Washington, n.d.).

Figure 4.31. Ni-MH batteries (Salkuti, 2021)

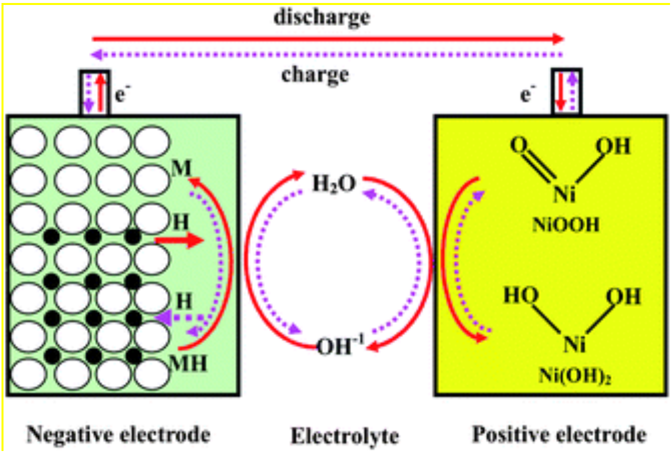


Table 4.18. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
15	Electrochemical	Ni-MH batteries	hours	500-1500	60-70	Milliseconds	3	some MWh	some MW

s) Redox flow batteries Zn Fe

Zinc-based flow batteries have attracted tremendous attention for their outstanding advantages, which include a high theoretical gravimetric capacity, low electrochemical potential, rich abundance, and the low cost of metallic zinc. Among these, zinc-iron (Zn/Fe) flow batteries show great promise for grid-scale energy storage. However, they still face challenges associated with the corrosive and environmental pollution of acid and alkaline electrolytes, hydrolysis reactions of iron species, and the poor reversibility and stability of Zn/Zn2+ redox couple electronics (**Figure 4.32, Table 4.19**).

Figure 4.32. Redow flow batteries Zn Fe (Yang et al., 2022)

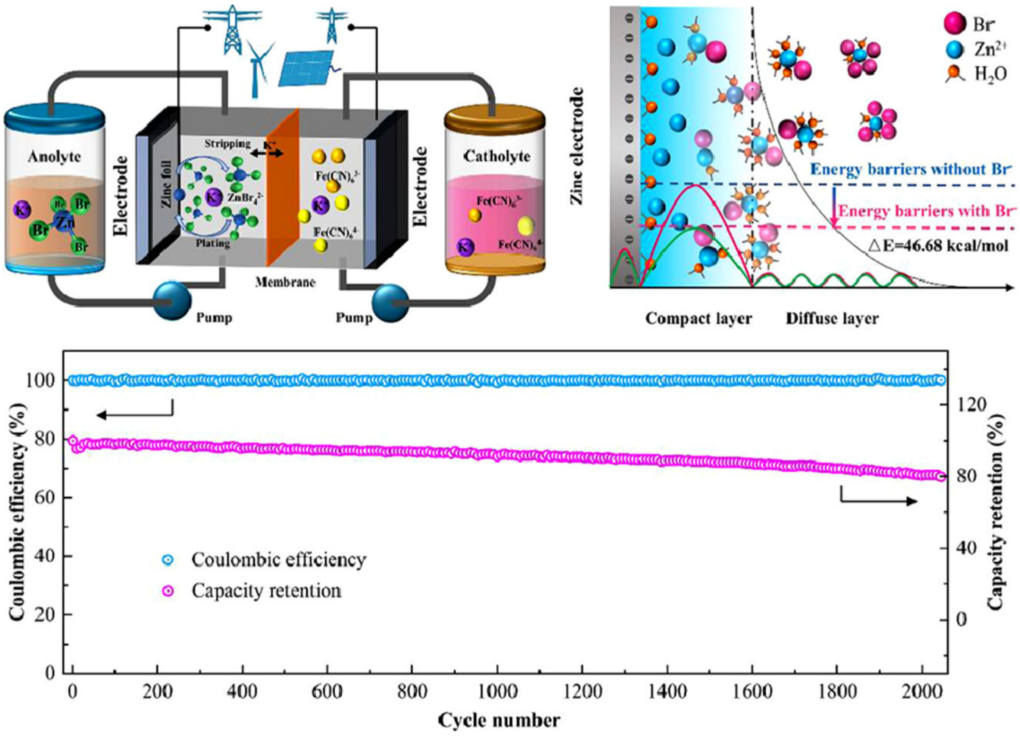


Table 4.19. Annex I extract

EDA ESS									
ID	Categories	Technologies	Storage duration at full power	CAPEX (€/kW)	Round-trip efficiency (%)	Response Time	Level of maturity, Level 1,2,3	Energy Capacity	Power installed capacity
17	Electrochemical	Redox flow batteries Zn Fe	hours	Un-Clear	85%	Milliseconds	2	< 100 MWh	< 10 MW

t) *Redox flow batteries vanadium*

Vanadium is an element that can commonly exist in four different oxidation states, meaning it can exist as an ion with different charges. For example, a vanadium ion that is missing three electrons would have a charge of V3+. If you add an electron to it, this will convert to a V2+ ion. This transfer of electrons back and forth allows VFBs to charge and discharge as the vanadium ions in the battery swing from V2+ to V5+. This differs from lithium-ion batteries in that every time lithium charges and discharges, it plates and depletes lithium metal on the cathode. Although this reaction is almost completely reversible, it leads to degradation after three to five thousand cycles, and performance will decrease. A VFB consists of two tanks of electrolytes dissolved in water, separated by a proton exchange membrane. Both electrolytes are vanadium-based. As the batteries are charged and discharged, vanadium ions move between oxidation states, this can be done tens of thousands of times over a time period measured in decades, with no degradation in the ability of the vanadium solutions to hold a charge electronics (**Figure 4.34, Table 4.20**).

Figure 4.33. Redox flow batteries vanadium (Robert Rapier, 2020)

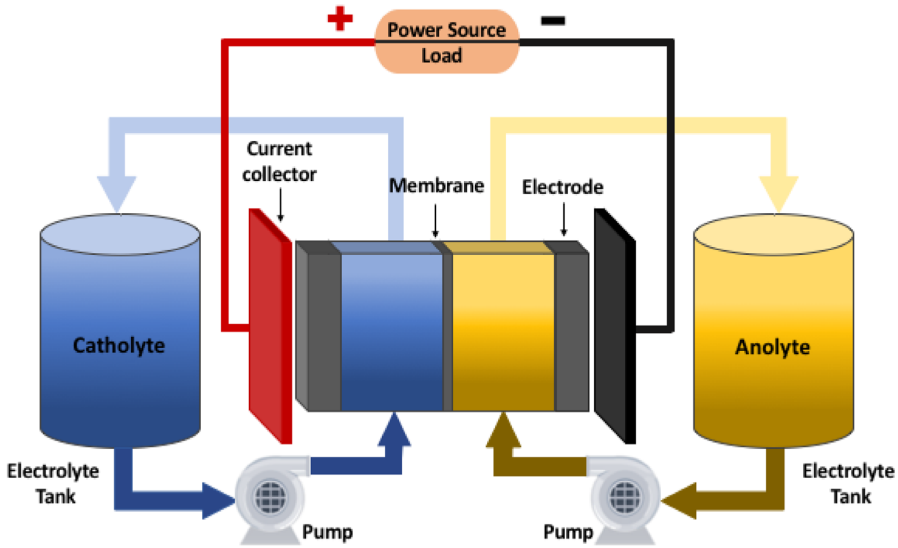


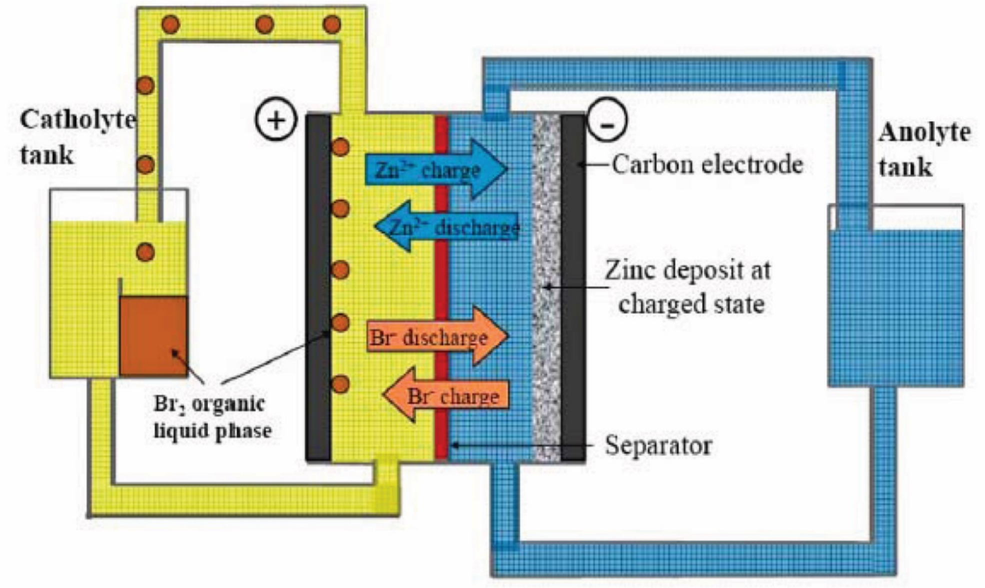
Table 4.20. Annex I extract

EDA ESS									
ID	**Categories**	**Technologies**	**Storage duration at full power**	**CAPEX (€/kW)**	**Round-trip efficiency (%)**	**Response Time**	**Level of maturity, Level 1,2,3**	**Energy Capacity**	**Power installed capacity**
18	Electrochemical	Redox flow batteries Vanadium	hours	500-2300	70	Milliseconds	2	< 100 MWh	< 10 MW

u) Redox flow batteries ZnBr

Zinc-bromine (ZnBr) flow batteries can be categorised as hybrid flow batteries, meaning that some of the energy is stored in the electrolyte, and some of the energy is stored on the anode by plating it with zinc metal during charging. In a ZnBr battery, two aqueous electrolytes act as electrodes of the battery and store charge. The electrolyte solutions contain the reactive components, zinc and bromine; as these solutions flow through the battery's cells, reversible electrochemical reactions occur, and energy is either charged to the battery or discharged. When the battery is charging, elemental zinc attaches to the carbon-plastic electrodes connecting each cell in the battery to form the anode and bromine forms at the cathode. Carbon plastic is used for the electrodes because of the highly corrosive nature of bromine. A selective membrane is included in the battery's design to separate the electrolytes while still allowing ion transfer to maintain charge neutrality electronics (**Figure 4.34**) (Johnson et al., 2019).

Figure 4.34. Redox flow batteries ZnBr (CredibleCarbon, n.d.)



v) *Power to gas (H2)*

Power-to-Gas (P2G) converts surplus renewable energy into hydrogen gas through electrolysis technology. The hydrogen can then be injected into the natural gas grid. In doing so, hydrogen displaces natural gas, reducing greenhouse gas emissions and reliance on high-carbon fuels. P2G also supports the anaerobic digestion processes, where microorganisms are broken-down to organic matter to produce fuels. With the addition of hydrogen, the process (otherwise referred to as methanation) greatly improves conversion rates of carbon dioxide (CO_2) to biomethane (from 60% to 95%). hydrogen generated via PEM water electrolysis technology is key to transforming surplus electricity generated from renewables into storable methane that can be utilised within the traditional natural gas grid.

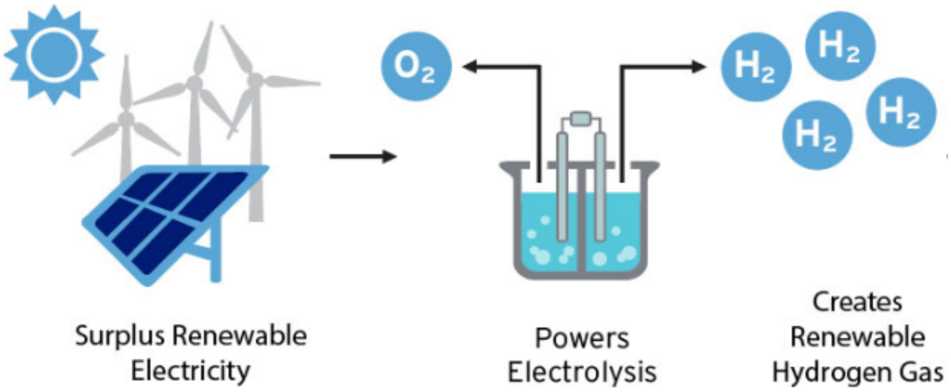
Modern technologies can generate these large volumes of H_2, including steam methane reforming and water electrolysis. Steam methane reforming is the main production method for most of the hydrogen generated in the world today. However, this process generates C02, so the use of carbon capture technologies would likely be required for this to be part of a carbon-free ecosystem.

Hydrogen can be generated from a variety of feedstocks and chemical processes. These include (but are not limited to) photosynthesis using algae, steam methane reforming (SMR) of natural gas, partial oxidation of crude oil, gasification of coal, and water electrolysis. The next sections will provide further details on steam methane reforming and electrolysis as potential pathways to generating hydrogen for power generation.

Hydrogen has several other attractive properties, such as higher gravimetric energy content and wider flammability limits than most fossil fuels. However, there are practical limitations to its widespread use at present, including its low volumetric energy density in the gaseous state and high well-to-wheel costs compared to fossil fuel production and distribution. Liquid hydrogen is light and has fewer potential risks compared with compressed gas in terms of storage pressure. However, hydrogen liquefies at 20.25 K. Thus, storage vessels require highly sophisticated insulation techniques to minimise unavoidable heat transfer leading to hydrogen loss via boil-off.

Liquid hydrogen has been used as a fuel in space technology for several decades. It has a higher density and fewer potential risks in terms of storage pressure compared with compressed gas. Liquefaction is done by cooling gas to form a liquid. Liquefaction processes use a combination of compressors, heat exchangers, expansion engines, and throttle valves to achieve the desired cooling. The Linde cycle or Joule–Thomson expansion cycle are the simplest liquefaction processes. In this process, the gas is compressed and then cooled in a heat exchanger before passing through a throttle valve, where it undergoes an isenthalpic Joule–Thomson expansion, producing some liquid electronics (**Figure 4.35)** (Allevi and Collodi, 2017).

Figure 4.35. Power to gas (H2) (FCHEA, 2019)

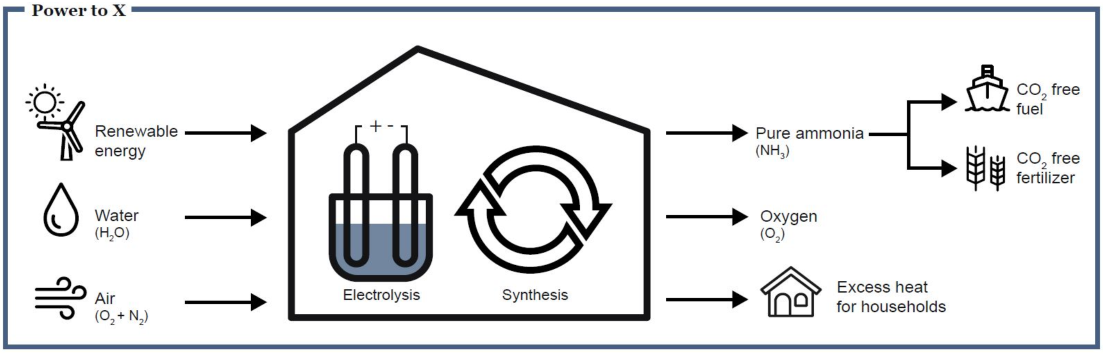


w) Power to ammonia – gasoline

Ammonia (NH_3) is a colourless and pungent-smelling gas at room temperature. It is a compound formed of nitrogen and hydrogen. Pure ammonia is hygroscopic and easily dissolved in water and humidity. Ammonia is, however, corrosive due to its alkaline properties. Having said that, it is one of the most commonly produced industrial chemicals around the world. More than 75% of the ammonia produced is used in the agriculture sector as a fertiliser. Ammonia can also be used as a working fluid in a refrigeration cycle. Current ammonia production is not a "green" process; the synthesis occurs starting from gaseous hydrogen currently produced from hydrocarbons. Ammonia is a versatile compound composed of nitrogen and hydrogen (NH_3). The importance of hydrogen in the transition toward the decarbonisation of the transport sector is well recognised (Capurso et al., 2022; Zhang et al., 2022). However, hydrogen storage remains a significant challenge, limiting its direct application to vehicles: It must be stored at −253°C as a liquid or at pressures of about 700 bar as a gas. Liquid ammonia, on the other side, can be stored at a more realistic temperature of -33°C at standard pressure and +20°C at 9 bar. This makes the storage and transport of this energy carrier much easier.

Early utilisation of liquid NH_3 (ammonia) as a fuel for motor buses took place in Belgium in 1943. Emeric Kroch developed these ammonia/coal gas hybrid motors to keep public transportation in operation despite the extreme diesel shortages posed by World War II. This motor-bus fleet logged tens of thousands of miles (and there is anecdotal evidence that some individuals used the ammonia pumps built for the bus fleet to fuel their cars during this period) (**Figure 4.36**) (Chalmers, 2014).

Figure 4.36. Power to ammonia – Gasoline (Fathom World, 2021)

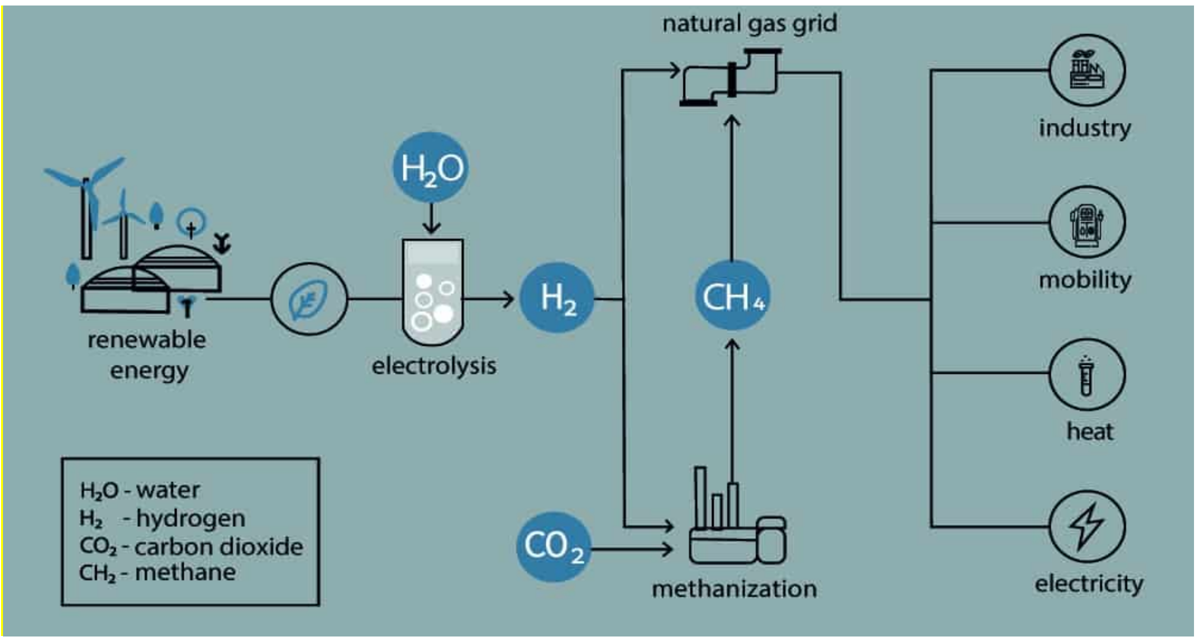


x) *Power to methane*

Power-to-Methane is a concept that converts electrical into chemical energy using CO_2 and H_2O. The concept brings the possibility of connecting the power grid to different sectors where CH4 is needed, such as mobility and industry. Synthetic natural gas (methane) offers a clear advantage in terms of storage time and the range of power that it can store over other similar technologies.

A power-to-methane system combines hydrogen from a power-to-hydrogen system with carbon dioxide to produce methane using a methanation reaction (such as the Sabatier reaction) or biological methanation causing an additional energy conversion loss of 8%. The methane may then be fed into the natural gas grid or stored if the purity requirement is reached (**Figure 4.37**) (Climate Adaptation Knowledge Exchange, n.d.).

Figure 4.37. Power to methane (Schneider, 2022)

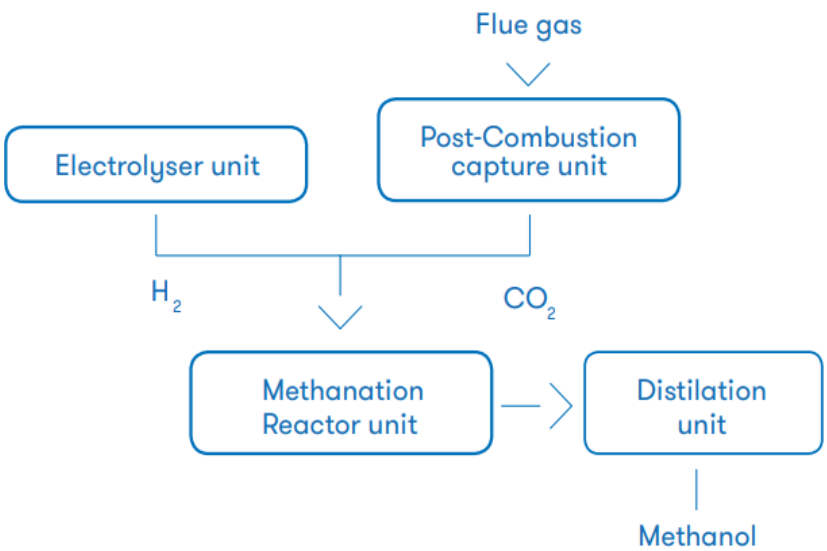


y) Power to methanol + gasoline

Hydrogen is produced by water electrolysis. Meanwhile, carbon dioxide is captured from flue gas via post-combustion capture. Both gases are converted to methanol using a catalytic reactor. The required product quality is ensured via a distillation process which is located downstream from the methanol conversion process. An additional high-temperature heat pump utilises the waste heat from the electrolyser so that overall system efficiency can be further increased up to 50-55%.

Gasoline can be produced by methanol conversion, e.g. using the CAC process. The efficiency of this process is up to 93% (during the conversion of methanol and hydrogen to product fuels, such as gasoline and LPG, LHV-based). The efficiency of the complete process is up to 48-53% (**Figure 4.38**).

Figure 4.38. Power to methanol + gasoline (EASE, 2018)

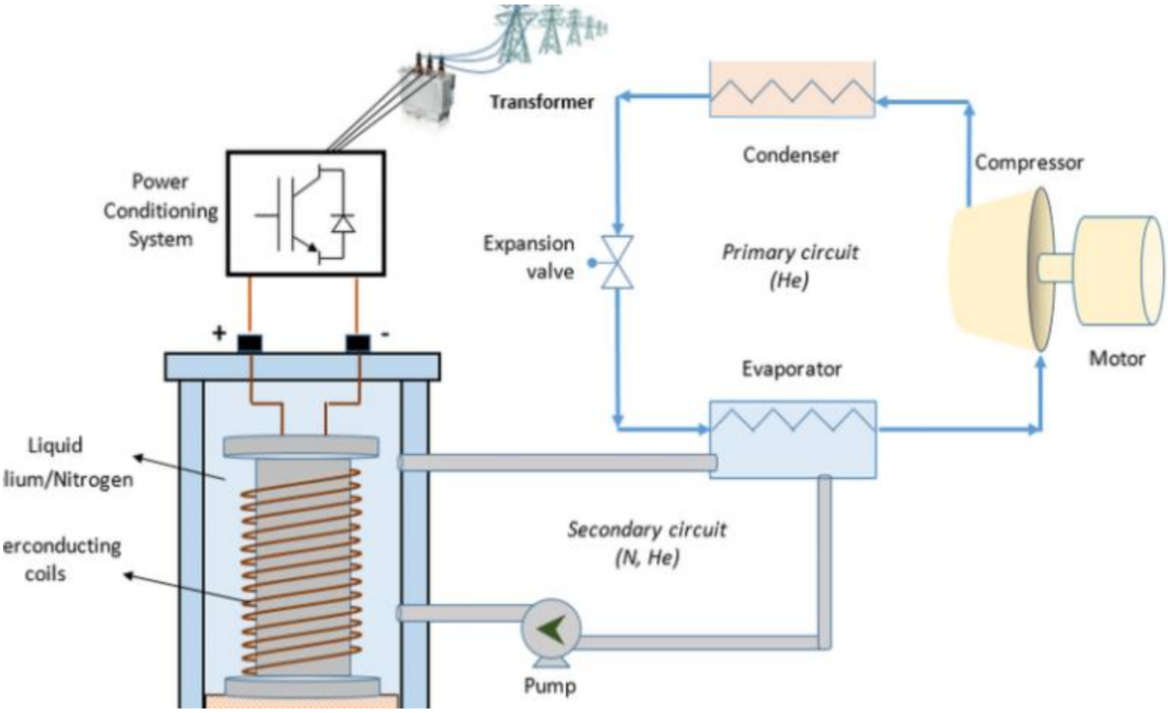


z) Electro-magnetic

<u>*Superconducting Magnetic Energy Storage (SMES)*</u>

Superconducting magnetic energy storage (SMES) systems store energy in a magnetic field generated by a DC current travelling through a superconducting coil. In a normal wire, as an electric current passes through, some energy is lost as heat due to electric resistance. However, in a SMES system, the wire is made from a superconducting material that has been cryogenically cooled below its critical temperature. As a result, electric current can pass through the wire with almost no resistance, allowing energy to be stored in a SMES system for a longer period of time. Common superconducting materials include mercury, vanadium, and niobium-titanium. The energy stored in a SMES system is discharged by connecting an AC power converter to the conductive coil. SMES systems are extremely efficient storage technologies, but they have very low energy densities and are still far from being economically viable (**Figure 4.39**) (Bindra and Revankar, 2019).

Figure 4.39. Superconducting magnetic energy storage (SMES) (OpenPR, 2019)

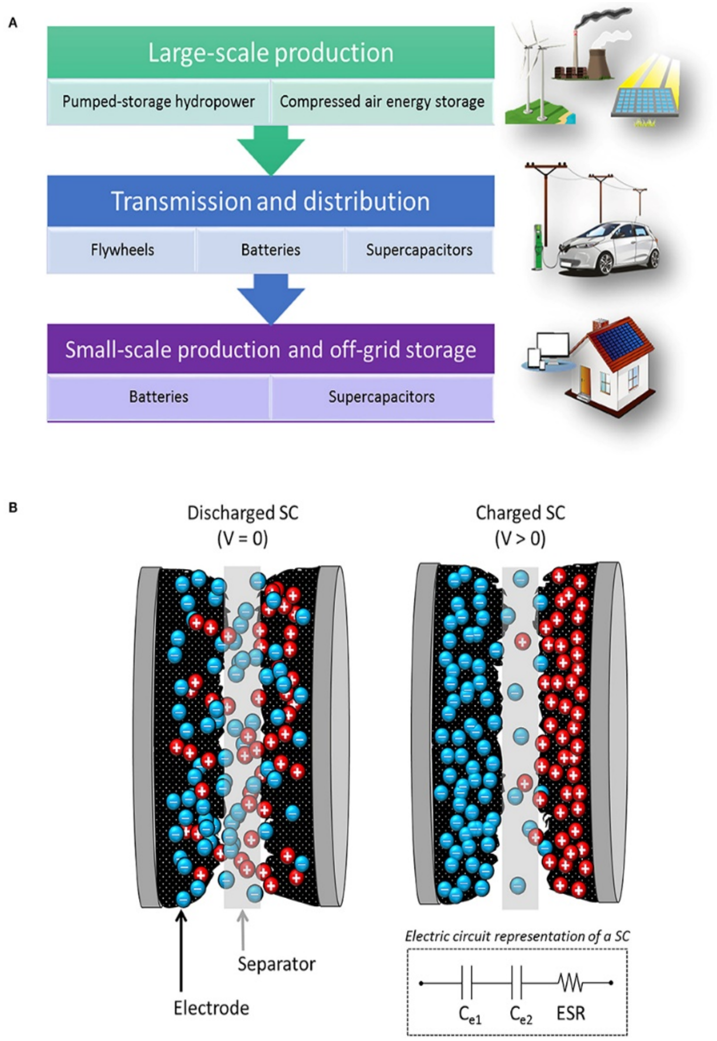


aa) Supercapacitor

In pursuing higher energy density with no sacrifice of power density, a supercapacitor-battery hybrid energy storage device—combining an electrochemical double layer capacitance (EDLC) type positive electrode with a Li-ion battery type negative electrode—has been designed and fabricated. The energy density of the hybrid supercapacitor is comparable to lithium-ion batteries, and the power density also reaches that of symmetric supercapacitors, indicating that the hybrid supercapacitor could be a promising novel energy storage system for fast and efficient energy storage in the future (Zhang et al., 2013).

Supercapacitors (SCs) are energy storage devices that bridge the gap between batteries and conventional capacitors. They can store more energy than capacitors and supply it at higher power outputs than batteries. These features, combined with high cyclability and long-term stability, make SCs attractive devices for energy storage. SCs are already present in many applications in combination with other energy storage devices (mainly batteries) or as autonomous energy sources. Porous carbons are presently used in the electrodes of commercial SCs due to their high surface area and their good conductivity. However, new porous materials are continuously being developed (**Figure 4.40**).

Figure 4.40. Supercapacitor (Castro-Gutiérrez et al., 2020)



4.6. Analysed results from members' targeted questionnaire

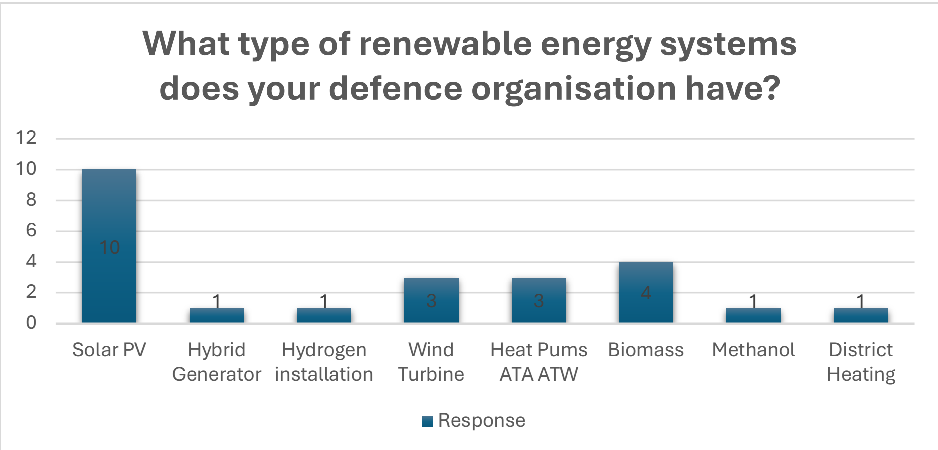
A questionnaire was sent to the members of (WG-2RES) in relation to this study and renewable energy generation and storage in general. The questions and results are documented below. The results of this questionnaire aided in the final direction of this study and alluded to the level of renewable energy generation and storage existing or planned within the community. The questions gave an outline of load profiling of the significant energy users (SEU), time of use and geographical constraints, and attributes that can affect energy production and storage, e.g. rivers, mountains, valleys, the height of installation, atmospheric pressure, peak Summer/Winter temperatures, etc. The answered questions set out the base line for the study and indicated how diverse renewable energy and storage technologies are within the community. Quite a mix of energy and storage technologies exist within the community and the study needed to reflect this and bring some new ideas to the table. The scale of existing systems and the level of unused energy points to the types of storage that may satisfy the needs of the community. The geographical location and the location of the closest city gives a relatable scenario as to how reliable the electrical transmission grid is and what types of application may suit the community as well as how weather conditions may affect the performance of the energy storage systems. The members indicated that financial aspects were the main factors considered when choosing a system, this result led to the suggested future work in the revaluation of energy and CO_2 projects on non-monetary terms. The final question related to difficulties that are encountered while trying to select a storage system, the study gives an explanation for the majority of the difficulties answered in the question.

The posed questions to the members of (WG-2RES) and their answers are as follows (**Figure 4.41**):

1. **Does your defence organisation have any renewable energy generation installed already?**
   All responders acknowledged that they had renewable generation installed.

2. **What type of renewable energy systems does your defence organisation have?**
   The answers to this question are as typically expected and are in line with market predictions. Clear indicators suggest the markets favour the growth of solar PV driven by the continual reduction in unit price, closely followed by wind generation.

Figure 4.41. Members' questionnaire Q2



3. How many kWhs of energy a year does such a system typically produce?
   The answers to this question ranged from 1kWp to 9MW.

4. How much energy is produced but not used within such systems?
   - The answers to this question were in the region of 30%.

5. Do you have an existing energy storage system installed in tandem with such renewable energy systems?
   - 69% answered yes.
   - 31% answered no.

6. What types of energy storage systems do you have?
   - 75% answered Battery.
   - 13% answered Thermal.
   - 12% answered hydrogen.

7. Taking one example, what size in kW is the storage system?
   - The answers ranged from 5kW to 300,000 kWh.

8. What factors (logistics, financial, technical, environmental) were taken into account when deciding on the appropriate storage system?
   - Financial was the dominating answer.

9. How near is the closest city to your selected installation?
   - All answers were less than 20 kilometres.

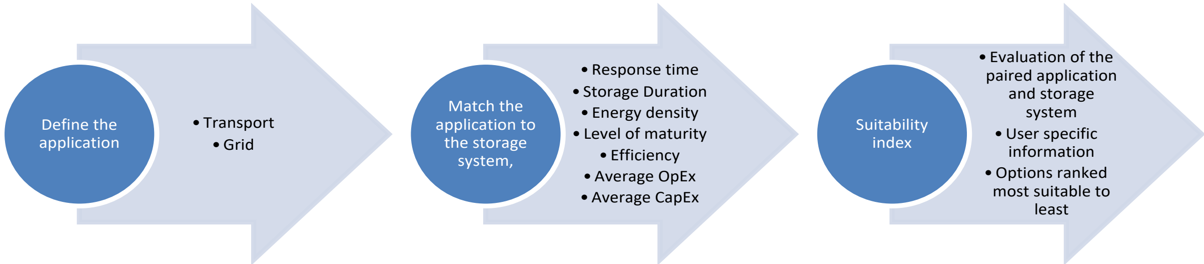
10. What is your most challenging aspect of specifying a renewable energy production system and/or storage system?
    - "Typically, with solar, we would try to specify the peak to use all the power generated".
    - "Orientation".
    - "For solar and wind: the availability of energy and the payback time".
    - "Energy density and weight and EMS".
    - "Safety standards include mechanical integrity, even if it is hit by grenades or missiles or is damaged by an explosion".
    - "Logistic (if high volumes to be supplied or stored)".
    - "Options to supply larger amounts of energy to deployed forces, especially on heavy terrain or extreme meteorological weather".
    - "Resources (budget and personnel) and unknown parameters (evolution of energy prices, the evolution of new technologies, the evolution of new regulations, ...)".
    - "To guarantee energy availability often requires a diesel backup, after all".

4.7. Identification of key requirements for developing a decision support tool

Many elements must be considered when identifying the essential requirements for an energy storage system selection tool. Defining the application for the storage system in terms of usage, power requirement, and storage duration is the most fundamental decision that needs to be made. Once the application is defined, a storage system can be matched by its identifying qualitative properties. Each qualitative property of the storage system should be weighed against the specific application. A decision matrix, the Pugh matrix, or the multi-attribute utility theory may then be used to identify the most suitable storage system from the database.

The Pugh Analysis Matrix is an analysis tool that results in an optimal concept. The user refines a list of ideas by using a matrix-based process to weigh and compare the conceptual designs. When used for decision-making, this matrix helps the user select the most viable and feasible option from a list of given alternatives. However, to do this, it must first determine the most important criteria needed to finalise the decision about alternatives. Then, the user can select the best one based on this criterion. The multi-attribute utility theory function is used to choose between two or more options. The decision is based on the attributes of the options. The most general situation is that there are both multiple attributes and uncertainty. Thus, the multi-attribute utility theory is useful in large multi-dimensional selections (**Figure 4.42**).

Figure 4.42. Requirement graphic



4.7.1. Identifying the application

The primary step in matching the storage system to an application is identifying the application with which the energy storage system is to be coupled or defining the critical responses the energy storage system should have when called upon. The application may be broken down into electrical grid applications and transport applications (**Table 4.21**).

Grid applications

- Daily load shifting.
- Seasonal storage.
- Grid support.

Transport applications

- Light use < 3 Ton.
- Heavy use > 3 Ton.

Table 4.21. Grid application storage requirements

Grid Application Storage Requirment			
	Energy Density	**Response time**	**L(long term) S (Short term)**
Daily load shift	Medium	Seconds	S
Seasonal storage	High	Minutes	L
Grid Support	Low	Seconds	S
Transport application storage requirements			
Light use < 3 tons	Medium	Seconds	S
Travel distance < 400K			
Heavy use > 3 tons	High	Seconds	S
Distance travelled > 400K			

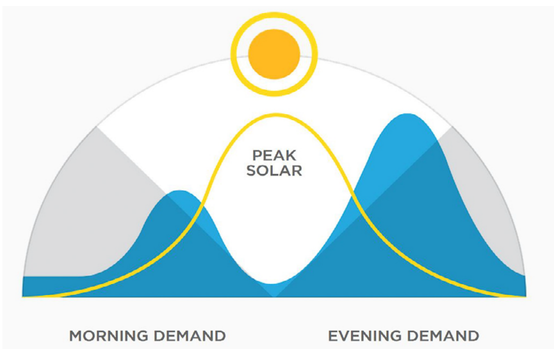
Grid applications

Daily load shifting

Daily load shifting is where the peak energy load is advanced or delayed in time, so the power supply system is ready to accept the additional burden. By way of example, peak sunshine and solar PV production happen when the sun is at its highest point in the sky.

Load shifting or peak shaving would see energy-intensive applications implemented during this peak PV production period as there is more capacity in the energy supply system. **Figure 4.43** below illustrates the demand profile of an energy user in blue vs the peak PV generation in yellow.

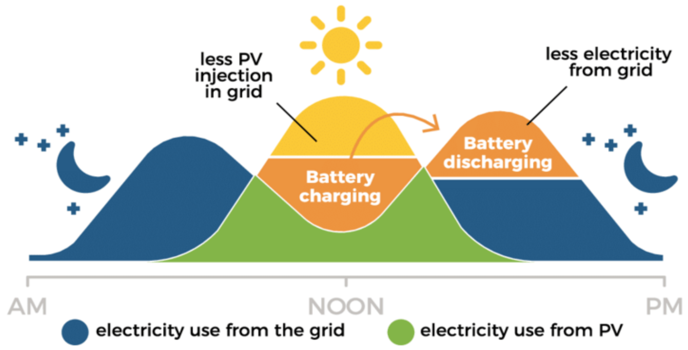
Figure 4.43. Peak generation vs demand



More often than not, advancing or retarding energy loads to coincide with the peak generation of renewables is not practical. Solar PV has reasonable predictability regarding peak production; wind energy is not as predictable. Implementing an energy storage system in this scenario makes it possible to turn an intermitting energy source into one that is relatively stable, uniform, and of constant output.

Figure 4.44 illustrates a peak load shifting profile. During peak renewable production, the once-unused energy is now used to charge an energy storage system, which can be used later as required. It indicates that a battery storage system and an alternative energy system will have the same effect.

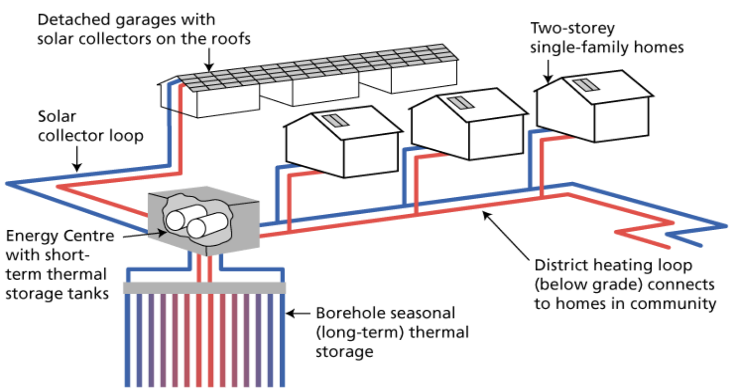
Figure 4.44. Peak load shifting



Seasonal storage

Seasonal energy storage takes advantage of seasonal changes; the energy storage requirement has a very large storage capacity and high energy density with a slow discharge. Seasonal storage is not unlike load shifting as the major difference is scale and time. Seasonal storage assists in load shifting over a greater period that can span several months. During the summer months, excess PV energy would be stored in an energy storage system that could be used during less productive months. Similarly, during the winter months, excess wind generation would be stored in an energy storage system that could be used during less productive months. The same is applicable for rainfall and surface water stored in reservoirs to be used in hydro energy generation at a later period. Alternatively, excess thermal energy may be stored during the summer by means of pit storage or borehole storage that could be later used in the winter. **Figure 4.45** illustrates long-term borehole storage. The borehole storage tanks collect excess heat from solar collectors during high production. The borehole collectors then release the stored thermal energy into district heating lines as required.

Figure 4.45. Borehole storage (https://www.dlsc.ca/how.htm)

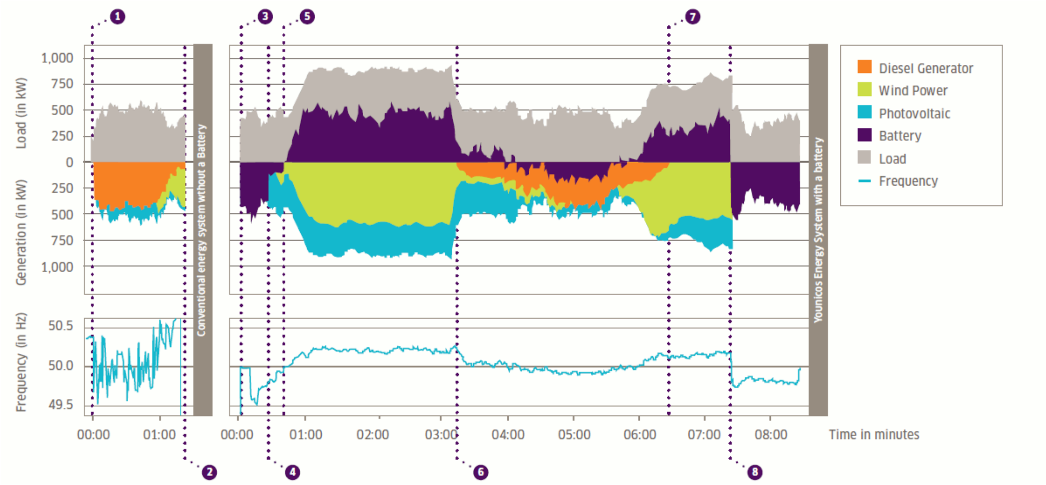


Grid support

In traditional power generation plants (coal, gas, or hydro), the turbines that produce the power rotate with immense force and inertia so that a sudden disruption to the power supply can efficiently be dealt with since the rotating turbine, in effect, becomes a flywheel generator for a short period of time. However, solar and wind generators do not have this build-up of inertia and react differently to a sudden loss of power. Maintaining a stable supply grid becomes more challenging with the intermitting renewable generation and a sudden drop in power output from renewable sources; this could lead to a rapid decline in the electrical frequency and voltage and destabilisation of the network grid. Frequency and voltage are intrinsically linked. The decline in frequency and voltage on a transmission grid will significantly burden the remaining generation stations. As the frequency further decreases, the remaining generation stations will start to shed the load and disconnect from the grid to protect themselves, ultimately resulting in a blackout scenario.

Energy storage systems can assist in grid support services, delivering power as required to stabilise the supply grid. The energy storage system must have a rapid response time. As such, it is not uncommon to use hybrid energy storage systems for grid services. Rapid response low energy density storage initially stabilises the supply grid and is superseded by a slower response, high energy density system. **Figure 4.46** below shows how multi-generation and storage systems can be managed for stable electricity transmission.

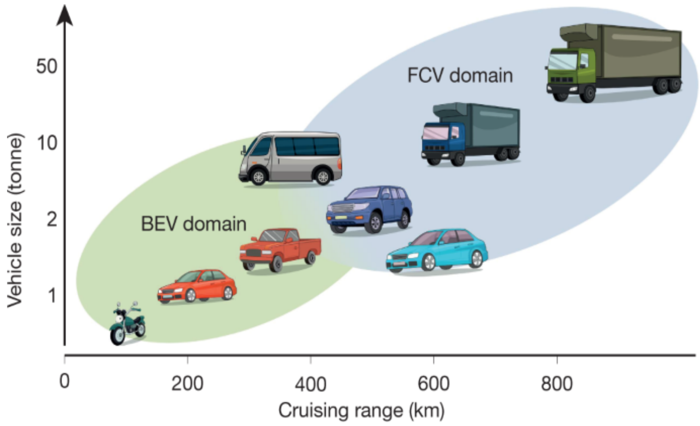
Figure 4.46. Grid stabilisation (Energy Transition, 2015)



Transport applications

To select an energy storage system categorised under transport applications, we can split transport into light use (vehicles under 3 tons) and heavy use (vehicles over 3 tons). The over 3-ton categorisation should include marine and aviation sectors. Vehicles under 3 tons in transportation are at an advanced commercialised stage. EV transport under 3 tons and with a range of less than 400 km are readily available for purchase, with Lithium Ion batteries dominating the market. Transportation methods over 3 tons and with a more than 400km range are still in the development and test stage (see **Figure 4.9**). **Figure 4.47** below illustrates the relationship between vehicle size and energy density.

Figure 4.47. Transport selection (Jiao et al., 2021)



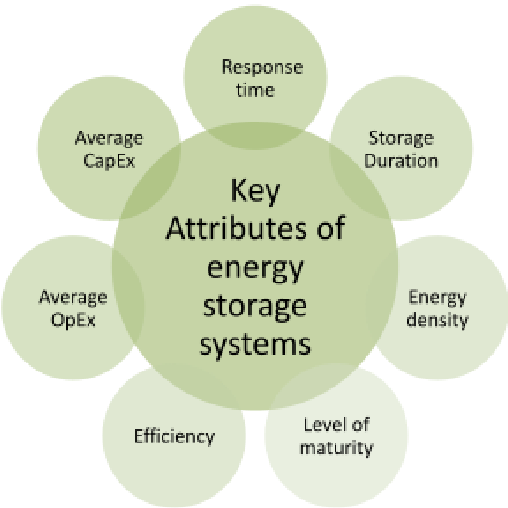
	BEV	FCV
Storage media	Li–ion batteries	Hydrogen
Energy density	<200 Wh kg^{-1}	~300 Wh kg^{-1}
Refuelling time	Hours	Minutes
Low temperature	Severe degradation	Demonstrated at −30 °C
Efficiency	~90%	~60%
Infrastructure	Grid and charging piles	Hydrogen stations

4.8. Identification of key attributes in energy storage systems

Defining the key attributes of an energy storage system is vital in matching the storage system with the application. Some attributes are more important than others; below are key attributes ranked below from 1 to 7 (**Figure 4.48**).

1. Response time
2. Storage Duration
3. Energy density
4. Level of maturity
5. Efficiency
6. Average OpEx
7. Average CapEx

Figure 4.48. Key attributes energy storage system

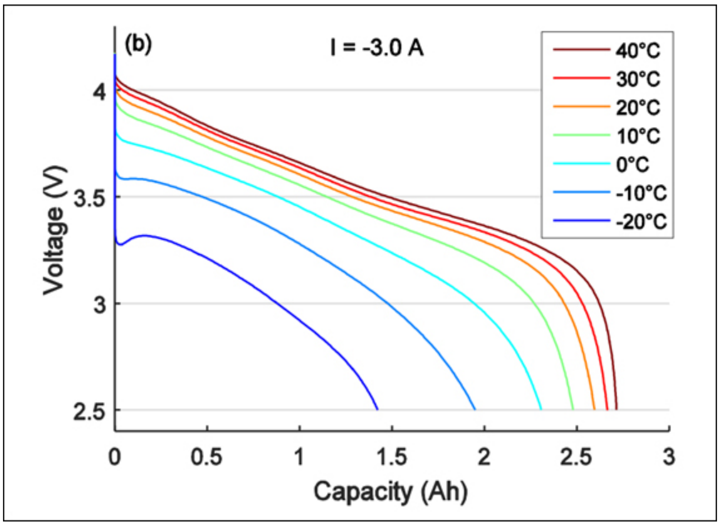


4.8.1. Environmental conditions

Environmental operating conditions, in particular extreme heat and extreme cold, affect in a negative manner the performance and life cycle of batteries. Consideration should be given when selecting a battery storage solution.

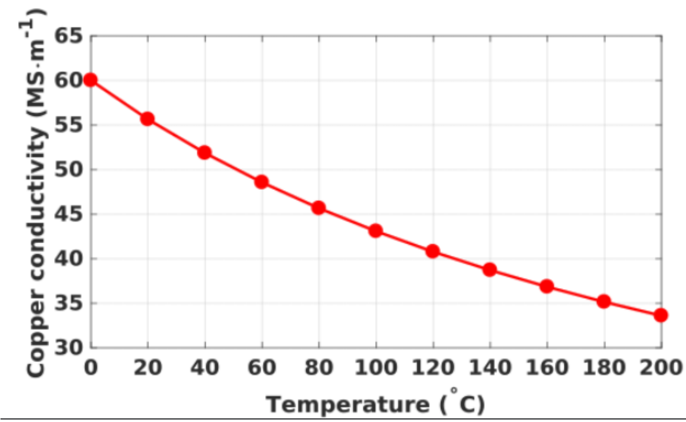
The standard rating for batteries is at room temperature of 25 degrees C. At freezing point, capacity is reduced by 20%. At approximately -22 degrees C, battery Ah capacity drops to 50% (**Figure 4.49**).

Figure 4.49. Discharge voltage of a 18650 Li-ion cell at 3A and various temperatures (Battery University, 2021)



Capacity is increased at higher temperatures at 50 degrees C, and battery capacity would be about 12% higher. On the contrary, as the temperature rises, the resistance in the electrical circuits as the conductivity of copper decreases (**Figure 4.50**).

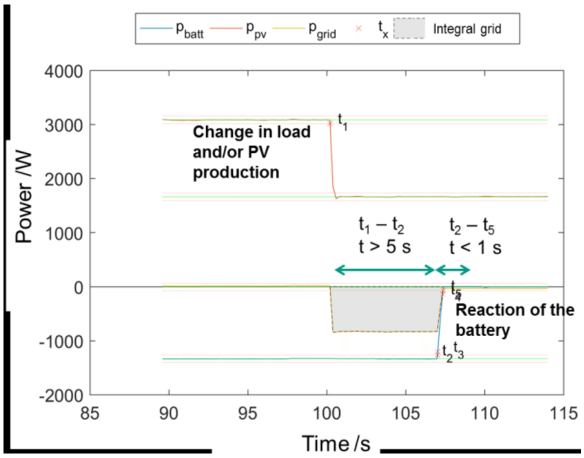
Figure 4.50. Copper conductivity at temperature (Fontchastagner et al., 2018)



4.8.2. Response time

The response time of an energy storage system is the difference between the time taken for the storage system to deliver the rated current and the request to deliver the current. This time can range between milliseconds and minutes. **Figure 4.51** illustrates the change in generation in the upper graph and the storage system reaction on the lower graph.

Figure 4.51. Storage system response time (Barry and Munzke, 2016)



4.8.3. Storage duration

Energy storage duration, or energy storage capacity, is the amount of time in which the energy storage system can deliver the rated current before being depleted. The maximum amount of energy stored is denoted by multiples of kilowatt-hour [kWh].

4.8.4. Energy density

Energy density is a measure of the amount of energy that can be stored in a given system. The unit of measurement for energy density is energy per volume or mass. **Figure 4.52** below represents the energy density against the rated power of a few energy storage technologies while **figure 4.53** represents the conventional energy storage. The energy density of the material dictates the physical size of the energy storage system.

Figure 4.52. Energy density (IEC, 2011)

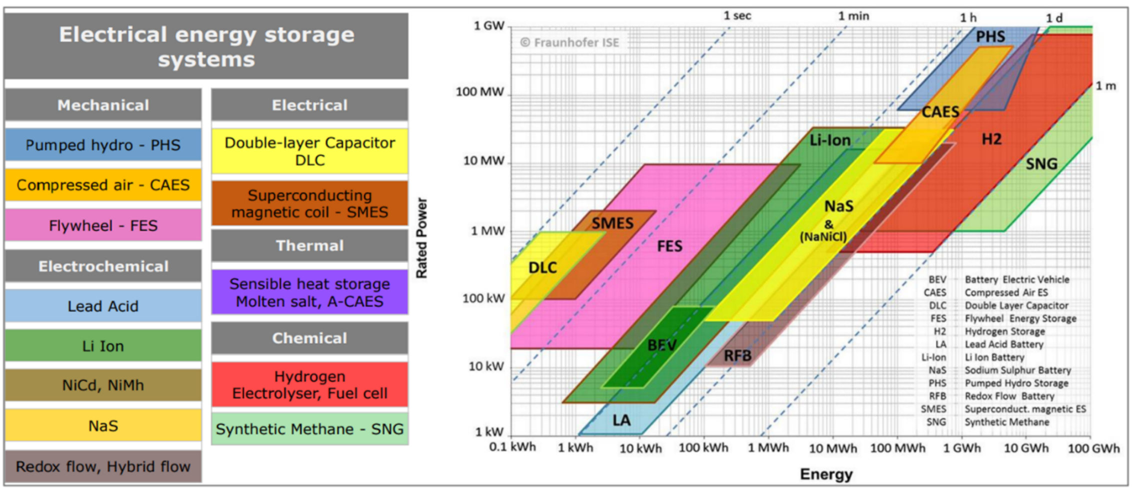


Figure 4.53. Conventional energy density (energycite.com)

Storage material	Energy Type	Specific energy (MJ/kg)	Energy density (MJ/L)	Direct uses
Uranium (in breeder)	Nuclear fission	80,620,000	1,539,842,000	Electric power plants (nuclear reactors)
Thorium (in breeder)	Nuclear fission	79,420,000	929,214,000	Electric power plants (Nuclear reactors)
Hydrogen (compressed at 70 MPa)	Chemical	142	5.6	Rocket & automotive engines, grid storage& conversion
Diesel/Fuel oil	Chemical	48	35.8	Automotive engines, power plants
LPG (incluiding Propane/Butane)	Chemical	46.4	26	Cooking, home heating, auto engines, lighter fluid
Jet Fuel	Chemical	46	37.4	Aircraft
Gasoline (Petrol)	Chemical	44.4	32.4	Automotive engines, power plants
Ethanol (E100)	Chemical	26.4		Flex-fuel, racing, stoves, lighting
Coal	Chemical	24		Electric power plants home heating
Methanol fuel (M100)	Chemical	19.7		Racing, model engines, safety
Wood	Chemical	16.2		Heating, outdoor cooking
TNT	Chemical	4.6		Explosives
Gunpowder	Chemical	3		Explosives
Lithium non-rechargeable)	Electrochemical	1.8	4.32	Portable electronic devices, flashlights
Lithium-ion battery	Electrochemical	0.36 - 0.875	0.9 - 2.63	Laptops, mobile devices, modern electric vehicles
Alkaline battery	Electrochemical	0.67	1.8	Portable eletronic devices, flashlights
Nickel-metal hydride battery	Electrochemical	0.288	0.504 - 1.08	Portable electronic devices, flashlights
Lead-acid battery	Electrochemical	0.17	0.34	Automotive engine ignition

4.8.5. Level of maturity

The maturity level or technology readiness level has already been defined **in Figure 4.9** in section 6.

4.8.6. Efficiency

Round-trip efficiency, measured as a percentage, is a ratio of the energy that can be stored and recovered from the same energy storage system. The difference in the two quantities is the percentage efficiency of the system (**Table 4.22**).

Table 4.22. Percentage efficiency of technologies

Technologies	Efficiency (%)
Super Capacitor	80-98
Superconducting Magnetic Energy Storage	80-95
Pumped hydro storage	70-85
Compressed air storage	70-85
Flywheels	70-75
Lead acid battery	80-90
Li-ion Battery	85-98
Flow Battery	60-85
Hydrogen	20-45
Synthetiv Natural gas	20-50
Molten Salt	80-90

4.8.7. Average CapEx

Capital expenditures (CapEx) are purchases of significant goods or services that can be used to improve a company's performance in the future. They include the cost of fixed assets and the acquisition of intangible assets (such as patents and other forms of technology).

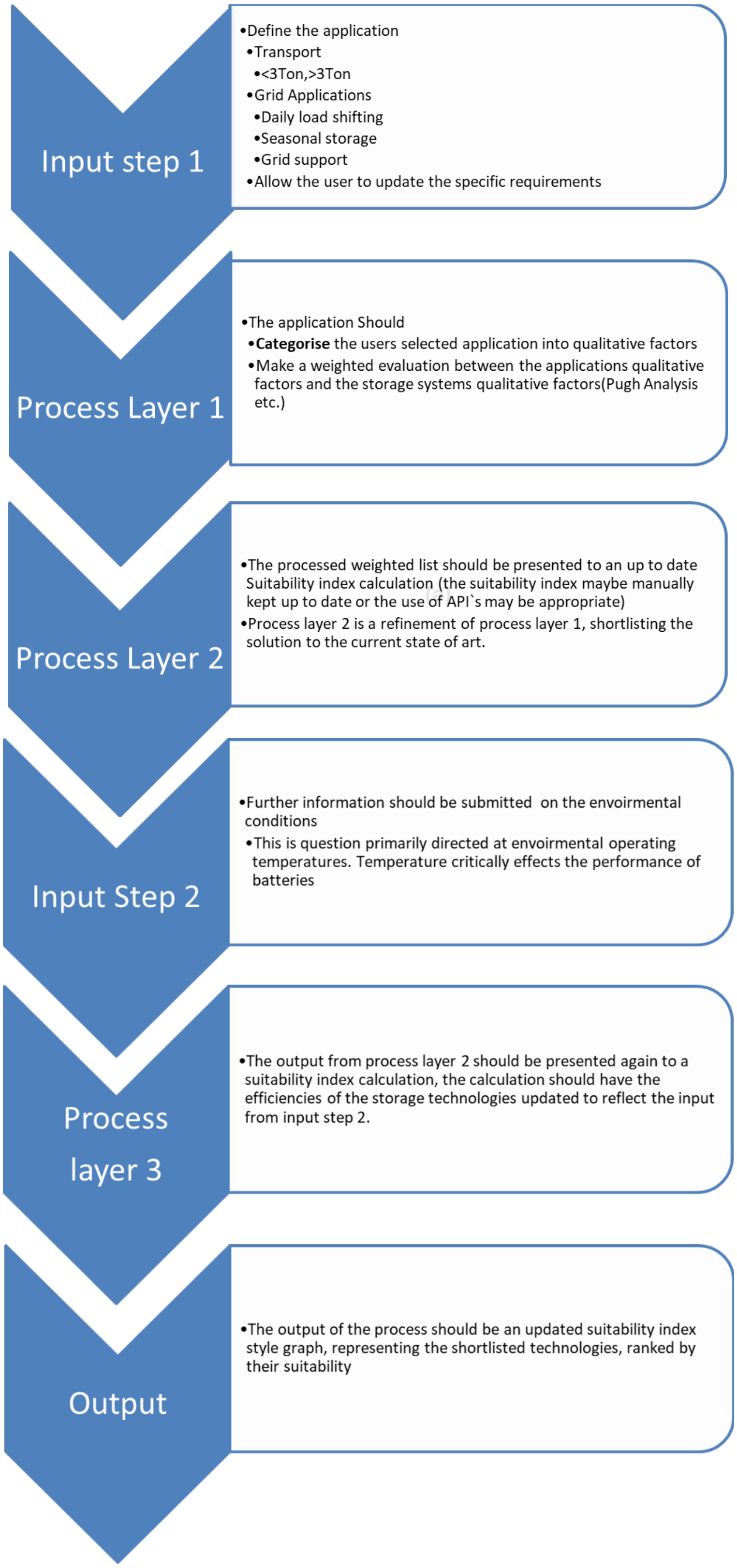
4.8.8. Average OpEx

Operating expenses are a company's costs for running day-to-day operations. These expenses must be ordinary and customary costs for the company's industry.

4.9. Process

As with all decision-making processes, there is a structure to how the best outcome is obtained. Selecting an energy storage system is no different. **Figure 4.54** sets out and summarises the design process visually.

Figure 4.54. Decision process with (a) input step 1 and (b) input step 2



4.9.1. Example of the process

1. Input Step 1

a. For the purpose of this example, we are going to select a daily load-shifting requirement (Figure 4.55).

Figure 4.55. Example storage requirement

Grid Application Storage Requirement			
	Energy Density	Response time	L(Long Term)S(Shorterm)
Daily load shifting	Medium	Seconds	S

b. No current requirement for the suitability index

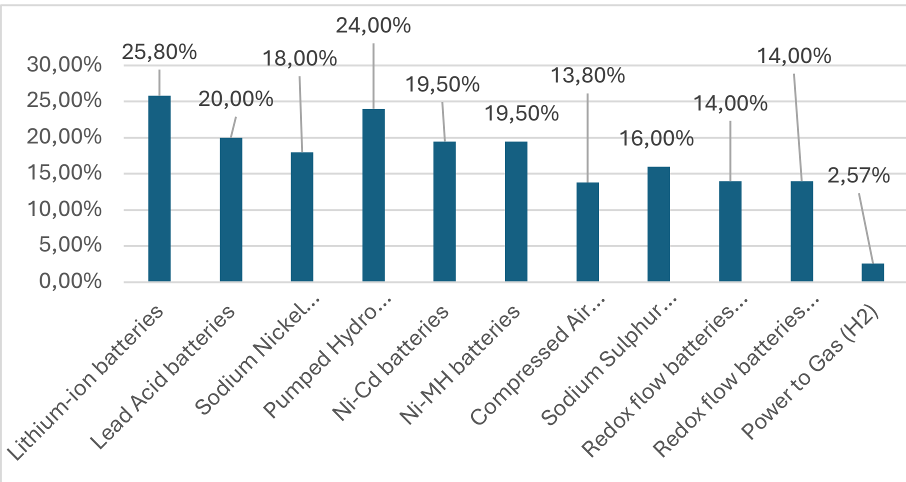
2. Process layers 1 & 2

a. A manual selection is performed for this example (**Figures 4.56-4.57**)

Figure 4.56. Example technology table

ID	Categories	Storage Technologies	Energy Density	Response time	Avg Capex€/kW	Avg Eff (%)	Temp Degrade	Level of maturity, Level 1,2,3	Suitability Index
10	ElectroChemical	Lithium-ion batteries	Medium	Sec	725	86	66.00	3	35.59%
9	ElectroChemical	Sodium Nickel Chloride batteries	Medium	Sec	575	90	70.00	2	31.30%
18	ElectroChemical	Redox flow batteries Vanadium	Medium	Sec	1400	70	50.00	2	10.00%
19	ElectroChemical	Redox flow batteries Zn Br	Medium	Sec	1400	70	50.00	2	10.00%

Figure 4.57. Example technology graph



3. *Input step 2*

a. Environmental temperature conditions.
   i. Consideration should be given here to extreme seasons. The degradation inefficiency in this example is 20% for battery technology (**Figure 4.58-4.59**).

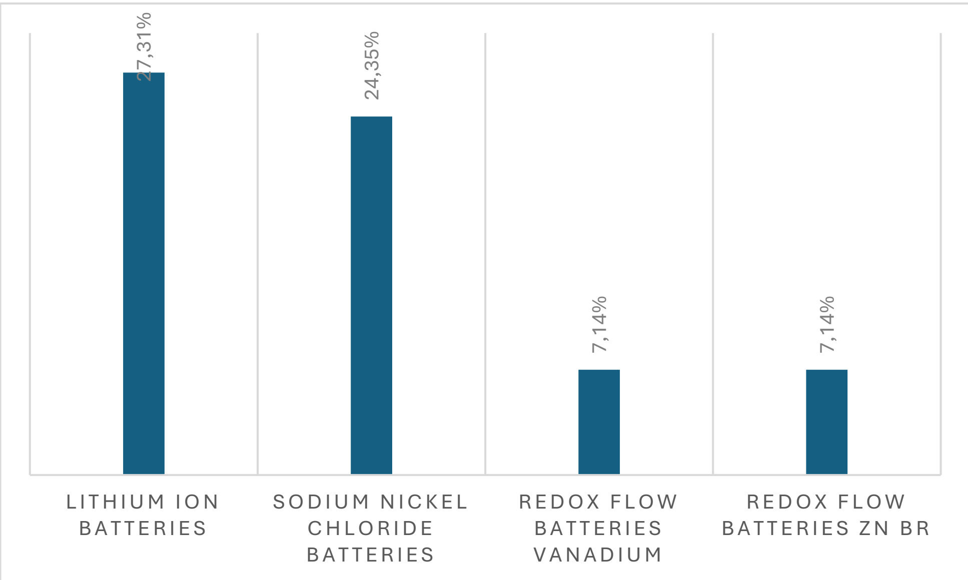
4. *Process layer*

Figure 4.58. Grid application storage requirements

ID	Categories	Storage Technologies	Energy Density	Response time	Avg Capex€/kW	Avg Eff (%)	Temp Degrade	Level of maturity, Level 1,2,3	Suitability Index	Suitability Index with Temp Coef
10	ElectroChemical	Lithium-ion batteries	Medium	Sec	725	86	66.00	3	35.59%	27.31%
9	ElectroChemical	Sodium Nickel Chloride batteries	Medium	Sec	575	90	70.00	2	31.30%	24.35%
18	ElectroChemical	Redox flow batteries Vanadium	Medium	Sec	1400	70	50.00	2	10.00%	7.14%
19	ElectroChemical	Redox flow batteries Zn Br	Medium	Sec	1400	70	50.00	2	10.00%	7.14%

5. *Output*

Figure 4.59. Examples technologies graph



Although the above example is trivial and only considers a few defining attributes of the storage technologies for its selection, it alludes to how the tool may work.

All key attributes should be considered in the selection evaluation. The example also highlights that the suitability index calculation should be dynamic; this will affect the ranking of the technologic. For example, the suitability index calculation in the last example was defined in equation 3:

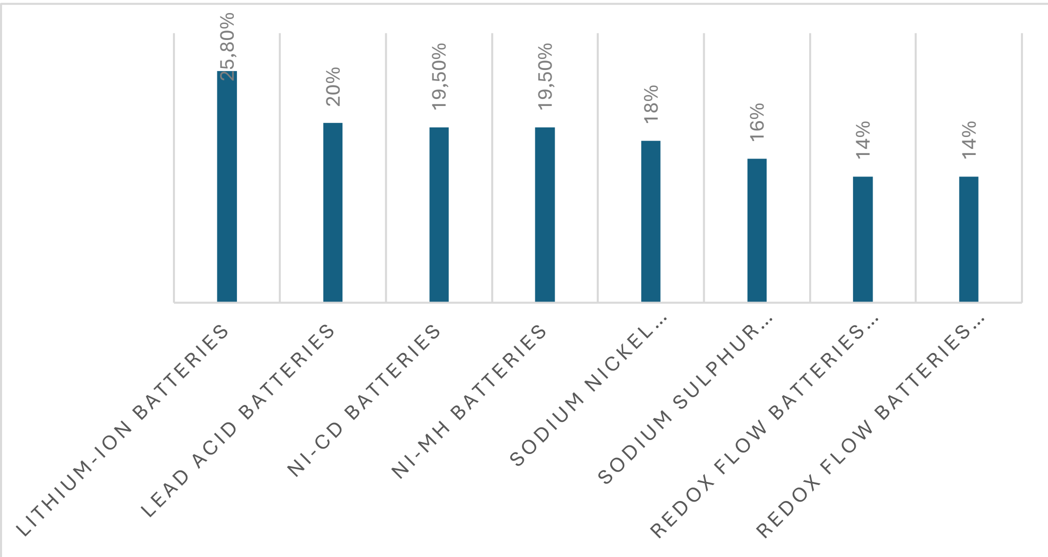
$$\text{Suitability Index} \ \frac{Level\ of\ maturity * Average\ efficiency}{Average\ Capex/kW} \qquad \text{[Eq.3]}$$

If the user decided at the start of the process that the cost per kW was not essential and that the energy density could be Low and Medium, the outputs of the model are illustrated in **figures 4.60-4.61**.

Figure 4.60. Examples technologies table

ID	Categories	Storage Technologies	Energy Density	Response time	Avg Capex€/ kW	Avg Eff (%)	Temp Degrade	Level of maturity, Level 1,2,3	Suitability Index
10	ElectroChemical	Lithium-ion batteries	Medium	Sec	1000	86	66.00	3	25.80%
8	ElectroChemical	Lead Acid batteries	Low	Sec	1000	80	60.00	2.5	20.00%
14	ElectroChemical	Ni-Cd batteries	Low	Sec	1000	65	45.00	3	19.50%
15	ElectroChemical	Ni-MH batteries	Low	Sec	1000	65	45.00	3	19.50%
9	ElectroChemical	Sodium Nickel Chloride batteries	Medium	Sec	1000	90	70.00	2	18.00%
7	ElectroChemical	Sodium Sulphur batteries	Low	Sec	1000	80	60.00	2	16.00%
18	ElectroChemical	Redox flow batteries Vanadium	Medium	Sec	1000	70	50.00	2	14.00%
19	ElectroChemical	Redox flow batteries Zn Br	Medium	Sec	1000	70	50.00	2	14.00%

Figure 4.61. Examples technologies graph

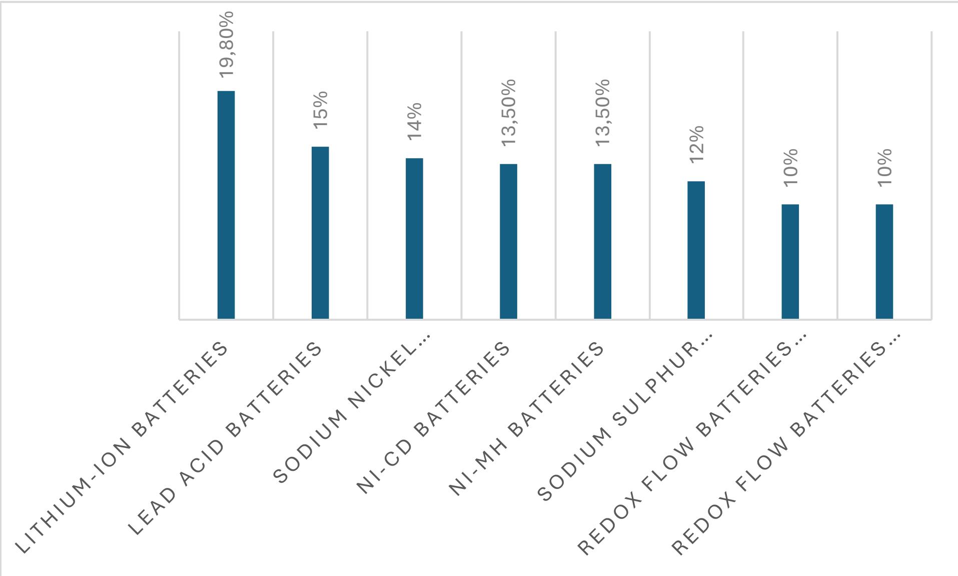


And again, to input step 2, if the temperature coefficient is to be added, the results change slightly (**Figures 4.62-4.63**):

Figure 4.62. Examples technologies table

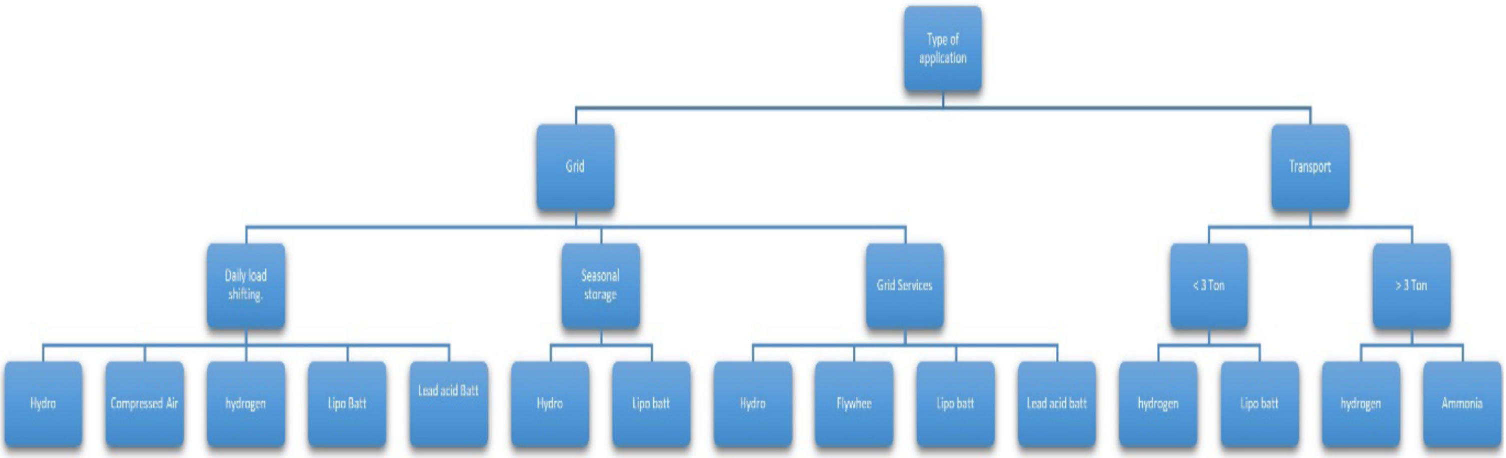
ID	Categories	Storage Technologies	Energy Density	Response time	Avg Capex€/ kW	Avg Eff (%)	Temp Degrade	Level of maturity, Level 1,2,3	Suitability Index	Suitability Index with Temp Coef
10	ElectroChemical	Lithium-ion batteries	Medium	Sec	1000	86	66.00	3	25.80%	19.80%
8	ElectroChemical	Lead Acid batteries	Low	Sec	1000	80	60.00	2.5	20.00%	15.00%
9	ElectroChemical	Sodium Nickel Chloride batteries	Medium	Sec	1000	90	70.00	2	18.00%	14.00%
14	ElectroChemical	Ni-Cd batteries	Low	Sec	1000	65	45.00	3	20.00%	13.50%
15	ElectroChemical	Ni-MH batteries	Low	Sec	1000	65	45.00	3	19.50%	13.50%
7	ElectroChemical	Sodium Sulphur batteries	Low	Sec	1000	80	60.00	2	13.80%	12.00%
18	ElectroChemical	Redox flow batteries Vanadium	Medium	Sec	1000	70	50.00	2	14.00%	10.00%
19	ElectroChemical	Redox flow batteries Zn Br	Medium	Sec	1000	70	50.00	2	14.00%	10.00%

Figure 4.63. Examples technologies graph



The examples provided are of a basic form and intended as a starting point in selecting a storage system. The decision hierarchy below is in general terms but can be used as a starting point for the most appropriate selection of storage technology (**Figure 4.64**).

Figure 4.64. Decision hierarchy alternative example process



An alternative process for selecting and matching an application to the energy storage system is to use a statistical evaluation. Statistical tools would provide a much more robust model if the selection tool were an automated process rather than a manual one. The selection process can be mapped to a hypothesis test, where: Alternative energy storage devices = Hypothesis to be tested.

- Key attributes energy storage devices = Sample data.
- Application criteria = Population data.

The null hypothesis states that there is no difference or association between variables of interest (population data) and the sample data (key attributes energy storage devices). There will always be a difference between variables of interest and the sample data; the option with the highest correlation represents the most suitable energy storage device. A manual hypothesis test is an arduous task and is more suited to software applications. As such, a simpler alternative selection method is to use a Pugh decision matrix. The Pugh Matrix is a criteria-based decision matrix which uses criteria scoring to determine which of several potential solutions or alternatives should be selected. The technique's name is called after Dr Stuart Pugh and has become a standard part of the Six Sigma methodology.

The steps taken to create a Pugh Matrix are (**Figures 4.65-4.66**):

1. Define the evaluation criteria. What are the most important and desired characteristics of the solution?
2. Weigh the evaluation criteria regarding the relative importance of each option.
3. Define the different improvement alternatives and optional approaches.
4. Select a "BASELINE" from the alternatives (typically your current state).
5. For each criterion, rate each alternative as better, the same, or worse than the baseline. Simply + for better, 0 for same, and – for worse.
6. Total the count of each.
7. Select the best alternative.
8. Explore whether another more optimal solution might exist by creating a hybrid of the best from various alternatives.

Figure 4.65. Pugh Matrix (https://citoolkit.com/templates/pugh-matrix-template/)

Problem/Situation: Daily Load shifting

		Alternatives						
		1	2	3	4	5		
Criteria	Baseline	Lead Acid batteries	Lithium-ion batteries	Pumped Hydro Storage (PHS)	Compressed Air Energy Storage (CAES)	Power to Gas (H2)		
Response time	Seconds	+	+	–	–	–	-1	9
Energy density	Medium	–	+	–	0	+	0	8
Level of maturity	High	0	+	+	+	–	2	5
Efficiency	High	+	+	+	0	0	3	2
Average OpEx	Medium	+	0	+	0	+	3	2
Average CapEx	Low	0	+	0	0	+	2	4
Storage duration	Short	0	+	+	+	+	4	1
	0						0	
	0						0	
	Totals	2	6	2	1	2		
	Rank	2	1	3	5	3		

Comments/Conclusion:

+	Better than baseline	1
0	About the same	0
–	Worse than baseline	-1
Symbols	Relationship	Value

Guide:

1. Before you start, collect the two sets of data.
2. Insert the criteria on the left hand column.
3. Insert the alternatives on the top row.
4. Work through the matrix and indicate how the criteria will affect the various alternative being considered.
5. Review the completed matrix to make the best decision for your situation.

Note: You need only to fill the white, blue and yellow cells.

Figure 4.66. Pugh analysis results

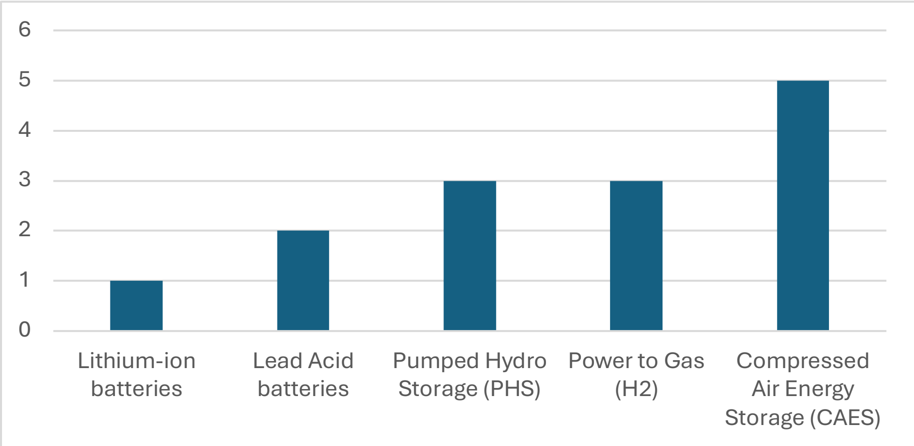


Figure 4.66 displays the results of the analysis, this time ranked by efficiency; first place is given to Lithium-Ion batteries. This analysis is given by way of example and is not necessarily a true representation of the results; though it is likely correct, the alternatives were limited to a random selection of 4 technologies. In a use case, the entire database should be selected for evaluation.

4.10. Matching an application to a storage system example

The quality of the application's derived criteria will impact the tool's output; the user's application must be derived into the categories of the key qualitative factors of storage systems. The key qualitative factors of a storage system, as represented by **Figure 4.48**.

- Response time.
- Storage Duration.
- Energy density.
- Level of maturity.
- Efficiency.
- Average OpEx.
- Average CapEx.

By way of an example, a trivial situation is represented below.

An industrial/commercial building warehouse of approximately 10,000m^2 has a base load of 500kW and a maximum demand of 10,000kW; the period of max demand for the electrical load of 10,000kW is present for two hours and happens at approximately 19:00 hrs. The facility has offices with I.T. services, server applications, and backup UPS systems.

A solar PV array has been installed on the roof of the facility of size 1MW. This array produces 900,000 kW annually and helps offset the energy usage of the building. During peak periods of generation, when the sun is highest in the sky, the PV array produces more energy than the building can consume, and the excess energy is exported to the national distribution grid. By the time the maximum demand comes on the building, the PV array's production has dropped considerably as the sun is in a different position in the sky. There is no opportunity to bring the max demand forward in the day. This scenario provides a perfect example for an energy storage application.

A storage solution is to be implemented to harness the overproduction of energy during peak sunlight hours and use this energy during times of maximum building demand. **NOTE: the figures in the scenario are fictional**.

Question 1

Response time

What does the response time of the system need to be? The storage system is designed to manage a known max demand load of 1000 kW. A demand of 1000 kW in a building would not happen instantly; if it did, the electrical network would fail. Given that the load happens at a known time of day, it is acceptable that the storage solution can have minutes to respond. The other consideration about the response time is how to handle I.T. services; sudden loss of power to servers is quite damaging and uncontrolled shutdowns present mutable problems. The example above states that I.T. services have a backup UPS, so the response time selection can last for minutes. If I.T. services did not have a backup UPS, then the storage system's response time would need to be in milliseconds, as with any power-critical service.

Question 2

Storage duration

What duration does the storage system need to provide power for?

The above scenario states that the max demand is 1000 kW for two hours; this would mean the storage system would need to be suitably sised to deliver at least 2000kWh or 1000kWh for two hours. It is always advisable to build a safety factor into this assumption. For instance, if the storage solution was a battery, the depth of discharge may limit the battery to 20%, even though it may be rated for 2000 kWh, meaning that the actual usable power from the battery is only 80% of its rating.

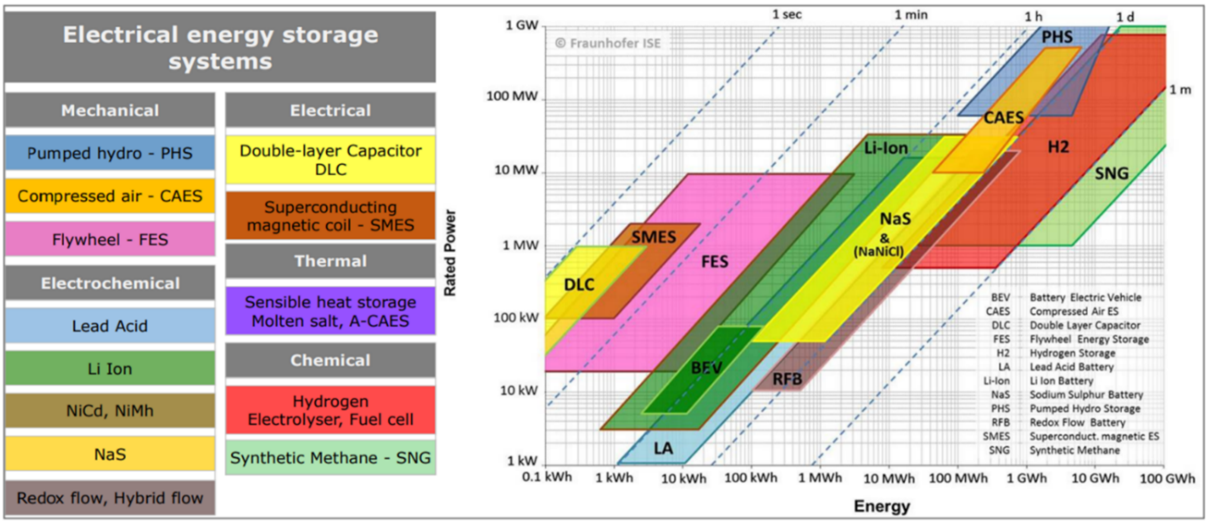
Question 3

Energy density

How much energy needs to be released, given the mass or volume of the storage system?

- Question #2 has partially answered this question. According to the scenario, the storage system needs to have an energy density of no less than 2000 kWh or 2 MW for 1 hour. The other aspect of energy density is energy per mass/volume. Simplifying this example, energy density is described as low, medium and high. **Figure 4.67** below denotes Low energy density as 1kW to 100kW, Medium as 100 kW to 10 MW, and High as 10 MW to 1 GW.

Figure 4.67. Energy density



Within the window of 2 MW for 1 hour, the below technologies are suitable:

- RFB.
- NaS.
- CAES.
- PHS.
- H2.
- Li-Lon.

The volume size and weight of the storage system also have a relationship with the energy density; for transport applications, it is desirable to look for high energy density and low weight. For this scenario, as the storage solution is stationary in a building, the physical space needs to be considered. Storage solutions with higher energy density take up less space, as presented in **Table 4.23**.

Table 4.23. Energy density and technology

Technology	Energy density Avg (Wh/kg)	The required size of storage in Tons for 2MWh
RFB	15	133 Tons
NaS	195	10.26 Tons
CAES	4500 W/m^3	252 m^3
PHS	1.75	1142 Tons
H2 (compressed 200Bar)	20000 W/m^3	100 m^3
Li-Lon	265	7.55 Tons

Question 4

Level of maturity

How mature does the solution need to be?

As described by the level of maturity and **Figure 4.9**, the level of maturity of the energy system can bring additional risk and costs. The more mature the system, the less capital cost and risk are involved.

Question 5

Efficiency

While modern storage systems have high efficiency, the question of how efficient the system needs to be must be asked. The lower the efficiency of the storage system, the more is needed and the higher the operational cost.

Question 6

- Average OpEx.
- Average CapEx.

How much will the system cost to buy, and what will it cost to run? Are there refinements for budget or operational costs that need to be evaluated?

4.11. Recommendations and future work

Future work and follow-on work from this study to identify the appropriate energy storage solution should include the following:

4.11.1. Software tool

A fully-fledged software tool should be developed to assist the user in identifying suitable energy storage systems. The Pugh matrix or the multi-attribute utility theory should then be used to identify the most suitable storage system from the database or the utilisation of Fuzzy logic. The most likely solution may be utilising a mixture of both. There are numerous computations that need to be evaluated when matching storage systems with renewable generation and selecting an adequate storage system to match the application.

The first step in making a software tool is to create a functional specification for the tool. The software tool should guide the user through their application and make suggestions for the most suitable storage system. Live information on installation costs, cost per kWh, etc., could be obtained by the tool using an API to statistics providers like statista.com. The tools should also be able to evaluate environmental conditions and indicate the physical size and mobility of such a storage system.

4.11.2. Impact protection

The IK rating is an international standard that indicates how resistant a product is to impact. The standard BS EN 62262 relates to IK ratings to identify the degree of protection provided by enclosures for electrical equipment against external mechanical impacts. Considering some of the environments in which the energy storage systems and equipment are to operate or the potential change in the environmental conditions due to military operations, the IK rating should be investigated further. There is currently a limited number of storage systems available commercially, and none that consider military environments. The term "military grade" in relation to storage systems should first be defined. This definition could form a survey across the EU ministries of defence to collectively define what is required under the various operations that the MoD performs. With this information defined, it should form part of the technical specification for energy storage systems within the MoD.

4.11.3. Financial evaluation

Capital expenditure, operational expenditure, return on investment and internal rate of return. These financial terms all play their part in evaluating budgetary expenses. However, it is becoming apparent that these methods are outdated when it comes to evaluating energy projects, which are becoming more projects of necessity than projects that provide a return on investment. A revised collective method for finically evaluating energy projected should be investigated. This method could become part of the software tool and should take into account future carbon charges. However, the evaluation should put more emphasis on the cost, not in monetary terms but in environmental terms. It should also consider the cost to human life of not doing the projects. The social cost of carbon is an important concept that is often overlooked. It represents the social damage from emitting one metric ton of carbon at a specific time. Prof. David Archer of Michigan State University, a computational climate scientist, has significant research in this area.

4.11.4. Power to gas

Energy-intensive applications, such as mobility and transport, require high energy density from their fuel source. Hybrid fuels, such as HVO (hydrogenated vegetable oil) and diesel, are proposed as a solution to a greener form of fuel in the transportation sector. HVO, at best, will reduce CO_2 by up to 90%; HVO may become an interim solution. Ammonia is comprised of three molecule parts hydrogen and is a better carrier of hydrogen than hydrogen itself. By volume, ammonia (15.6 MJ/l) carries 70% more energy than liquid hydrogen (9.1 MJ/l at cryogenic temperatures) and nearly three times as much energy as compressed hydrogen gas (5.6 MJ/l at a pressure of 700 bar). By weight, ammonia carries 6,250 Wh/kg, which is significantly less than hydrogen's 33,300-odd Wh/kg and has been proposed in the shipping sector as a solution.

Ammonia

As an engineering solution, ammonia as a fuel has many advantages. A deeper dive into the use of ammonia for heavy transportation should be investigated, and a report should be generated on the potential of using ammonia as a fuel rather than letting it be overshadowed by hydrogen.

Hydrogen

The European Union is sending a crystal clear message that hydrogen as a fuel source is the direction Europe is following. The European Commission has approved 5.2 billion euros in funding for hydrogen projects, propped up by an additional 7 billion euros from the private sector as of August 2022. The EU ministries of defence should hence take advantage of this and consider implementing hydrogen projects.

4.11.5. Future work

1. Break the projects up into areas of storage applications, as defined in the report.
2. Define the technical specifications for an MoD energy storage system by application, considering the key attributes discussed in this report.
3. Between the working groups, collectively identify test sites for implementing hydrogen storage and possible hydrogen generation that cover all application types.
4. Form a project proposal and apply to the European Union for funding.
5. Present the project proposal to a hydrogen conference of interested tenderers.
6. Use the previously developed technical specification as the basis for tender documentation.
7. Procure the project.
8. Develop centralised cloud-based monitoring software so all parties can view all project performance data live. The monitoring platform should have the ability to run APIs for external analysis. A centralised data warehouse is essential for information sharing and data collection.
9. Share information, experiences and performance.

Conclusions

The main objective of this study was to define the key requirements for an energy storage selection decision support tool for homeland defence installations. In order to define the key requirements, a review of renewable energy generation systems was performed. This was followed by a review of energy storage systems and their defining key attributes, which were recorded as categorical data.

The key requirements for an energy storage selection decision support tool are as follows:

1. The tool should be software-based.
   a. Fussy logic, the Pugh matrix, or the multi-attribute utility theory should be used to select a suitable storage system. This type of reasoning is suited to software.
2. The tool should allow the user to select their preferred type of renewable source input.
3. The tool should have the ability to pull in information from other sources of online information, i.e., running internet services, Rest APIs, IoT commands, Rest, Post Soap, etc.
4. The tool should have the ability to reference database information such as Annex A of this report (a Microsoft access sheet).
5. The tool should be able to select from multiple storage systems performing analysis for the best outcome based on the users' input.
6. The tool should present the key attributes of the energy storage system in this report as part of the information contained in its selection for the storage system.
7. The tool should have the ability to run PDF reports on the findings from the user inputs.

The review of the energy generation systems generated a relatively small list of available technologies. The maturity and technology readiness levels are relatively high, indicating that both onshore and offshore solar PV and wind generation will dominate the current and short-term markets.

The review of the available energy storage systems is not as clear, and there were quite a few potential energy storage systems reviewed. The level of maturity and technology readiness is low. Furthermore, it leaves a concise list of available solutions on the commercial market. The solutions that are ready and available have a limited scope and are more suited to lower energy-intense applications. Information on the impact rating and risk to the consequence of a catastrophic failure are non-existent.

Although further investigation is suggested, the level of maturity of storage technologies is quite low and a further investigation may not be fruitful. It may be a better use of time to initially define what the MoD requires for impact protection and define a complete specification for military requirements for energy storage systems. Given time, in approximately 2-5 years the maturity level of a wider range storage technologies will have had significantly had more testing and commercialisation. A further investigation at this point is recommended. Alternatively, there is an opportunity for the MoDs to run their own pilot projects, gather their own data and make informed decisions.

The collaboration of the MoD to utilise funding and begin getting test projects in hydrogen, both production and storage, off the ground will ultimately indicate the practicality of the use of hydrogen storage and fuel in the MoD. The relevant research studied alludes that Europe has no hesitation in rolling hydrogen out. As the MoD operates under slightly different rules to the private sector and has different requirements, the MoD should become a leader with pilot projects in hydrogen. The working groups of the European Defence Agency as a collective have considerable potential to carve out the way forward and should not be reliant on adapting a storage solution, particularly hydrogen from the private sector.

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CF SEDSS III
Consultation Forum for
Sustainable Energy in the Defence
and Security Sector

5. The impact of defence activities on offshore renewable energy developments: constraints and recommendations for improving coexistence

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Abstract

The European Green Deal, including the offshore renewables sector strategy, reflects the European Union's commitment to achieving climate neutrality by 2050 and a 55% reduction in greenhouse gas emissions by 2030. The transition towards renewable energy, particularly offshore wind, will significantly impact society. As offshore wind farms become critical infrastructure, concerns arise regarding the protection of electrical assets, interconnectors, and the potential consequences on defence domains. The deployment of large wind turbine generators (WTGs) poses challenges to defence activities, affecting radar systems, communication, and underwater sensors. This study explores defence concerns and requirements for offshore renewable energy deployment, aiming to provide insights for the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS) community. The report identifies areas for regulatory review, key stakeholders, and proposes actions to ensure harmonious coexistence between offshore renewables and military activities.

Executive summary

The innovation and determination of the European Green Deal and specifically the offshore renewables sector strategy have proven the commitment of the European Union (EU) and its Member States to become climate neutral by 2050 and reduce greenhouse emissions by 55% (according to 1990 numbers) by 2030. This will impact our societies in many ways and specifically the move away from fossil fuels and the significant electrification of our society, where the power sources mainly will be renewables (wind, solar, biomass) and to a great extent offshore renewable in the form of offshore wind. The strategic context is changing. Offshore wind farms will increasingly be considered as critical infrastructure, which introduces concerns by the armed forces on how to protect the electrical generation and transmission assets offshore, including the related interconnectors.

The inevitable impact of the significant increase on offshore renewable power plants (primarily offshore wind, however, this includes other forms of offshore energy developments) must absolutely be given great consideration, as the impact on the maritime seabed, animal, marine and bird life and not least to other users of the marine space is not trivial. Nor is the impact to the three recognised defence domains – air, surface, and subsurface. Several phenomena can cause a negative impact on defence activities and systems (air and marine radar systems, communication, weapons) which are in line of sight of offshore renewable installations primarily offshore wind turbine generators (WTG). The rotor diameters of WTGs expected to be erected after 2024 are more than 230 meters (the new Vestas 15MW V236 has a rotor diameter of 236m). They represent very large radar cross sections thus reflect radar signals tremendously interfering the normal operations. New and modern radar and communication systems include advanced tracking systems and digital solutions which are expected to mitigate some of the negative effects of the WTGs. Offshore wind farm layout and design may similarly mitigate some of the negative effects. In the subsurface domain underwater sensors are negatively impacted by the large steel structures deployed offshore. Passive sensors may be affected by offshore renewable installations as the steel structures create noise which impact the sensors' ability to detect submarines and other underwater equipment.

The scope of the study is to help the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS) community to contribute with insights and understanding of the defence concerns and requirements for the deployment and exploitation of offshore renewable energy sources in maritime areas reserved or used for present or future military activities and purposes. The potential impacts from defence activities on the offshore renewable developments are therefore in focus. The study appreciates that the EU and its Member States have set strong and ambitious targets for the future energy generation offshore and thus the aim is to contribute to achieving these targets by analysing the potential impacts coming from defence activities on the marine environment and domain where the energy production is envisioned to occur.

The study report will identify areas where regulations, processes and methodologies (what we do today) may require review and potential amendments. It will identify the key stakeholders in the process and finally, the report will, based on its analysis, suggest future actions to how the EU (European Commission, European Defence Agency), Member States and other relevant parties can contribute to the process ensuring continued beneficial coexistence between the expected and increased build out of the offshore renewables and the armed forces.

5.1. Introduction

Each coastal Member State in the EU has developed their individual maritime spatial plan (MSP). The MSPs shall according to the EU MSP Directive of 2014[100] '*contribute to the effective management of marine activities and the sustainable use of marine and coastal resources, by creating a framework for consistent, transparent, sustainable and evidence-based decision-making.*' In other words, the MSPs shall identify the distribution of relevant existing and future activities and uses in their marine waters i.e., '*installations and infrastructures for the exploration, exploitation and extraction of oil, of gas and other energy resources, of minerals and aggregates, and for the production of energy from renewable sources*', '*maritime transport routes and traffic flows*' and '*military training areas*' (article 8).

On 19 November 2020, the European Commission published the communication "An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future" with the objective to make offshore renewable energy a core component of Europe's energy system by 2050. One of the key actions of the offshore strategy is that the "**Commission and the European Defence Agency will set up a joint action to identify barriers for offshore renewable energy developments in areas reserved for defence activities and improve coexistence"[101]**. The EU and their Member States are therefore asked to effectively create a framework which enables offshore renewables to become a core component of the EU's energy supply through making transparent and evidence-based legislation. A portion of the future activities is to identify barriers that may obstruct the role out of offshore renewables – barriers that stem from the parallel use of the marine space by offshore renewables and defence activities.

This study has set out to identify these potential barriers, explain these from a developer's perspective and similarly explain these from the defence perspective. By identifying the barriers, the study aims to help the CF SEDSS community to deepen further its insights and understanding of the defence concerns and requirements for the deployment and exploitation of renewable energy sources (RES) in maritime areas reserved or used for military present and future activities and purposes. The study should also identify the key stakeholders that can address these impediments and should present recommendations and alternative options to support future work on fostering the development of RES in defence maritime areas and creating viable conditions for coexistence.

100. Directive 2014/89/EU of the European Parliament and of the Council of 23 June 2014, https://eur-lex.europa.eu/eli/dir/2014/89.
101. See "An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future", p. 11.

5.2. The study's objectives

- Contextualise the interface between deployment of offshore renewables and defence by briefly describing the relevance of the study and presenting current state of play at the EU level.
- Build awareness and knowledge on the matter through identifying studies, policies, legislation and relevant cases showing the interface between offshore energy and defence.
- Identify barriers that may constrain the development and build out of offshore renewable in the EU.
- Identify key stakeholders which are required to be involved, informed or otherwise engaged to improve and enable the sustainable coexistence between offshore renewables and defence.
- Provide recommendations, including alternative options to support future work, e.g., defence requirements to offshore renewable developments, establishing fora where relevant parties discuss and decide viable and sustainable processes and methodologies which minimise risks to developers and authorities and enable defence to continue their primary tasks i.e., defence of the respective Member States.

The methodology which is intended is a structured fact-finding based on relevant sources, e.g., previous studies, legislation and policies, identification and mapping of stakeholders, semi-structured interviews and workshops with previously identified key stakeholders. Based on the initial key stakeholder analysis, a number of stakeholders will be chosen based on accessibility, relevance and interest (if the interviewee shows interest in the project).

Next step in the study is to structure and map the captured input from stakeholders, together with expert judgement and potentially input from the reviewed written sources, e.g., case studies, public available reports and analyses. It will constitute the foundation for identifying and developing the understanding of possible barriers, actual obstructions and impediments which may constrain the build out of renewable energy in the maritime areas reserved or used for present or future military activities and purposes. The study will also provide a list of potential risks and describe the negative effects that offshore renewable installation may create for the military operational effectiveness. Particularly the private sector defence stakeholders are intended to provide evidence of this.

5.3. Context

The EU has the largest maritime space in the world with its sea basins and oceans (the North Sea, the Baltic Sea, the Mediterranean, the Atlantic and the Black Sea). Their variety and complementarity offer a vast potential to develop offshore renewable energy, which can be harnessed in a sustainable and environmentally sound way, complementing other economic, social and defence activities. This fact in itself makes it relevant for any EU agency to focus efforts in contributing to achieving the EU renewable targets.

As far as the defence sector is concerned, significant issues constrain the release of maritime areas reserved for military purposes for the deployment of offshore renewable energy installations and exploitation. These concerns are related to the possible negative effects on the operational effectiveness of the armed forces. For instance, wind turbines may interfere with military radars, impact the surveillance sensors, impair the military air traffic safety, and cause obstruction. The European Commission communication on the offshore strategy notes that "areas with the highest potential for offshore renewable energy are also the most exposed to risks of collisions with vessels, fishing gears, military activities, or dumped ammunitions and chemicals." A common strategic approach would benefit all maritime activities, and especially the offshore renewable energy sector with its high demand for new accessible sites. This strongly indicates the relevance of the EDA/CF SEDSS III to partake in enabling the co-existence between the defence sector and the offshore renewable sector.

This study will address through the problem and data collection and analysis the challenges which may arise in the endeavour to achieve the EU's ambitious goals. The study will identify and recommend future work in terms of impact/solution studies and trials, processes/procedures/permitting mapping and finally, determining the significance of the barriers seen from the perspectives of MoD, developers and, permitting agencies. The EDA can and should play a role in preparing the way for the facilitation of co-existence between the parties enabling the EU and its Member States to reach their carbon neutrality targets and other supporting goals.

5.4. Strategic context

The scientific evidence for climate change is overwhelming. The increased attention from the political level and through the ranks, in organisations, in businesses and not least the populations is evident. The Paris Agreement (COP21) from 2015 sets the ambition and this was confirmed at the latest Glasgow summit. The ambitions for renewable energy and the target of a carbon-neutral society are part of the context we must understand. The recently revised renewable energy directive raises the EU's binding renewable target for 2023 to a minimum of 42.5%[102].

The European security environment is recognised to be changing towards a more competitive and multipolar world including increased national threats, where the states are having an increased focus on traditional defence (territorial) but also a focus on protecting critical infrastructure, e.g., offshore renewables installations, power to X facilities and interconnectors between Member States. The threat picture in the EU is more complex and diffuse than before. The separation between peace and war is no longer as clear as earlier and this unclear state is often referred to as "grey zone" condition. The traditional threat from third states is again a component in the threat picture resulting in the EU Member States and NATO having an increased focus on the ability to survey, control and defend approaches to the EU, i.e., the Baltic Sea, the North Sea and the Mediterranean Sea. Offshore wind habitually generates large "holes" in the surface, air and maritime radar picture, which raises increased concerns by Member States' MoDs, as particularly the wind farms are growing in scale, size and coverage in combination with an evolving threat picture.

In the grey zone condition a state could be faced with attacks by non-state actors using advanced weapons, drones and methods previously expected only from official state actors (e.g., Russia's Crimea annexation 2014 and Iran's attack on Saudi oil production 2019). It can also be difficult to determine whether conscious antagonistic acts are behind the various events or disruptions that significantly affect the functioning of society. Terrorism and sophisticated organised crime (SOC) are also threats which continue being part of the commonly recognised risk picture.

Not only is the threat picture changing but also the energy production and supply system. A supply of secure and affordable energy has always been essential, but the system that makes up a secure supply is no longer a broad energy supply chain of traditionally oil, coal, and gas together with strategic depots of energy for crises and war. The transition towards renewable energy predominately from offshore wind and an electrification of the society increases the need for a reliable and uninterruptable source of power generation, as we can no longer rely on the ability to protect key "onshore" power plants, petroleum infrastructure and shipping-based supply chains. The offshore wind farms, transmission systems, interconnectors and possible power to X production/storage are therefore expected to become critical infrastructure. Further, the latency build into the fossil fuel supply chain is dramatically different from the electrification of the societies we will see in the future. An example of this is the impact the tripping of the world's largest offshore windfarm Hornsea 1 had on 9 August 2019 causing a widespread blackout in the greater London area

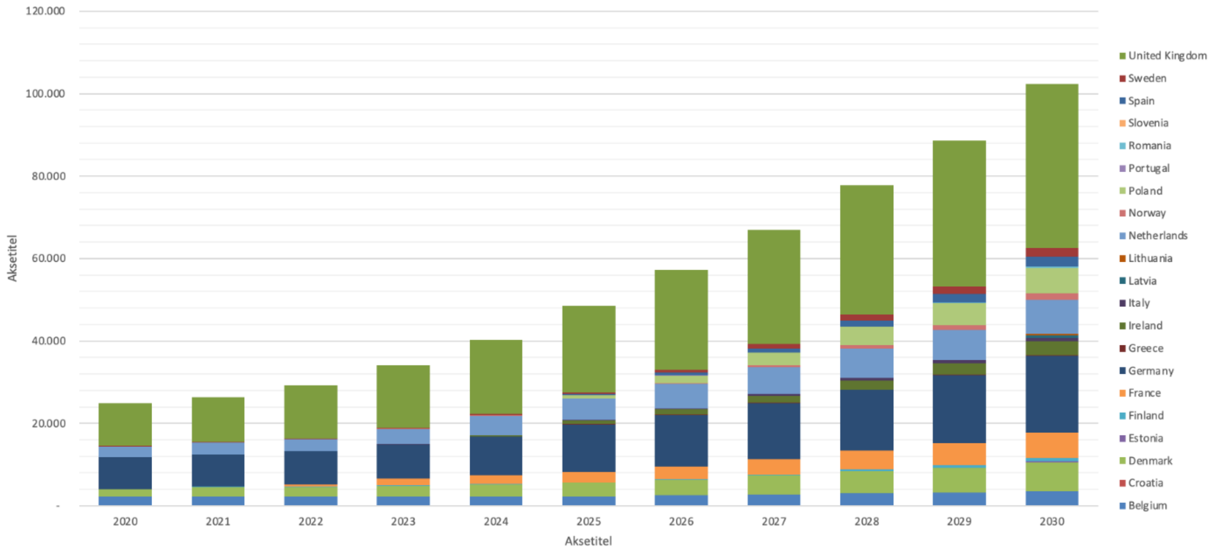
102. EU directive 2023/2413 of the European Parliament and of the Council of 18 OCT 2023. This directive increases the 2030 target of renewable energy share from 32% to 42.5%.

and Mid-England[103]. Hence, there is an imperative need for protection of the critical energy infrastructure which now becomes decentralised in nature which consequently demands new thinking in terms of planning, doctrine, action plans and tactics. Offshore renewables, primarily wind (foreseeable future) and large offshore infrastructure, e.g., energy islands need to find a place in the threat picture and deliver acceptable defence co-existence and security solutions to meet stakeholder expectations (stakeholders being addressed later in the report). Not addressing the issues in a timely fashion imposes risks such as a hard stop/objection from authorities, e.g., Taggen offshore wind farm[104].

5.5. Offshore renewables in Europe – status and outlook

Offshore renewables in Europe are developing at an unprecedented pace. The national parliaments as well as the EU with its 2050 strategy are setting ambitious targets. **Figure 5.1** below shows the known anticipated developments in the EU and adjacent countries. The cheapest way to produce power (see below) is today by using wind generation. This indicates that the ambitious political targets will be superseded by ambitions originating from businesses, as they must develop and construct an increasing amount in terms of MWh (and potentially the derived storage, e.g., hydrogen) to accommodate their investors' demand for green transition and expectations to return on investments.

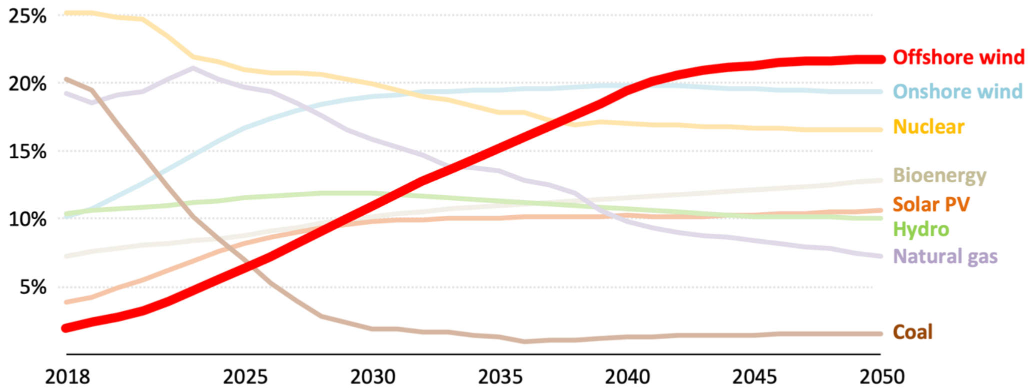
Figure 5.1. Offshore wind development – open source (gathered by Author)



103. https://www.current-news.co.uk/news/blackout-investigation-what-went-wrong-at-hornsea-one-and-little-barford (Accessed 26 November 2021).
104. https://group.vattenfall.com/se/nyheter-och-press/pressmeddelanden/2019/vattenfall-avbryter-vindkraftsprojektet-taggen.

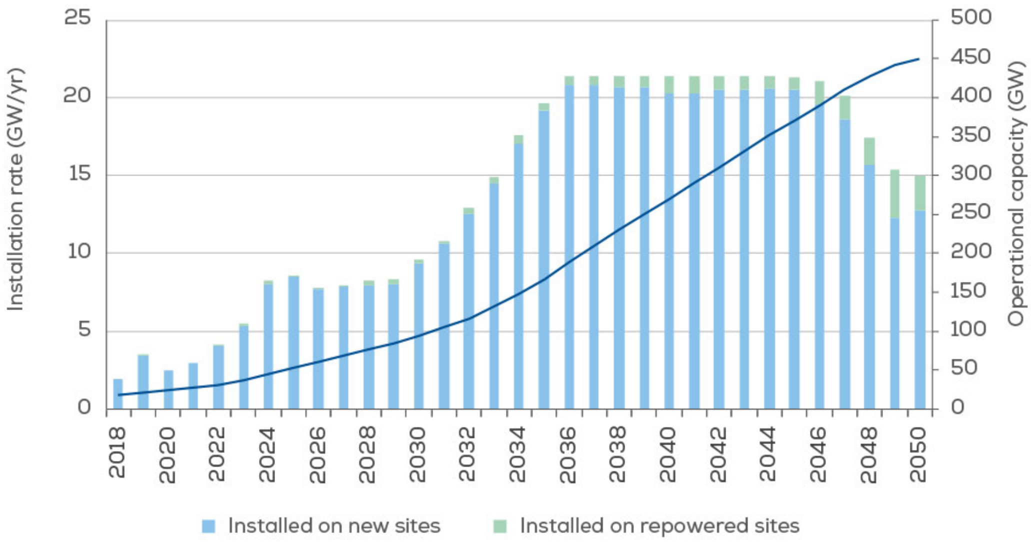
In simple terms what we are witnessing is an almost quadrupling offshore wind development. We have no indications to believe the development will lose momentum in the foreseeable future. In 2020 renewable overtook fossil energy production (eurotiv.com[105]), and this trend will continue. According to the International Energy Agency (IEA[106]), offshore wind is set to become the largest source of electricity in the EU by 2042, complementing other renewables towards a fully decarbonised power system, **Figure 5.2**.

Figure 5.2. Energy mix generation in the European Union, IEA 2019



Scaling up from 20 GW today to 450 GW by 2050 will require a visionary approach[107], **Figure 5.3**. The EU itself has in its Offshore Strategy a requirement of scaling up to 300 GW offshore wind and 40 GW of ocean energy by 2050.

Figure 5.3. Installation rate required to achieve 450 GW by 2050, BVG associates for wind Europe

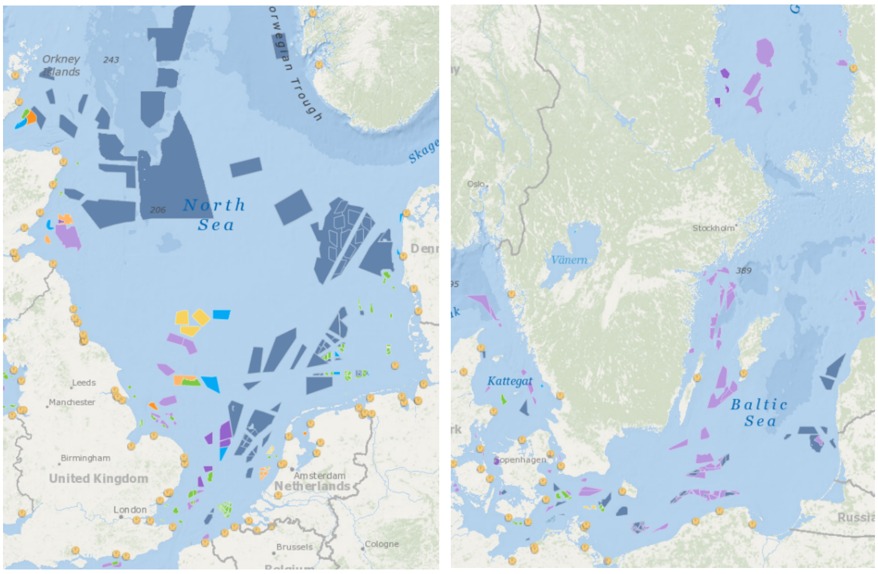


105. https://www.euractiv.com/section/energy/news/renewables-overtook-fossil-fuel-as-main-source-of-eus-electricity-in-2020/ (accessed on the 14.11.2021).
106. https://iea.blob.core.windows.net/assets/2e7ec2d6-7cf1-4636-b92c-046ae16f4448/OffshoreWind-Launch-Presentation1.pdf (accessed on the 27.10.2021).
107. https://windeurope.org/about-wind/reports/our-energy-our-future/ (accessed on the 27.10.2021).

The build out in the North Sea over the coming decades accounts for about 85w % which equals 380 GW (of the 450 GW). The remaining 70 GW would be developed in Southern European waters according to Wind Europe[108]. In at least 60% of the North Sea that has potential for offshore wind farm development, it is currently not possible to build offshore wind farms due to "exclusion zones" according to the same report. Military activities are cited as one of the reasons behind this. The future allocation of sites for offshore wind will depend crucially on how we handle this obstruction from areas allocated to military purposes and how we ensure co-existence.

Figure 5.4 shows the planned areas for offshore wind in European waters. Both the North Sea and the Baltic Sea are and will become increasingly more condensed with offshore renewable installations. For instance, Denmark is planning the so-called (renewable) energy islands[109] in both the North Sea and the Baltic Sea in support of the development of renewable energy (offshore wind and power-to-X) – as an example of the ambition for the use of the (national) sea space. In the Mediterranean Sea, **Figure 5.5**, it is evident that the area is less condensed in terms of offshore renewables. This, on the other hand, indicates that co-location of offshore renewable and military is less likely however not less relevant and important – also considering the EU's Southern border, i.e., immigration from the African continent with the security challenges this brings (typically a Coast Guard task).

Figure 5.4. North Sea and the Baltic Sea (www.4coffshore.com)



108. 'Our Energy Our Future', Wind Europe 2019 (report).
109. Fakta om energiøerne | Energistyrelsen (ens.dk) (accessed on the 28.10.2021).

Figure 5.5. The Mediterranean Sea (www.4coffshore.com)

In **Figures 5.6-5.7**, there are two examples of how EU Member States (the Netherlands and Denmark) have composed their MSPs. In these examples, it is shown that the Netherlands, only on one occasion, has planned an offshore wind designated areas co-located with military training areas whereas Denmark, potentially more representative of the remaining Member States and in several areas, has restricted areas co-located with offshore renewable development areas. The co-located areas are indicated with circles.

Figure 5.6. Extract from the Danish MSP (www.havplan.dk)

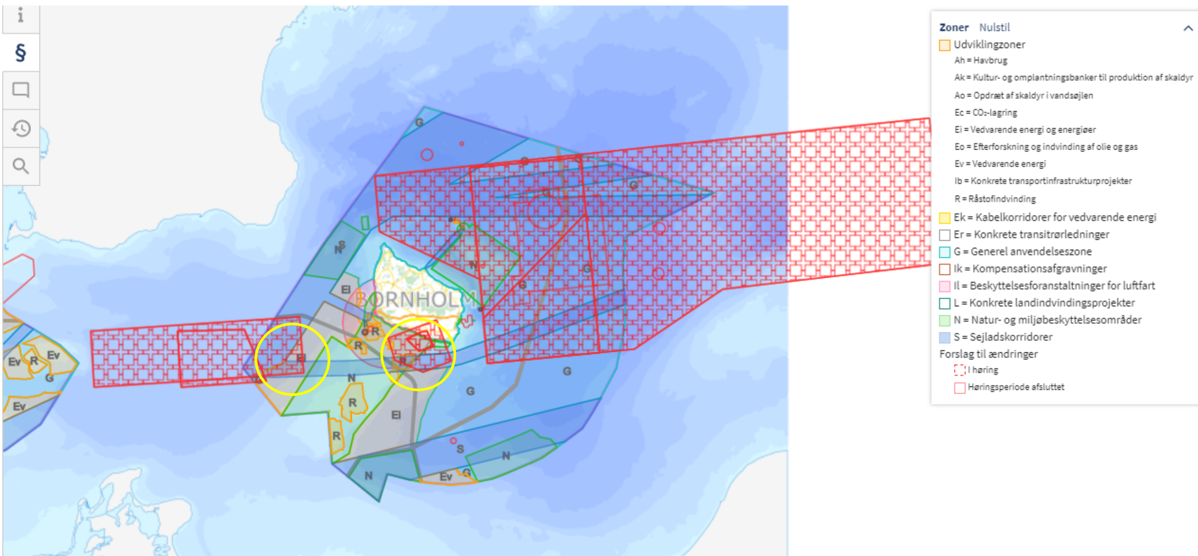
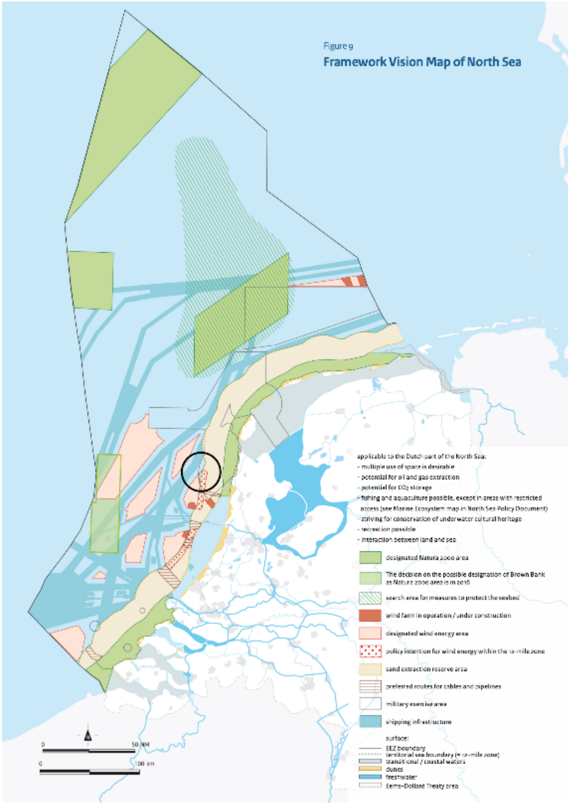


Figure 5.7. Extract of the Dutch MSP (www.msp-platform.eu/countries/netherlands)



Offshore wind farms obviously do come with some impact on areas allocated to military purposes as the construction of the windfarm will hinder the free movement of air, surface and subsurface forces. This can affect practice areas and shooting ranges. Furthermore, as earlier elaborated, the wind farms impact radar and radio coverage and induce "noise in the water column". Offshore wind farms, however, also constitute an opportunity for the military in terms of remote sensors, extended operating platforms and cover, and radar or missile leeway in the maritime environment for the navy. The offshore installations constitute both offensive and defensive opportunities in the open sea that have yet to be explored by navies and described in doctrines.

5.6. Problem analysis

EU and the Member States have common and individual goals and targets in the context of energy policy[110]. However, from a conceptual perspective some generic headlines may help to getting an overview and a framework from where to begin the problem analysis. We want to have access to **reliable** and **affordable** energy to meet the challenges of **climate change** and the **increasing energy demand**.

5.6.1. Affordable energy

It is in nations' interest to be able to ensure that populations have access to affordable energy (competitive). This basically means that the cost of energy must be as low as reasonably practicable. This is not only to prevent social unrest due to high energy prices but similarly important to the businesses' ability to adequately control their cost of energy and cost of production and in the larger perspective the nation's competitiveness is at stake. Affordable energy is therefore a focus area for any nation's policy makers. The Member States in the EU have applied various systems, and processes ensuring that businesses can bid into auctions and leases of the sea to support the effort of achieving affordable energy.

5.6.2. Reliable

Reliable energy means that a nation has access to energy in form of:

- Predictable price (preventing significant variance).
- Available (the light turns on when asked).
- Security of supply (no black- or brown outs, adequate amount of production facilities domestically and a surplus of interconnectors to international partners to import/export in peak and through demand situations).

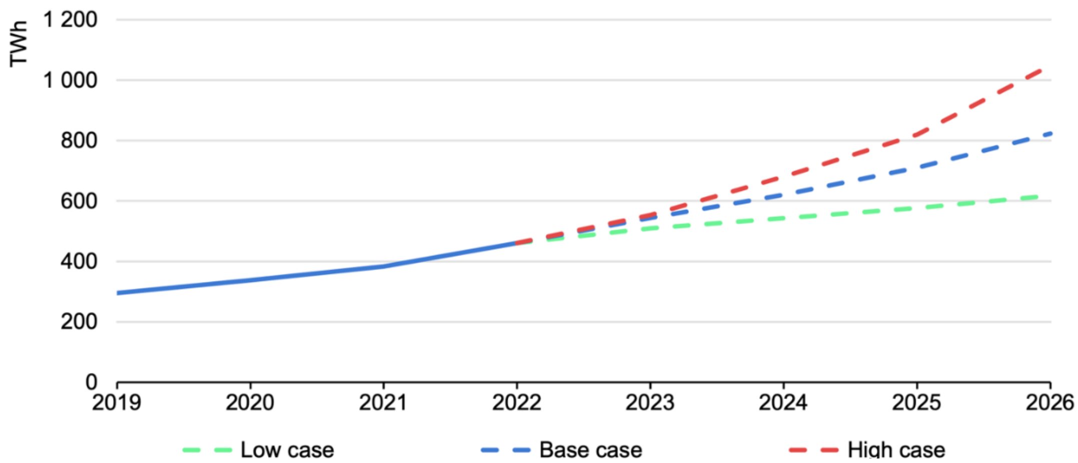
Especially the latter used to be ensured by strong gas deliveries from Russia, fossil fuel from the Middle East, coal and nuclear. A general consensus is that the EU wants to become less reliant on oil and gas from Russia thus decrease potential impacts from policy driven energy supply. This consensus has only strengthened due to the Ukrainian war[111]. The Middle East has historically provided a significant amount of fossil fuels to Europe, however as the region has become unstable it is only natural that Europe looks elsewhere to get its provisions, i.e., create a surplus of renewable power production to create a homebased e-fuels production. Lastly, although part of energy mix going forward, it is highly unlikely that new nuclear powerplants developments will be implemented for a variety of reasons that is outside the scope of this report.

110. https://ec.europa.eu/info/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-long-term-strategies_en (accessed 27.10.2021).
111. REPower EU is a good example of how the EU and member states engage with the challenge, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en refers.

5.6.3. Increased demand

'Renewables are expanding quickly but not enough to satisfy a strong rebound in global electricity demand (after Covid-19), resulting in a sharp rise in the use of coal power that risks pushing carbon dioxide emissions from the electricity sector to record levels next year' (IEA, May 2021). After falling by about 1% in 2020 due to the impacts of the Covid-19 pandemic, the global electricity demand is growing by approximately 2.5% year on year and from 2024 by 3.4%[112] driven primarily by the global increase in data centres (**Figure 5.8**).

Figure 5.8. Global electricity demand from data centres, AI, and cryptocurrencies, IEA January 2024



The demand is driven by the fact that fossil free power is becoming more and more competitive and has surpassed nuclear, coal, oil and gas in both capital expenditures (CAPEX) and operating expenses (OPEX). Thus, electrification of societies drives the increased demand for renewable energy and secondly the e-fuels to power trucks, shipping, and aircraft.

5.6.4. Climate change

Fighting climate change, adhering to the Paris Agreement has become mainstream politics in the EU. According to the EU's 2050 strategy:

- *The EU aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement.*
- *The transition to a climate-neutral society is both an urgent challenge and an opportunity to build a better future for all.*
- *All parts of society and economic sectors will play a role – from the power sector to industry, mobility, buildings, agriculture and forestry.*
- *The EU can lead the way by investing into realistic technological solutions, empowering citizens and aligning action in key areas such as industrial policy, finance and research, while ensuring social fairness for a just transition.*[113]

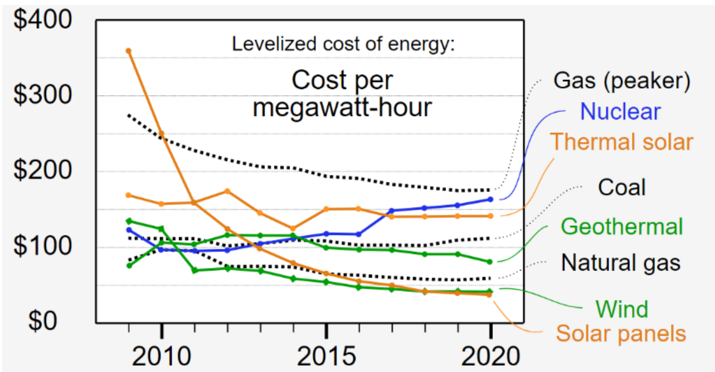
Considering the EU's high-level ambition on energy transition and climate adaptability, the defence sector needs to adapt and evolve to support energy autonomy and climate resilience.

112. IEA, 'Electricity 2024, demand and forecast to 2026', January 2024, https://iea.blob.core.windows.net/assets/6b2fd954-2017-408e-bf08-952fdd62118a/Electricity2024-Analysisandforecastto2026.pdf (accessed on 2024-01-29).
113. https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en (accessed on the 27.10.2021).

5.7. Increased political ambitions

As mentioned above we want to have access to *reliable and affordable* energy to meet the challenges of *climate change and the increasing energy demand* thus energy producers, investors and, distributors transition to lower carbon energy accordingly. The increased level of ambitions is expressed nationally and at EU level through strategy papers, legislation, etc. The currently primary sources of developing RES are offshore wind, onshore wind and solar. Hydro is in certain areas a very important energy source and may in the future be used to conduct grid balancing and storage filling in the gaps when neither wind nor solar produce sufficient energy. Wind energy is today the cheapest source of electricity generation (**Figure 5.9**) in majority of places in the world. Unsubsidised onshore wind energy is cheaper than any other energy source, including conventional power generation sources such as coal and gas[114]. When taking into consideration pollution costs and subsidies, which are not included in levelised cost of electricity (LCOE) estimations, onshore wind is by far the cheapest generation source throughout most of in Europe and the world.

Figure 5.9. Levelised cost of energy (www.lazard.com)



Increased ambitions combined with economic sensemaking make the development of renewable energy and in particular offshore wind very relevant, **figure 5.9** (above) shows the strong increase in developments.

5.8. Affected parties

In the stakeholder analysis below the affected parties are described. This shows in particular the entities involved in supporting, developing and facilitating the creation of a context in which the development of a sufficient amount of sustainable energy generation and transmission offshore may occur in sustainable co-existence with the defence sector in the EU. However, they also represent significant barriers to the development of offshore wind that must be addressed. The stakeholder analysis does per se not include the citizens (themselves) as they may be assumed to be included in democratic institutions which regulate the development. The entities, supported and facilitated amongst others by the EDA, shall perform to the benefit of the EU populations, the prosperity of the Member States and finally the planet through carbon neutrality.

114. Economics | WindEurope (accessed on the 28.10.2021).

5.9. Current practice

With the pace generated by new sustainable energy developments and its current policies the project installation capacity would lead to only approximately 90GW by 2050[115]. Therefore, the rate of developments must increase, which will require overcoming a number of obstacles, e.g., supply chain issues, regulatory and technological challenges, maritime spatial planning and more. It goes without saying that the EU, its Member States and all parties involved must focus and improve and perform to achieve the set targets. As the EU Offshore strategy rightly mentions, market development, technological advancements and "good will" and intentions are not enough. The Strategy states some areas where focus must be put on increasing the development offshore renewables in Europe.

1. **Maritime Spatial Planning** – The EU Member States have all in 2021 handed in their national plans and an EU led work is ongoing to facilitate collaboration between neighbouring states.
2. **A new approach to offshore renewables and the grid infrastructure.** In practice offshore renewables can act as drivers for the infrastructure development and interconnectors, e.g., the Kriegers Flak Offshore Wind Farm (Vattenfall) is connected to both the Danish and German grids via the offshore substation (Energinet and German 50 Hertz Transmission will use this opportunity to connect the two wind farms; creating the world's first offshore power grid which combines wind energy with the possibility of exchanging power between the two countries. The combined grid solution is granted financial support from the EU[116]).
3. **A clearer EU regulatory framework for offshore renewable energy.** There is no common EU framework for offshore renewable energy – this must be developed as this could potentially speed up things as developers and Tier 1117 suppliers would only have to adapt slightly when developing their assets. This should potentially include the defence sector.
4. **Mobilising private-sector investment in offshore renewables:** the role of EU funds. It is inevitable that EU funds can progress and accelerate developments. The current strong will and focus of the political level in the EU on renewables should facilitate this.
5. **Focusing research** and innovation on supporting offshore projects.
6. **A stronger supply and value chain across Europe.** Viewed globally, particularly some countries in Europe have been on front runners of renewable energy innovation118. This created a strong home/local market enabling that suppliers to the industry, developers, and contractors in general in the industry has developed strongly within the supply and value chain across Europe. However, it is quite obvious that non-European companies are entering the industry taking their share of the supply chain. This is partly reinforced by the protectionist policies witnessed in some markets119. According to a BVG Associates report dated June 2017 but still very relevant, Member States at governmental level are required to collaborate with suppliers and developers to provide a continuous, sufficient and visible pipeline of projects. This will enable further investments in technology, skills, development, job creation and potentially cost reduction. Looking at the numbers they were right.

In the latter part of the strategy, it is noteworthy that the European Commission calls all EU institutions, and other stakeholders to participate in the necessary discussion of how to develop further strategies, policies and actual plans which will enable the EU to reach carbon neutrality by 2050, if not earlier.

115. European Commission, Brussels, 19.11.2020 COM(2020) 741 final, 'An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future'.
116. https://en.energinet.dk/Infrastructure-Projects/Projektliste/KriegersFlakAC#onshore, accessed 2021-09-10.
117. Tier 1 suppliers are the largest and first order suppliers to the developers, i.e., Engineering, Procurement and Construction suppliers. Tier 1 suppliers could be WTG OEMs, foundations and cable suppliers or the like.
118. E.g., the Danish offshore wind farm Vindeby was the first of its kind in the world. Constructed between 1990-1991 and consisted of 11 turbines with a combined electricity generation of 5 MW, www.orsted.com, accessed 2022-01-18.
119. Examples of protectionist legislation. In the US the Jones Act (the Merchant and Marine Act of 1920) is an example of a technical however protectionist legislation. Similar legislation can be found in Japan, Taiwan and other non-European countries.

5.10. Methodology

The methodology of the study is a structured review and fact-finding based on relevant sources, e.g., previous studies, legislation and policies, identification and mapping of stakeholders, semi-structured interviews with previously identified key stakeholders. Below the sources are referenced and the most relevant are mentioned, constituting the knowledge base for the study. In the proposed work streams, it is suggested that a similar fact-finding is carried out, led by the EDA at the EU level.

Based on the key stakeholder analysis, a number of stakeholders has been selected based on accessibility, relevance, and interest. The stakeholders were presented with a questionnaire to fill in and return. In some cases, the authors have provided some explanation to their provided replies in order to eliminate misunderstandings.

One workshop was held in London[120] with a number of developers with the purpose of capturing the input from the industry in a structured and manageable manner. Also, a workshop was held in Copenhagen, as a follow-up to the one in London. Lastly, a number of structured network talks have been executed with offshore wind and defence experts developing input and base for the study.

The next step in the study was to structure and map the captured input from stakeholders. Together with expert judgement and potentially input from the reviewed written sources e.g., case studies, public analysis and reports. It will constitute the foundation for identifying and developing the understanding of possible barriers, actual obstructions and impediments which may constrain the build out of renewable energy in the maritime areas reserved or used for present or future military activities and purposes. The study will provide a list of potential risks and describe some of the effects that offshore renewable installations may create on the military operational effectiveness. The private sector defence stakeholders are intended to provide evidence of this.

Based on the analysis and the identified barriers and risks, the study will propose some future workstream which EDA may develop and execute in their continued work. Finally, the study will include a conclusion to the observations, identified barriers and risks. The conclusion will assess if the study purpose has been achieved or not.

5.11. Solution implementation

5.11.1. Knowledge base

In the following section the study includes a few selected articles on offshore renewable energy relevant for the study. Section 'Proposed ' describes how it is proposed to collect further evidence which shall increase the shareable knowledge base.

Legislation

Feedback received from the Danish Energy Agency[121] has provided some data regarding the legislation that consolidates the foundation for the authorities when developing areas for offshore renewable energy.

120. The Workshop was held in the Orsted offices in London on 1st October 2021 and facilitated by the Author. Participants from Orsted, RWE, Vattenfall and SSE.
121. The Danish Energy Agency was the only Government agency contacted for the Study.

Promotion of renewable energy act (Act no 1392 of 27 December 2008, with amendments).

This act's purpose is to promote the production of energy through the use of RES in accordance with climate, environment and macroeconomic considerations in order to reduce dependence on fossil fuels, ensure security of supply and reduce emissions of CO_2 and other greenhouse gases. The act shall in particular contribute to ensuring fulfilment of national and international objectives on increasing the proportion of energy produced through the use of renewable energy sources.

The act also includes a description of the process of how the Danish Government and therefore the Danish Energy Agency intend to promote offshore renewable energy. To establish an offshore renewable energy installation on Danish soil (the territorial sea, Exclusive Economic Zone-EEZ) the developer must obtain three licenses, i.e., 1) License to carry out preliminary investigations, 2) License to establish offshore wind turbines, 3) License to exploit wind power for a certain number of years. This example is relevant for offshore wind development and a similar system – with some variations – is in place for most offshore development in some shape or form.

Establishment of radar surveillance of the danish territorial sea act (Act no 533 of 24 June 2005, with amendments).

This act's purpose is to create the necessary judicial foundation for the establishing and developing the Danish Defence' coastal radar surveillance system. The coastal radar surveillance system's main purpose is to create a credible surveillance system thus increase maritime security in the Danish Straits and territorial sea and secondly protect the environment at sea. The act includes some public tasks, supports protecting the Danish sovereignty, and finally ensures maintaining Danish jurisdiction over the Danish territorial sea.

EUROCONTROL Guidelines on the assessment of ground-based surveillance interrogations (surveillance performance and interoperability commission implementing regulation (art 6 of regulation (EU) No 1207/2011 as amended by Regulation (EU) 2017/386 and Regulation (EU) 2020/587 of 29 April 2020).

This document defines a process to assess the compliance with point 1 of Article 6, including the management of issues that may arise. Different methods of analysis supporting the process are described in this document, allowing States to select the most efficient method for their environment. In particular, this document recommends that States verify that the aircraft transponder occupancy generated by interrogations eliciting or not eliciting a reply remains below a maximum threshold for any aircraft transponder flying in its airspace.

Similar legislation would be relevant for all coastal EU Member States (and is potentially already in place) and the proposed work stream does **recommend an EDA-led information gathering exercise to take place to map out the legislative framework relevant for the relevant EU Member States**. Hogan Lovells, an international law firm, has produced a very interesting handbook[122] providing a good understanding of the regulatory details for offshore wind energy in some EU Member states (the handbook does cover other areas as well). The handbook covers in its 2021 version the following EU Member States: *Belgium, Denmark, France, Germany, the Netherlands, and Poland*. **A similar handbook is proposed to be produced providing interested and relevant parties with a strong insight of the regulatory framework.** The managing director of the World Forum Offshore Wind confirms:

'The immense interest in understanding the regulatory details for offshore wind energy in existing and emerging markets has made the first edition of this handbook an instant success. However, given the dynamic nature of regulation, it is essential to keep track of the changes in these offshore wind markets. This second edition of the

122. Access the handbook here: https://www.hoganlovells.com/en/publications/handbuch-zur-regulierung-von-globalen-offshore-windmaerkten.

handbook is therefore hugely beneficial to the global offshore wind community as it captures all regulatory updates made by governments throughout the past year' (Gunnar Herzig, MD of the World Forum Offshore Wind, from the foreword to the Hogan Lovells handbook, April 2021).

The relevance of capturing and having a good knowledge of the legislative framework is only made stronger by the fact that **floating offshore wind developments** are soon becoming financially viable however expected to be even more regulatory complex.

5.11.2. Barriers and risks

Establishing offshore renewables and in particular offshore wind (as it is by far the largest, cleanest and most reliant source of energy production in the foreseeable future) will impact the defence capabilities of the EU Member States. The military capabilities are normally divided into those of the air-, surface-, and subsurface domains. They differ in terms of the environment, speed, tactics, and sensors.

a) The air domain[123]

It is widely recognised that offshore wind farms may reduce the performance of defence systems such as radars significantly and negatively impact the operational capability in terms of shadowing effects and track seduction. This is to some extent reinforced by a similar decrease in communications due to interference from the spinning Wind Turbine Generation systems (WTGs). Larger offshore wind developments are expected to impact other types of sensors, e.g., the airborne identification system 'identification friend or foe' (IFF), electronic warfare sensors and optical sensors.

b) The surface domain

As above, the EU Member States' capability to perform surface surveillance will be reduced as a consequence of the build out of offshore wind (unless mitigated by radars or communication repeaters installed offshore on the assets) due to the reduced performance of land/shore-based radars and communication systems. The surface borne automated identification system (AIS) may suffer from negative effects from the presence of offshore wind farms. AIS is primarily line-of-sight thus the negative impact is primarily when the wind farms are located in vicinity of traffic lanes and thus interferes with already in place systems. AIS is a civilian system used by armed forces to establish what is known as the common operational picture and is the peace time standard operational procedure keeping oversight of activities within the nation's area of interest.

c) The subsurface domain

The subsurface domain differs greatly from the surface and air domain. The presence of large steel structures offshore will dramatically change the acoustic conditions through its own produced noise and will act as reflectors when operating sonars. Some surveys indicate that offshore wind farms depending the sea conditions i.e., significant wave heights less than 0.5m may be heard at a distance of 30 km. Disturbances to own sensors and manoeuvres are expected however not yet wholly described. For instance, in the German sector, offshore wind farms are equipped with sonar pingers.

123. Traditionally, the armed forces would divide the battle space into 3 separate domains. Air, Surface, and Subsurface domain. Each domain would have its own unique characteristics which would determine how the armed forces would plan and execute warfare. Today armed forces have included further domains such as the cyber domain and space domain.

5.11.3. Identified risks

Offshore renewables and offshore wind in particular are in risk of negatively impacting the performance of permanently installed surveillance and communication systems. According to Terma A/S:

'When wind turbines are grouped in large wind farms, they can have a significant effect on radars and specifically on radars used for aviation, as they are typically designed to show only moving objects and filter out anything stationary. The spinning blades of the wind turbines can appear on the radar screen as false "targets"'[124]. The interference (or "clutter") generated by the turbines can desensitise the radar in the area of the wind farm, causing legitimate targets to disappear'[125].

In the feedback received from some of the MoDs it is stated that large clusters of WTGs will negatively impact or interfere with permanent radar installations. According to a Rambøll report of February 2021, *'the establishment of Thor Offshore Wind Farm will impact the radar in Thyborøn and possibly the radars in Hanstholm and Oksbøl. It is assessed that the impacts on the Danish Defence's radars as a result of the establishment of Thor Offshore Wind Farm are moderate and the need of mitigation measures must be anticipated'*[126].

It is a fair assumption that the technical negative impact exists also for the mobile and platform-based radar communication installations. In this mobile context, it is primarily navy operated radar and communications that are affected, and radars for navigation and civilian maritime communication not so much. Potentially the offshore installations may impact shore-based surface surveillance radars and thus coast guard like operations and the monitoring of maritime sovereignty.

According to experts, the reduced radar performance when in vicinity of offshore renewables installations is due to the creation of false targets and lowered detection probability is caused by the rotating nature of the WTG and especially the doppler effect of the rotating blades. The WTGs are also causing a shadow effect (line of sight) thus reducing detection ranges. The two mentioned implication will affect the ability to perform electronic warfare. It is therefore concluded that offshore renewable installations will affect weapon systems negatively. The negative impact is expected in all warfare domains. Another obstacle is the fact that '*large offshore wind farms can be up to 300m above water. This would create no-go areas for low flying so reducing options for battle space planners*', and '*Offshore Renewable Energy could occupy grounds for training or disturb operational deployment*' (MoD feedback). The statements clearly show that offshore renewable installations are hampering the effective training and exercises including live firing. In turn this will affect ability of the armed forces of EU Member States to maintain operational capacity.

It may be claimed that legacy thinking within MoDs is a barrier in its own. As the future battlespace worldwide will have the presence of offshore renewables thus evidently having national areas and the possibility to train and operate in the right environment is a clear advantage. It has been expressed that reducing live firing training areas and training areas too much constitute a risk to the armed forces' ability to build and retain operational capability.

Not only is the threat picture changing, but so is the energy system which will impact the armed forces domain. We are moving toward an increased reliance on electrical energy and expect supply of secure and affordable energy. However, the system that makes up a secure supply is no longer based on traditional energy supply chains of oil, coal, and gas together with strategic reserves of energy for crises and war. The transition toward renewable energy from offshore wind and an electrification of the society increases the need for a reliable and uninterruptable source of power generation. The societies can no-longer rely on the ability to protect key "onshore" power plants, petroleum

124. www.terma.com.
125. www.terma.com accessed 2021-10-09.
126. Rambøll, 'Thor offshore wind farm, radar and radio interference', report for Energinet.dk, February 2021.

infrastructure and shipping-based supply chains being sufficient as the energy transition specifically moves away from this kind of infrastructure. The offshore wind farms, transmission systems, interconnectors and possible power to X production/storage are expected to – or should pending size and impact on supply – become critical infrastructure. This in turn, requires that the Member States and potentially EU realise the requirement for an increased focus on the protection of this infrastructure during crisis and conflict.

Finally, there have been identified risks of the available sea space possibly falling short of the political ambition. According to Wind Europe (www.windeurope.org), increasing activity in European waters has led to increased marine spatial demand and growing competition between sea users. In particular (amongst others), '*collaboration with the **Defence sector** provides opportunities for joint trainings and simulations, unexploded ordnance (UXO) management, and security patrols and reactions. These require close coordination and can be done using mobile or fixed assets in partnership. In Europe, this is already happening both at an international and Member State level, with the European Defence Agency (EDA) and ministries of defence already engaging with policymakers and wind industry representatives'*[127].

5.11.4. Identified barriers

Some of the above-mentioned risks materialise into actual barriers for developing offshore renewables which challenge the rate of development our policymakers envisage; the certainty required for the developers and finally but not least accommodating the decarbonising agenda set out by the Member States' citizens.

'In relation to screenings conducted to locate suitable locations for future offshore wind farms it can be a significant barrier, if information about areas used by the defence/armed forces for military exercises etc., is not publicly available, as it may cause locations otherwise suitable areas to be abandoned later in the process' (an EU permitting agency, October 2021). This indicates that during the marine spatial planning process it is relevant and important that military sensitive information somehow can be included and shared. Such a forum is currently only available in a limited context.

Offshore wind developers have observed and experienced during consultations with stakeholders from the armed forces a concern based on **minimum or lack of knowledge regarding the impact of the possible solutions, legacy thinking and a reluctance towards potential mitigation strategies** that could ensure sustainable coexistence between offshore renewables and armed forces. This is an important observation as some of the mitigation strategies actually increase the military capabilities and extend operational awareness across the warfare domains.

Developers across the EU have had bilateral discussions with relevant armed forces stakeholders, and they confirm that armed forces in some situations have been opposing developments due to uncertainties in assessing the impact on their ability to train, operate weapons and communications systems and ultimately their capability to defend the nation. The feedback received via the questionnaire from armed forces seems to confirm the statements provided by developers, '*in general the fear of degradation of situational awareness is a major concern and the primary obstacle*', '*will make interdiction of surface vessels and aircraft more difficult, particularly in extensive developments*. As mentioned above in the risk section, the legacy thinking of the status quo is predominant and whereas mitigation solutions to the degradation of situational awareness can be – and have been – found, the changed environment provides opportunities for extended offshore surveillance, operating platforms and other opportunities that can possibly be exploited[128].

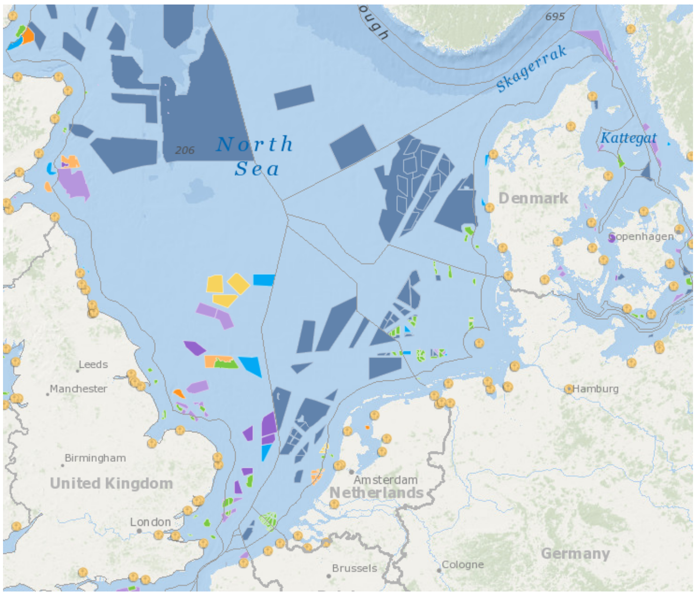
127. Wind Europe paper dated September 2021, 'An overview of Offshore Wind in Europe'.
128. The Belgium Navy is collaborating with the offshore wind industry, '*Captain Jan De Beurme of the Belgian Navy also underlined the importance of collaboration. Wind farms, like nuclear sites, require protection because of their importance to national security. This means that the military needs to understand and be familiar with offshore wind. The Belgian Navy is already looking into docking stations for military drones and helicopters at offshore charging stations. Capt. De Beurme encouraged the industry to actively reach out to military interests*', https://windeurope.org/newsroom/news/active-collaboration-with-military-shipping-and-conservation-essential-to-offshore-wind-success/ accessed 2022-01-22.

The current framework in use in many countries does not allow consultation of confidential impact assessments. This is not only concerning impact to military sensors, training, and operations however it is also relevant between businesses as their potential impact cannot be shared due to various confidentiality protections and competition. This creates a barrier as knowledge cannot freely be shared by the relevant parties which in turn decreases the rate of developing the suitable mitigative solutions and strategies. As impact to sensors due to offshore renewable installations is not a commonly agreed measurable unit, the basis of discussions between relevant parties is ambiguous. A wind farm developer from northern Europe has expressed following reflections on a needed framework and actions following dealings with armed forces: '*…developing good practice guidelines for engagement to enable co-existence. Undertaking studies to identify challenges/opportunities to enable co-existence. Developing tools for planning co-existence (including modelling, emulating/simulating); common set of trials to provide evidence that multiple MoDs will acknowledge*'. Particularly the last paragraph indicates that the developers are ready to engage with the armed forces to create a common, scientifically based knowledge base in the framework of offshore developments. However, the armed forces are not used to working together with developers and are usually tasked with significantly different topics and sharing of information can be a barrier just as the culturally different nature of engineering heavy organisations vs. the officer and non-commissioned officer (NCO) trained defence organisations. Bridging the span between the culture and language of the armed forces and the world of development engineering is a barrier that needs to be navigated and overcome.

Similarly, the developers and the military industry are not usually accustomed to work and trade together. Obviously, the contractual framework can be established between the parties, however these entities are not necessarily adapted to support each other. For instance, some radars that could be suitable as mitigation solutions are considered military grade and sole purpose and are thus only allowed to be sold to government organisations. This means that unless a piece of equipment, e.g., a radar is classified as "dual-purpose" it cannot be sold or exported to private entities or there might be other export restrictions. There is thus no "one size fits all" to any development or mitigation solution.

The legal and regulatory foundation for deploying military systems in the nations' economic exclusive zones (EEZ) is a grey zone. As the major bulk of the current (and future) offshore renewable developments are in the EEZ, (see **Figure 5.10** below – the dark blue areas represent future developments, and the coloured are offshore wind farms in different planning and execution stages), it is eminent that further investigation of this subject must be pursued. Uncertainty of what surveillance equipment can be installed, and for what purposes that equipment is installed in the EEZ needs to be clarified and the issue and grey zone of the militarisation of the EEZ must be addressed clearly. This will enable that policy makers, authorities, the armed forces and not least the developers in the EU have an agreed understanding and can engage in developing strategies to increase speed of permitting, etc.

Figure 5.10. Offshore wind farm development area, www.4coffshore.com

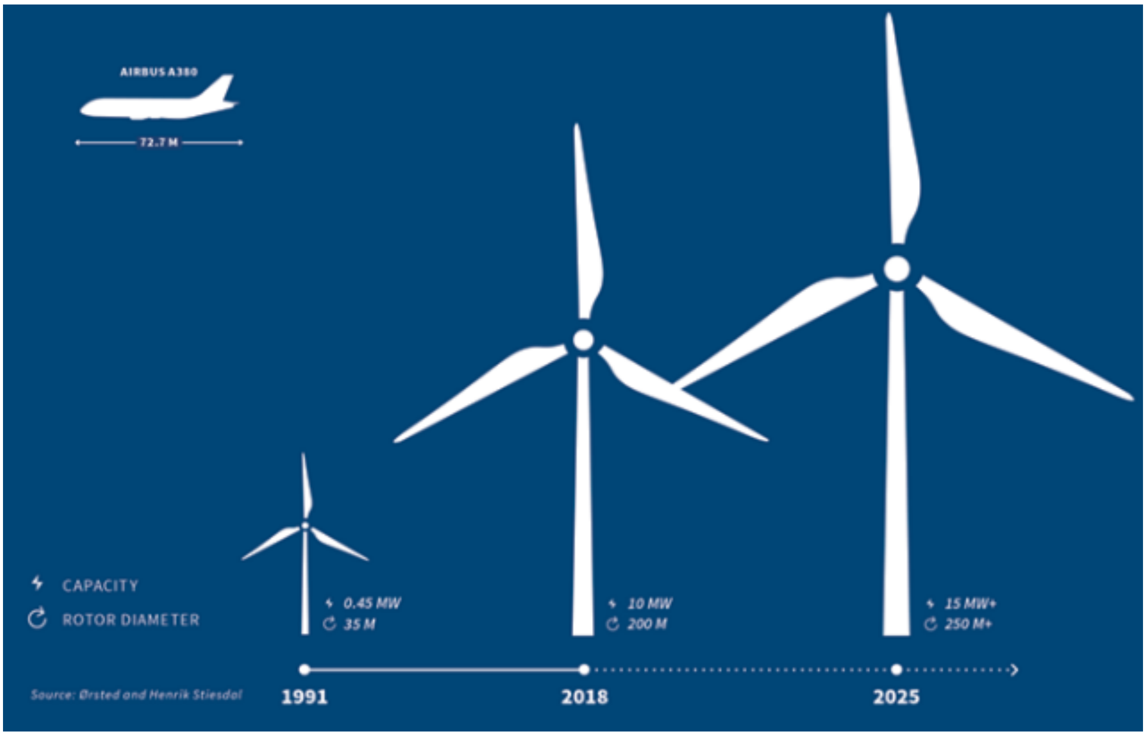


Currently, the mitigation solutions the market provides are immature to the effect offshore renewables has on e.g., air and sea surveillance. Consensus between authorities, developers and the military industry does not exist regarding enabling coexistence by implementing permanent surveillance and communication installations on offshore renewable installation. This hampers the consenting process as it drives the armed forces to object to projects. The offshore renewables industry is considered a young industry and develops at a fast pace. However, the offshore wind industry is of a size not seen before, both in terms of geography and turbine size. Offshore wind farm size 10 years ago was about 300-500 MW, now developers are constructing offshore wind farms above 1GW and are planning offshore wind farms of 2-4GW.

Figure 5.11 shows the rapid increase in the size of turbines over the 30 years, especially the last decade. The tangible solutions which may be used in mitigating the impacts on the armed forces have not yet been developed by the industry. Not only are the solutions not present but the common appreciation of the validity and credibility of the solutions are not present. The industry which will develop the solutions, the armed forces who will develop new doctrines/concepts, the developers who will include the mitigations in their design and cost models, and finally the authorities who will consent to the development will inevitably require time and effort and will to reach a common understanding. The time, however, is limited due to the political ambitions. Therefore, relevant parties shall seek to develop these in collaboration and preferably accelerate their efforts. Attempts at this sort of collaboration have already been done on this topic outside of the EU where the developer Ørsted has led a successful trialling campaign of two short range air defence systems on the 1.2GW offshore wind farm Hornsea 1 in the North Sea[129]/[130].

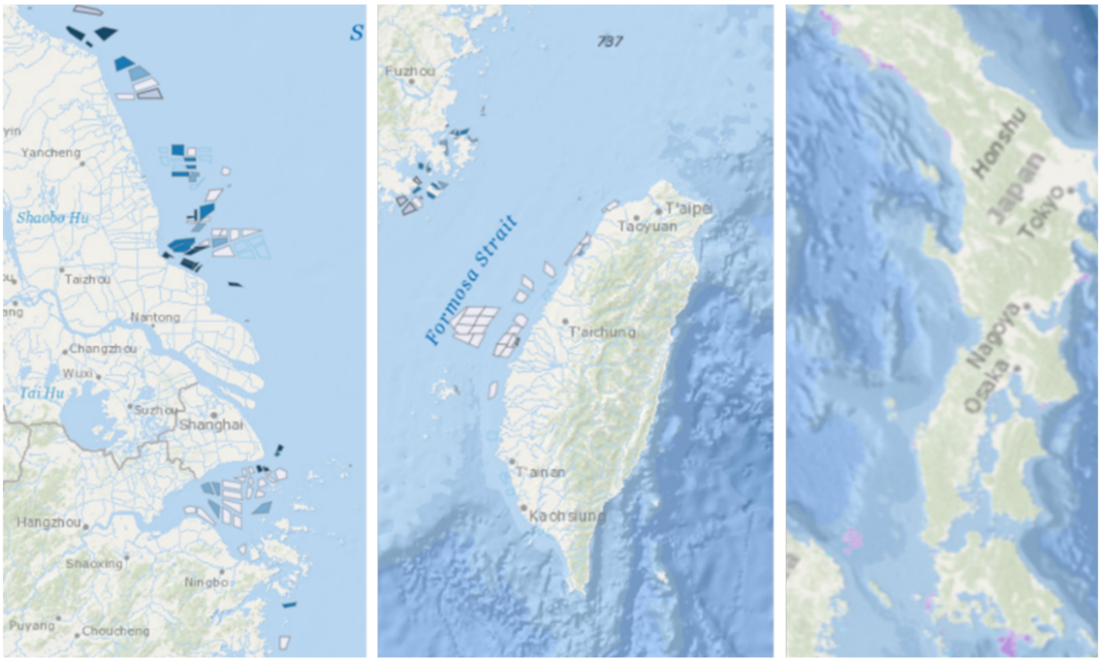
129. https://www.terma.com/markets/ground/wind-farms/radar-mitigation/
130. https://www.saab.com/newsroom/stories/2021/november/securing-the-worlds-largest-offshore-windfarm-with-giraffe-1x

Figure 5.11. **WTG development in size, Stiesdal and Ørsted**



It seems there is a resistance in certain areas of the armed forces to accept that the battlespace changes to accommodate the expanding offshore developments. '*The general fear of degradation of situational awareness is a major concern and the primary obstacle*', has been expressed by military representatives. It is therefore important to gather evidence and a scientific foundation with which resistance can be overcome and change the legacy thinking into looking at what sort of opportunities the offshore developments bring to the future battlespace. Secondly, it is a fact that the strategic context in which our armed forces operate changes regionally and globally (**Figure 5.12**) and it is therefore not a choice between rejecting or approving the developments but more a choice of how the armed forces may utilise the opportunities that arise.

Figure 5.12. Far East developments, www.4coffshore.com



In many cases, the new offshore renewable energy installations will represent part of national critical infrastructure according to a generally agreed definition of critical infrastructure[131]. However, the identification of EU/national critical infrastructure has allegedly occurred too late to allow knowledge, solutions, and the supply chain to develop and mature. Once critical infrastructure is identified, certain mandatory requirements will be enforced on the developer. The infrastructure then must meet specific obligations aimed at enhancing their resilience to threats. The barrier therefore consists of late implementation of mitigative strategies that then become either very expensive, time consuming, uncertain, or worse delays the overall timeline. It is particularly the uncertainty in the approval process which constitutes the challenges for the developers.

5.12. Identify key stakeholders

In this section the study addresses key stakeholders who are in this context defined as a person, corporation, governmental institution, etc., with the interest and capability to influence, mitigate or create barriers but also that encompasses information relevant to the study. The identified key stakeholders are representative of relevant stakeholder groups and the list is thus not exhaustive but can be used as a type indicator beacon for future work and studies. A selection of stakeholders below has been contacted and requested to provide input for empirical data for this study, however the number of responses has not been overwhelmingly satisfactory. **A future study should focus on gaining leverage and response from such stakeholders**. There is a majority of stakeholders from Northern Europe, mainly due to Denmark and Germany being the frontrunners of the outbuild of offshore wind in EU.

131. Critical infrastructure is defined by any system which is essential for providing vital economic and social functions e.g., energy. Council Directive 2008/114/EC *'critical infrastructure' means an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions.*

The key stakeholders fall within 4 sectors:

1. Governmental and civil community.
2. Defence community.
3. International and national organisations.
4. Private sector.

Table 5.1. Governmental and civil community

Governmental and civil community (indicative list)		
Name	**Function**	**Comment**
Ministry of Defence (MoD)	The Ministry of Defence is the Government ministry responsible for all defence related matters.	It is the MoD that during a hearing on the development of offshore renewables makes the assessment whether a future development will have an impact on national security, impact military use of areas such as training or live firing areas or if a development will impact air, sea or subsurface situational awareness.
Danish Ministry for Climate, Energy and Utilities	The Danish Ministry of Climate, Energy and Utilities is responsible for national and international efforts to prevent climate change.	The ministry is the governing body for the Energy Agency. (https://en.kefm.dk/) The governing body for the German BSH is the Bundesministerium für Wirtschaft und Energie
The Danish Energy Agency[132]	The Danish Energy Agency is responsible for tasks linked to energy production, supply and consumption, as well as Danish efforts to reduce carbon emissions. The Agency is also responsible for supporting the economical optimisation of utilities that in addition to energy includes water, waste and telecommunication.	The Danish Energy Agency serves as a one-stop-shop for the project developer to being provided with the required three licenses (https://ens.dk/en) All EU Member States have a similar governmental entity who on behalf of the central government permits the developer to build offshore renewables. The agencies of the two key markets, France and Germany, are: • Commission de régulation de l'énergie – CRE (France). • Bundesamt für Seeschifffahrt und Hydrographie – BSH (Germany).
Energinet (Denmark)	Energinet is an independent public enterprise owned by the Danish Ministry of Climate, Energy and Utilities. They own, operate and develop the transmission systems for electricity and natural gas in Denmark.	In the EU, the transmission systems are divided by region and owned by either public, private or, joint organisations (https://en.energinet.dk/). In Germany the four transmission system operators (TSOs) plan and maintain Germany's ultra-high voltage grid and regulate grid operations. These are TenneT, 50 Hertz, Amprion and, Transnet BW. Each single company equals that of the Danish Energinet.
Maritime Coast Guard Agencies	These agencies have the responsibilities for the civilian use of the maritime domain and are the authority on search and rescue, maritime demarcation, maritime traffic routes and certification to ships and seafarers etc.	In some EU countries the coast guard duties are handled by the Navy, but in other countries these duties are handled by a separate entity: https://www.kustbevakningen.se/en/

132. www.ens.dk accessed 2021-10-09.

5.12.1. Governmental and civil community

The civil community consists of governmental entities/authorities, such as ministries of energy, finance and environment and affiliated governmental agencies below. **Table 5.1** includes entities which are specific to the EU Member States or have members coming from the EU Member States.

5.12.2. Defence industry community

The defence industry community is a broad variety of privately held companies, organisations, and suppliers to the various armed forces of sensors and equipment. Below is mainly an abstract of relevant companies, but it is known that the first three have actively been engaged in dialogue with the offshore wind industry about mitigation solutions for co-existence between armed forces and offshore wind farms (**Table 5.2**).

Table 5.2. Defence community

Defence industry community (indicative entities)		
Name	**Function**	Comment
SAAB	SAAB is a Swedish aerospace and defence company delivering defence solutions, sensors and weapon systems for all warfare domains. https://www.saab.com/.	In 2021, SAAB supported offshore wind developer Ørsted with their Giraffe 1X 3D radar. The radar was extensively tested in the world's largest offshore wind farm Hornsea 01 located 150km east of UK in the North Sea.
Terma	Terma A/S is a Danish defence and aerospace manufacturer for both civilian and military applications. https://www.terma.com/.	In 2020, Terma supported offshore wind developer Ørsted with their Scanter 4002 2D radar. The radar was extensively tested in the world's largest offshore wind farm Hornsea 01 located 150km east of UK in the North Sea. https://www.terma.com/markets/ground/wind-farms/radar-mitigation/. Terma also delivers Obstruction Light Control solutions using their radars. Lights from turbines are necessary for safety when planes fly over turbines. With Obstruction Light Control, the strong lights are only active when a plane is near. https://www.terma.com/markets/ground/wind-farms/.
Thales	Thales Group is a French multinational company that designs and builds electrical systems and provides services for the aerospace, defence, transportation and security markets.	Thales has been involved in testing their radars on offshore wind farms and is in addition delivering maintenance solutions to the offshore wind industry. https://www.thalesgroup.com/en/united-kingdom/news/meet-robot-team-will-be-vital-future-offshore-wind-and-net-zero.
Naval Team Denmark	Naval Team Denmark (NTD) is an export association with close ties to the Royal Danish Navy.	NTD has strategic insight and knowledge into the maritime domain and military vessels and technologies applied in the offshore wind domain.

Raytheon Technologies	Raytheon Technologies Corporation is an American multinational aerospace and defence conglomerate headquartered in Waltham, Massachusetts. It is one of the largest aerospace, intelligence services providers, and defence manufacturers in the world by revenue and market capitalisation.	Raytheon Technologies Corporation is an aerospace and defence company that provides advanced systems and services for commercial, military and government customers worldwide. With four industry-leading businesses – Collins Aerospace, Pratt & Whitney, Raytheon Intelligence & Space and Raytheon Missiles & Defence – the company delivers solutions that push the boundaries in avionics, cybersecurity, directed energy, electric propulsion, hypersonics, and quantum physics. The company formed in 2020 through the combination of Raytheon Company and the United Technologies Corporation aerospace businesses. https://www.rtx.com/.
Lockheed Martin	Lockheed Martin Corporation is an American aerospace, arms, defence, information security, and technology corporation with worldwide interests. It was formed by the merger of Lockheed Corporation with Martin Marietta in March 1995. It is headquartered in North Bethesda, Maryland, in the Washington, D.C., area.	Lockheed Martin Rotary and Mission Systems (RMS) delivers mission first innovation across its portfolio of rotorcraft technology, sensors, radar systems, command and control, combat simulation and training, advanced cybersecurity and undersea systems. https://www.lockheedmartin.com/en-us/who-we-are/business-areas/rotary-and-mission-systems.html.
Hensoldt	Hensoldt develops and manufactures radar systems for the purposes of surveillance, reconnaissance, air traffic control and air defence. These radars are used on such platforms as the Eurofighter, the German Navy's F125 frigates and the US Navy's littoral combat ships and ground-based systems.	Since 1955, HENSOLDT and its predecessor companies have been on the forefront of the development and production of radar systems. Significant R&D resources ensure the continuous development of radar solutions and technologies in the various domains to solve the challenges posed by a modern radar development. https://www.hensoldt.net/.

Table 5.3 is an overview of some of the international and national organisations that have influence across Europe on legislation and defence initiatives.

Table 5.3. International organisations

EU institutions and bodies and international organisations (indicative list)		
Name	**Function**	**Comment**
European Commission **Directorate-General for Energy – DG ENER** **and** **DG for Maritime Affairs and Fisheries – DG MARE** **and** **DG for Environment – DG ENV**	This Commission department is responsible for the EU's energy policy: secure, sustainable, and competitively priced energy for Europe.	DG ENER develops and carries out the Commission's policies on energy, i.e.: • Renewable energy. • Energy efficiency. • Energy Buildings Performance. • Energy data and analysis. • Law. • Policies. • Funding and grants. • Tenders and contracts. • Consultations. • Research. https://ec.europa.eu/info/departments/energy_en DG MARE works to: • Ensure that the ocean resources are used sustainably and that coastal communities and the fishing sector have a prosperous future. • Promote maritime policies and stimulate a sustainable blue economy. • Promote ocean governance at international level. Maritime Affairs and Fisheries | European Commission (europa.eu) https://ec.europa.eu/info/departments/environment_en DG ENV develops and carries out the Commission's policies on environment. Part of their responsibity is the strategy setting and building processes for international cooperation i.e. the Regional Sea Conventions through implementation of the Marine Directive.
EDA	The European Defence Agency was established under a Joint Action of the Council of Ministers on 12 July, 2004, "to support the Member States and the Council in their effort to improve European defence capabilities in the field of crisis management and to sustain the European Security and Defence Policy as it stands now and develops in the future". All EU Member States participate in the agency, except Denmark, which has opted out of the CFSP.	The European Defence Agency, within the overall mission set out in the before-mentioned Council decision, has three main missions: • supporting the development of defence capabilities and military cooperation among the European Union Member States. • stimulating defence Research and Technology (R&T) • strengthening the European defence industry. • acting as a military interface to EU policies. EDA acts as a catalyst, promotes collaborations, launches new initiatives and introduces solutions to improve defence capabilities. It is the place where Member States willing to develop capabilities in cooperation do so. It is also a key facilitator in developing the capabilities necessary to underpin the Common Security and Defence Policy of the Union. https://eda.europa.eu/.

European Network of Transmission System Operators **ENTSO-E**	ENTSO-E, is the association for the cooperation of the European transmission system operators (TSOs). The 39 member TSOs representing 35 countries are responsible for the secure and coordinated operation of Europe's electricity system, the largest interconnected electrical grid in the world.	ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the security of the interconnected power system in all time frames at pan-European level and the optimal functioning and development of the European interconnected electricity markets, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies. ENTSO-E Mission Statement (entsoe.eu)
International Energy Agency **IEA**	The International Energy Agency works with countries around the world to shape energy policies for a secure and sustainable future.	The International Energy Agency is a Paris-based autonomous intergovernmental organisation established in the framework of the Organisation for Economic Co-operation and Development in 1974 in the wake of the 1973 oil crisis. https://www.iea.org/.
International Renewable Energy Agency **IRENA**	The International Renewable Energy Agency (IRENA) is an intergovernmental organisation supporting countries in their transition to a sustainable energy.	The International Renewable Energy Agency is mandated to facilitate cooperation, advance knowledge, and promote the adoption and sustainable use of renewable energy. https://www.irena.org/.
NATO	The North Atlantic Treaty Organisation (NATO), also called the North Atlantic Alliance, is an intergovernmental military alliance between 28 European countries and 2 North American countries.	NATO constitutes a system of collective security, whereby its independent Member States agree to mutual defence in response to an attack by any external party. https://www.nato.int/.
Wind Europe	Wind Europe, formerly the European Wind Energy Association, is an association based in Brussels, promoting the use of wind power in Europe with more than 400 members from across the whole value chain of wind energy: wind turbine manufacturers, component suppliers, power utilities and wind farm developers, financial institutions, research institutes and national wind energy associations.	Wind Europe is the voice of the wind industry, actively promoting wind energy across Europe. Wind Europe actively coordinates international policy, communications, research and analysis. Wind Europe analyses, formulates and establishes policy positions for the wind industry on key strategic sectoral issues, cooperating with industry and research institutions on a number of market development and technology research projects. Additionally, the lobbying activities undertaken by Wind Europe help create a suitable legal framework within which members can successfully develop their businesses. https://windeurope.org/.
Eurocontrol	The European Organisation for the Safety of Air Navigation, commonly known as Eurocontrol, is an international organisation working to achieve safe and seamless air traffic management across Europe. Founded in 1960, Eurocontrol currently has 41 Member States and is headquartered in Brussels, Belgium.	Eurocontrol supports the Member States and stakeholders (including air navigation service providers, civil and military airspace users, airports and aircraft/equipment manufacturers) in a joint effort to make aviation in Europe safer, more efficient, more cost-effective and with a minimal environmental impact. Civilian air traffic control (ATC) is an important stakeholder for offshore wind developers both as users of the air-space with helicopters and drones, but also for the forecasted 250–300-meter tip height of the offshore wind turbines to co-exist in the airspace along with the potential interference to ATC radars and airport approaches. https://www.eurocontrol.int/.

5.12.3. Private sector

The list of private sector developers is not exhaustive; however **Table 5.4** represents some of the major offshore wind developers in the world presently and are a mix of Utilities and Oil & Gas majors that is turning their attention to the emerging market of offshore wind.

Table 5.4. Private sector

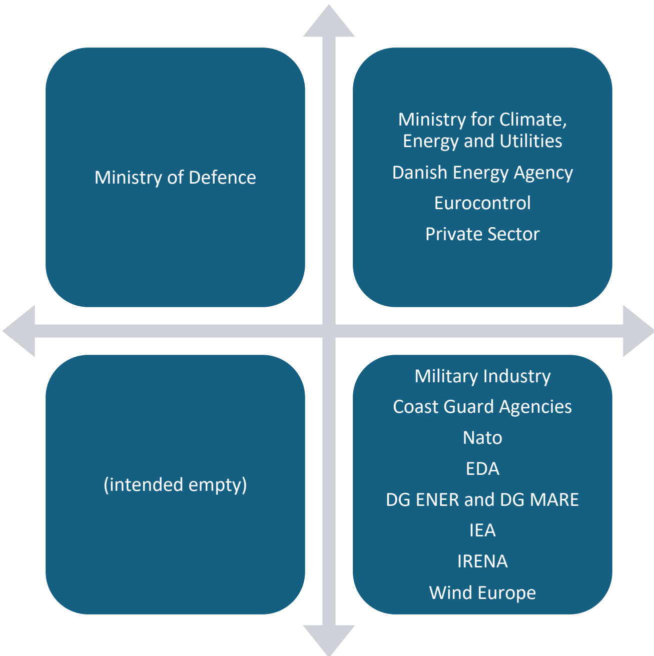
Private sector (indicative list)		
Name	**Function**	**Comment**
Ørsted	Ørsted is the world leading developer of offshore wind. Ørsted used to be one of the most coal-intensive companies in Europe, responsible for one-third of Denmark's total carbon emissions. In 2008, Ørsted embarked on a green business transformation. As a result, today, Ørsted is ranked the world's most sustainable energy company, almost all of its profit coming from renewable energy, and is on track to be carbon neutral by 2025.	The Ørsted vision is a world that runs entirely on green energy. Ørsted develops, constructs, and operates offshore and onshore wind farms, solar farms, energy storage facilities, and bioenergy plants, and provides energy products to its customers. Ørsted ranks as the world's most sustainable energy company in Corporate Knights' 2021 index of the Global 100 most sustainable corporations in the world and is recognised on the CDP Climate Change A List as a global leader on climate action. Headquartered in Denmark, Ørsted employs 6,311 people. https://orsted.com/.
Vattenfall	Vattenfall is a Swedish multinational power company owned by the Swedish state and is a developer of offshore wind.	Vattenfall is one of Europe's largest producers and retailers of electricity and heat. Vattenfall's main markets are Sweden, Germany, the Netherlands, Denmark, and the UK. The Vattenfall Group has approximately 20,000 employees. The parent company, Vattenfall AB, is 100% owned by the Swedish state, and its headquarters are in Solna, Sweden. https://group.vattenfall.com/who-we-are.
Shell	Shell is building an integrated power business to provide customers with low carbon and renewable energy solutions. The business spans trading, generation and supply and offers integrated energy solutions – from hydrogen, to solar, wind and electric vehicle charging – at scale, while using nature and technology to capture emissions from hard-to-abate sectors of the energy system.	Shell is working to provide more renewable and low-carbon energy options for customers through investments in wind, solar, electric vehicle charging, hydrogen, and more. Shell are increasingly involved in renewable development. Shell is part owner of the Borsele III/IV offshore wind farms and have recently with partners won 2GW of floating wind in the ScotWind auction. https://www.shell.com/energy-and-innovation/new-energies.html.
Equinor Offshore Wind	Equinor is a global offshore wind major and the world's leading floating offshore wind developer, being the only company in the world with a running commercial floating park and another under construction.	Equinor (former Statoil) have cemented their place as an offshore developer by developing Dogger Bank offshore wind farm (once commissioned they become the world's biggest development with 3.6GW nominal power. https://www.equinor.com/.
SSE	SSE Renewables provides energy needed today and is building a better world of energy for tomorrow through the world class operation, development and construction of renewable energy assets.	SSE Renewables is a renewable energy subsidiary of SSE plc, which develops and operates onshore and offshore wind farms and hydroelectric generation in the United Kingdom and Ireland. https://www.sserenewables.com/.

It is emphasised that the stakeholder tables do not include all stakeholders which should be addressed in developing strategies. The lists, where a specific agency is named i.e., specific to the country obviously would have a similar stakeholder in other relevant EU Member States.

5.12.4. Proposed stakeholder strategies

To address, approach, or engage with the above identified stakeholders it is suggested that stakeholder strategies are developed based on the categorisation of these. There are various models for categorisation, however, most of the models encompass an appreciation of their needs, expectations, interests, and potential impact their engagement may cause. **Figure 5.13** presents a proposed categorisation of the **identified stakeholders** according to their **level of concern** (**interest, x-axis**) and their **level of ability** to impact the **barriers/risk** relevant for the study (**y-axis**).

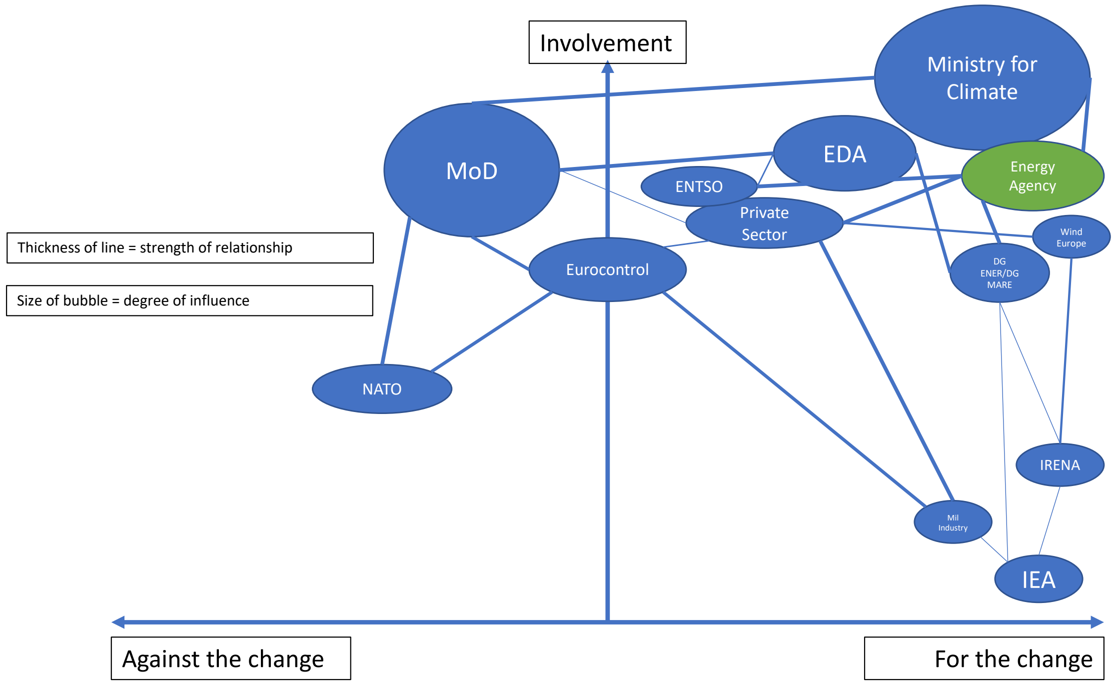
Figure 5.13. Stakeholder categorisation, Y-axis (impact), X-axis (interest), created by author



A well-designed stakeholder strategy brings key benefits to the originator (e.g., EDA) such as actionable plans for effectively interacting with the stakeholders. The stakeholders' objectives are important input in such strategy development as conflicting or opposing objectives may hinder engagement by or involvement of the stakeholders. Hence the developed strategies must ensure taking into account the stakeholders' perception of the situation, agenda, or wanted outcome.

Similarly, to **Figure 5.14**, stakeholders should also be mapped according to disposition to change. In this case the 'change' is creating mitigation strategies toward the identified risks and barriers to offshore renewable developments. The stakeholders are categorised **for and against change (x-axis)** and **involvement (y-axis)** and this model includes network mapping. It is worth mentioning that the above stakeholder maps are subjective and only represent one view and particularly the relationship assessments are based on the author's perception and not specific experiences. Such an analysis shall be developed to create strategies preparing formal and informal engagements. The analysis in its present form does indicate a general positive disposition toward change that includes finding solutions to the identified barriers and risks, creating the appropriate framework for development, etc.

Figure 5.14. Stakeholder mapping according to disposition to change, created by author based on Sherer and Palazzo, 2011



5.13. Recommendations and way ahead

5.13.1. Proposed study, test, simulation, and evaluation programme

The largest barrier to constructive/sustainable coexistence between offshore renewable energy and defence is the **fundamental lack of evidence-based knowledge on the impact of offshore renewable energy on defence systems** (sensors, radars, communications, weapons, etc). Understanding the impact is not expected to be sufficient to secure coexistence, as some significant impacts are expected. Further evidence-based knowledge is therefore needed on solutions to mitigate the impact as well as providing credible protection of the renewable energy assets and transmission system from hybrid and armed threats.

The lack of knowledge regarding defence systems performance and offshore renewable energy is evident thus supporting strategic management of the coexistence between offshore renewable energy and defence allowing timely transformation of the European energy system in accordance with EU and national policies and legislation is required. The lack of knowledge on impact and solutions argues for **an urgent need to provide a simulation environment and/or knowledge database to support the relevant EU Member States in identifying feasible areas for offshore renewable energy and support identification and implementation of coexistence solutions.**

The knowledge building could be done by individual EU Member States, developers and/or industry, but it could also be performed as a cross national/regional European initiative with the opportunity to reduce cost, facilitate cross border/regional knowledge sharing in the interest of accelerating the implementation of European and national energy plans. This section provides an outline of activities that EDA potentially should lead to secure evidence-based knowledge that will be available to guide European policy making and national authorities, MoDs and developers with timely implementation of European and national energy plans. The section also includes a recommended outline of a programme to support development of a radar and radio simulation environment.

5.13.2. Aim and objectives

The proposed combined programme is to provide knowledge and solutions for co-existence between offshore renewable energy and defence interests, which aims at supporting defence decisionmakers in understanding the impact on the ability to protect their respective nations, critical infrastructure and conduct military operations in offshore renewable energy rich environment.

It is recognised that Member States have different focusses and priorities within the domains of safety, security, defence, and power projection, and it is therefore essential to establish an overview and alignment of the first focus areas to secure support from members. Below are listed some main domains where the interests of the EU Member States require identification and mapping:

- Marine traffic safety, search and rescue.
- Border control and security.
- Critical infrastructure security.
- National defence and security.
- EU defence and security.
- Expeditionary warfare and power projection.

5.13.3. Negative impact on the permanent installed surveillance and communication systems

Some technical desktop studies have been carried out on how wind turbines interfere with air and sea surveillance radars. However, only limited physical trials and testing has been conducted offshore. Also, very limited evidence exists regarding the impact on other types of sensors and communication systems. It therefore becomes difficult to assess the impact wind turbines have on the military capability and discussions are often subjective and based on limited observational experience. The maturity of the knowledge required to secure (develop, finalise) co-existence solutions to preserve situational awareness, control and communications capabilities is insufficient. It is therefore proposed to:

- Conduct studies on non-radar systems and radar systems to establish overview and baseline.
- Conduct trials to establish evidence.
- Develop a simulation programme to provide Member States, project developers and system suppliers with a standardised means to understand the impact on specific sensors and performance of mitigation solutions.
- Conduct concept and requirement development to guide authorities and industry.

5.13.4. Negative impact on platform-based sensors and communication systems

Evidence through studies exists on civil marine radars. However, there is a very limited or no knowledge regarding the impact on military systems. This hinders correct impact assessment to military capability. The maturity of co-existence solutions to preserve situational awareness, control and communications capability is insufficient as is the ability to fight and win. It is therefore proposed to:

- Conduct studies to establish overview and baseline.
- Conduct trials to establish evidence.
- Conduct concept and requirement development to guide authorities and industry.

Negative impact on weapon systems

There is very limited or no knowledge regarding impact on weapon systems which hampers a correct impact assessment to military capability. The maturity of co-existence solutions to preserve situational awareness, control and communications capability is insufficient as is the ability to fight and win. It is therefore proposed to:

- Conduct studies to establish overview and baseline on the weapon system sensors.
- Conduct trials to establish evidence.
- Conduct concept and requirement development to guide authorities and industry.

5.13.5. Hampering the effective training and exercises including live firing

Offshore wind and other offshore renewable installations are fast becoming a significant part of the marine and land-based battlespace. None the less there is very limited knowledge on doctrine and training enabling military units to preserve situational awareness, control and communications capability and the ability to exploit fight and win in this new wind farm infested battlespace. There is a lack of knowledge in the armed forces on how to train in densely populated wind turbine areas, or 'designed' wind turbine sites. It is therefore proposed to:

- Conduct studies to establish overview and baseline.
- Conduct trials to establish evidence.
- Conduct concept and requirement development to guide authorities and industry.

5.13.6. Increased demand for protecting the offshore energy infrastructure

The definition of national critical infrastructure is very broad (not to mention the EU criteria for critical infrastructure). Work on scenario building on threats is very limited and centred on a few entities. Also, the understanding and knowledge of concepts and solutions to secure and protect are insufficient. It is therefore proposed to:

- Analyse how Member States interpret National Critical Infrastructure (NCI) with particular focus on critical energy infrastructure (CEI).
- Analyse how the EU interprets EU critical infrastructure and NCI.
- Develop scenario to mitigate possible threats against CEI.
- Explore with EU options to develop protection concepts.

5.13.7. Implementation of route to market

Regulatory and legislation mapping on how Member States (MoDs) and the EU interprets the militarisation of the EEZ is unclarified. The military industry is ready (and understands the urgency). It is therefore proposed to ***conduct national and EU level desktop and field studies – face-to-face stakeholder engagement in the EU Member States.***

5.13.8. Benefits of trials

In many of the above proposed actions contain trials/trialling. There is a general lack of knowledge and certainty as to how different defence systems are impacted by offshore renewable installations. Therefore, trials are an inevitable part of the solution to minimise the gap in knowledge. The lack of knowledge leads to a high uncertainty from armed forces on how the offshore renewable development is impacting current capability, which leaves the armed forces with no other option than to be conservative and potentially opposing proposed offshore developments. The lack of knowledge also means that possible mitigation solutions for co-existence may not be accepted. The lack of realistic simulation of trials means in practical terms that the effect of a given mitigation concept and specific system deployment can only be assessed and finally accepted when the deployment is fully constructed and commissioned. The situation is that either the MoD must accept a risk toward the ability to defend the nation or the developer has to accept the risk that the development cannot be operated freely; however, the developer could face curtailments if the specific co-existence solution does not perform as assumed.

Conducting trials with sensor, communication and weapon systems will create a fundamental knowledge base on the performance of the present systems to the benefit of short term offshore renewable developments. The knowledge base can also support identification of system capacity gaps that can be addressed by the defence industry in relation to development of required capacities.

5.13.9. Simulation model program

The broader and more scientific knowledge levels derived from trials could form the basis for development of a simulation environment, where renewable development can be assessed against present defence systems, but also support defence industry simulation of system performance against the offshore renewable development.

Investing in simulation environment would support:

I. The process of predicting the expected impact of offshore renewable developments on defence systems and related capabilities.
II. The process of estimating the effectiveness of possible mitigation/co-existence concepts.
III. The process of developing defence systems in accordance with required performance in an offshore renewable environment.

Trials are expensive and include a significant number of considerations and specifications to secure the required confidence in data recording and assessment. Conducting trials at an EDA or regional level can reduce costs and allow for a transparent design, planning, data recording and assessment, hence create greater confidence in the process by all stakeholders.

Developing simulation tools/models and environments is a considerable task for one country/region and this would naturally only support the specific need of that country/region. EDA could front such an initiative to the benefit of cost reduction, utilisation of limited resources and creating cross border/regional confidence to specific offshore renewable developments, which also often are related to cross border impacts and interests.

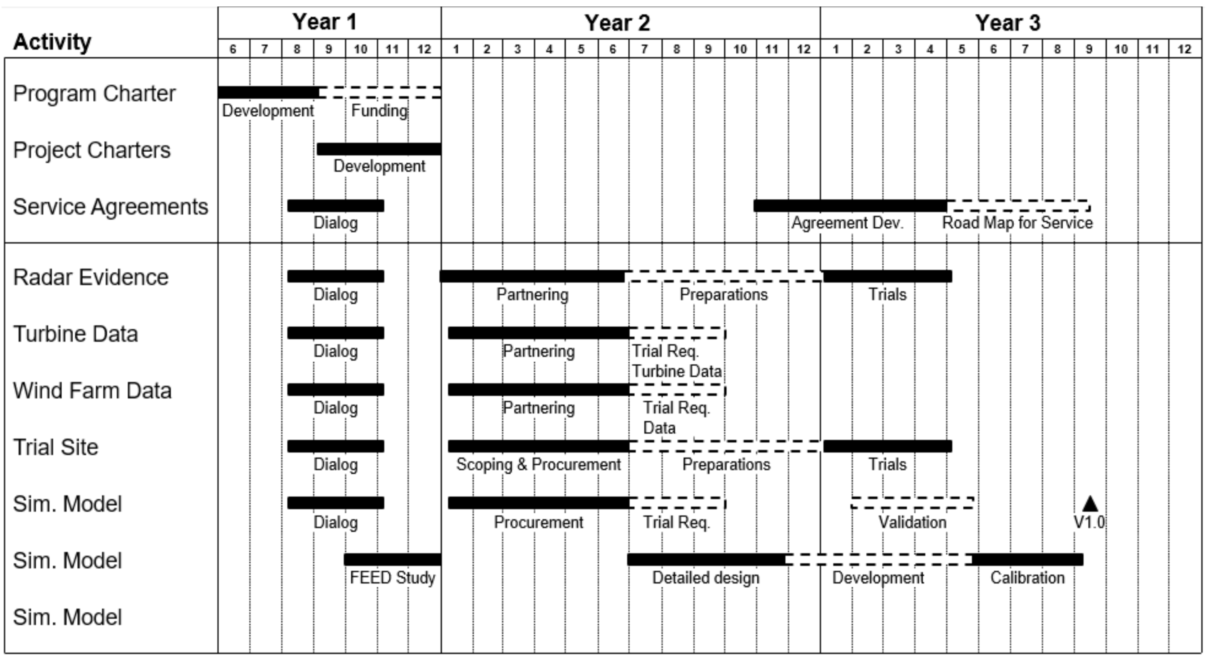
The simulation environment would allow a hypothetic offshore windfarm to be created with specific turbine choice and layout in a generic location. Weather scenarios can then be applied impacting wind turbine direction, rotation speed, angle of blades together with environmental factors such as sea direction and size, rain, snow, and other radar/radio relevant parameters. Creating the basic windfarm environment requires cooperation with wind turbine manufacturers to understand the 3D shape of turbines, behaviour in relation to weather and control conditions (operating, idling, stopped, etc.). It also requires cooperation with developers to understand weather data and layout options to covered. Turbine-specific data and weather data are very commercially sensitive and can only be shared in a classified/confidential and energy industry neutral environment.

Building the knowledge of how radar (including weapon fitted, surveillance and target acquisition radars), radio (including the wider band of frequencies required for communications, i.e., voice and data), and weapon systems in general are being reflected and impacted by wind turbines requires access to detailed trial data from trials conducted by relevant system providers. Such data are again very commercially and nationally sensitive and can only be shared in a classified/confidential and defence industry neutral environment.

It can be expected that development and calibration of a simulation environment will involve tailored trials to investigate different frequency levels and pulse types of interaction with wind turbines under different weather conditions. Development and use of the simulation environment are expected to be closely linked to conducting structured and standardised trials in wind farm rich environments, with locations feasible for conducting longer periods of live trialling. The NATO C3A initiative within Command, Control and Communication simulation could be investigated for deriving knowledge and synergies.

To sum up, the overall goal of developing trial programmes, executing trials, creating the simulation tools is to develop consensus amongst all stakeholders enabling risk mitigation, remove barriers, and minimise uncertainty in the offshore renewable development and operations phase, thus enable investments, potentially a faster consenting phase to the benefit of moving toward carbon neutrality. **Figure 5.15** presents a high-level outline of a possible EDA-led simulation programme.

Figure 5.15. Author created schedule for possible EDA led simulation programme



The purpose of the simulation programme depicted in Figure 5.14, is explained above however split into years:

Year 1: Ideation and Framing Phase. EDA should seek dialogue with stakeholder to determine interest, level of knowledge, requirement for knowledge and begin to frame future partnering and trial composition.

Year 2: Partnering. In this phase EDA enter into partnerships with WTG OEMs, developers, system suppliers and possibly other agencies with interests into the outcome of the trials and simulations.

Year 3: Execution phase. In year 3 the physical trials are execution, data is collected and developed into simulation models and validated.

5.14. Key take-aways

1. The EU and its Member States have set ambitious offshore renewable energy generation targets. This is creating a sense of urgency not only at political level but also amongst the developers to understand, plan and budget for the governance regimes required to develop offshore renewables in the maritime domain.
2. The populations expect their governments, and the EU to accelerate the fight against climate change including through, e.g., offshore renewable energy generation.
3. The strategic context is changing not only because of traditional changes in the security environment, but offshore renewable developments increasingly interfere and change the context across the maritime warfare domains.
4. The MoDs and armed forces are generally in favour of collaborating with developers and other parties and seeking solutions. The will, to co-exist is there, but not necessarily the understanding of how to co-exist.
5. There is a knowledge gap which needs to be addressed particularly regarding evidence-based data on the impact and opportunities of offshore renewable energy on defence installations, sensors, training, and operations.

Conclusions

The study set out to identify risks and barriers to develop offshore renewable and explaining these from the perspective of the armed forces and that of the developers. The feedback provided by both groups of stakeholders and documented in the study shows a solid and purpose driven engagement which can be positively used to achieve significant progress when developing methods and strategies to minimise the negative impact and identify new opportunities that offshore renewables can have on defence in terms of preserving the nations' defence capability and security in terms of protecting, e.g., critical infrastructure.

The study provides a non-exhaustive list of stakeholders and stakeholder types who should be visited and approached to support further knowledge creation supporting the achievement of a carbon-neutral society as defined by the EU without compromising the defence capabilities of the Member States. The study includes examples of stakeholder management strategies where EDA can choose the preferred option. The list of stakeholders must be further developed in collaboration with the Member States, potentially via the members of the Consultation Forum for Sustainable Energy in the Defence and Security Sectors (CF SEDSS) or other appropriate EDA formats.

The relevance of the study is confirmed by highlighting and evidencing the knowledge gap between the offshore renewable industry and the defence community which constitutes a barrier in its own right. This is exemplified by the defence communities sole focus on the impact and degradation to their environment rather than also broaden the perspective and seek opportunities and advantages of the changing battlefield. The reference list identifies several sources which may be further explored.

Finally, the study set out to establish and propose further workstreams which may be included in the EDA's future work, e.g., identifying further defence requirements and contributions and/or establish frameworks and fora where the communities can meet and accelerate the development of offshore renewable. It may be concluded based on the findings of the study that the EU Member States and the EU itself have set ambitious renewable energy goals in terms of how many GW installed capacity they want to achieve as well as the more general goal of obtaining a carbon-neutral society or zero greenhouse gas emissions. However, by expressing these clear goals and targets, it is evident that the societies, the organisations, the authorities, the businesses are facing a massive challenge that has not fully been addressed and pose significant barriers. Combined with the evidence from science on climate change (outside the scope of this study) the task is not about whether or not to buy-in to the ambitious renewable goals, but about how we can ensure a process across the EU Member States which will enable us to overcome the challenges and achieve the targets for both the renewable agenda but also satisfying the defence needs.

The study identifies some imminent risks and barriers which must be mitigated and overcome to facilitate the increased demand and time restraints of developing offshore renewables. The risks are present in the traditional warfare domains of air, surface and subsurface. Offshore renewable developments in each domain represent their own risks to armed forces' sensors and their ability to train and operate. The study indicates however that there might also be opportunities across all air and marine warfare domains that could be exploited and harvested.

Combined with the new strategic context as outlined in the study the armed forces are challenged on many levels, e.g., legacy thinking, rapid changes, application of doctrines/concepts, training requirements, sensors' capability, political pressure, etc. Ensuring that the armed forces are able to perform their main responsibility and task to protect the nation, it can be concluded that the MoDs must be included as early as possible in the planning process of offshore renewables and this is fortunately also the case in many countries, if not all. The level of participation, contributions and requirements of the armed forces should however be further defined and barriers of confidentiality and single-minded focus on the degradation rather than opportunities offshore renewables have on the sensors and battlespace should be properly addressed.

The defence industry is expressing motivation to collaborate (through participation in physical trials) and some of these trials have brought a deeper understanding of the opportunities the changed environment present. Onshore, the norm is having radar systems installed to mitigate the negative impact of structures including but not limited to WTGs, and the planning processes are clearly outlined in national and local regulations. It may therefore be concluded that the combination of identified motivation and knowledge sharing (from onshore to offshore) positively could contribute to the build of knowledge within the area.

A potential shortage of sea space has been identified and the inevitable conclusion to this is increased and smarter planning. This obviously involves not only the armed forces but all users of the sea. The MoDs in their planning contribution should identify areas where no barriers are imposed and areas where conditions are expected including a catalogue of options to meet or mitigate these conditions. This would contribute to accelerate developing offshore renewable energy as uncertainties are removed from project planning.

Offshore renewable developers express that during consultations with stakeholders from the armed forces it is a high concern that the armed forces lack knowledge of the impact of possible mitigation solutions (mitigate impact to sensors and systems and weapon engagement effectiveness) and that legacy thinking and a reluctance towards potential mitigation strategies and opportunities that could ensure sustainable co-existence between offshore renewables and armed forces is often preventing dialogue resulting in rejection from the armed forces and frustration of the developers. It is obvious this miscommunication and discrepancy hampers the development process and roll-out of the EU's ambitious renewable goals. In this context it is concluded that further collaboration is required potentially at all levels. The study provides examples of how such an increased collaboration could be implemented. It is evident that the task of gathering enough credible evidence and data is massive thus it may be concluded that not a single Member State, developer, or MoD should engage alone in such an endeavour however, an organisation, e.g., **EDA could step forward and on behalf of the many, commence the undertaking of securing the evidence-based knowledge for it to become available to guide European policy making and national authorities, defence, and developers with timely implementation of European and national energy plans.**

It is evident that the EU Member States have different focusses and priorities within the fields of safety, security, defence, and power projection and it can therefore be concluded that it is appropriate to establish an overview mapping; ensure alignment and secure support from the Member States. The main domains of interest are:

- Marine traffic.
- Marine safety, search, and rescue.
- Marine environment protection.
- Border control and security.
- Critical infrastructure security.
- National defence and security.
- EU/Alliance defence and security.
- Expeditionary warfare and power projection.

Again, it may be concluded that establishing such an overview of priorities and alignment between these stakeholders is not an easy task thus making **EDA a natural organisation to undertake the task on behalf of the Member States**.

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MoDs: Finland, France, Germany, Greece, Ireland, Latvia, Portugal, Slovenia, and Spain

Developers: Vattenfall, RWE, and Orsted

Authorities: Danish Energy Agency.

The '*Coexistance*' workshop was held in the Orsted offices in London on 1st October 2021 and facilitated by the Author. Participants from Orsted, RWE, Vattenfall and SSE.

EUROPEAN DEFENCE AGENCY | European Defence Energy Network

CF SEDSS III
Consultation Forum for
Sustainable Energy in the Defence
and Security Sector

6. New defence disciplines to increase energy security through life cycle assessment and material flow analysis

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Abstract

The defence sector can have a significant energy and environmental impact, both through its operational activities and its supply chain. Some of the main impacts in the defence sector include greenhouse gasses emissions, noise pollution, chemical and hazardous waste, habitat destruction, water pollution, end of life items/equipment, textiles, etc. The defence sector must be aware of its energy and environmental impact and work to minimise it through sustainable practices and technologies. Using life cycle assessment (LCA), the defence sector should assess its impact of a product or process throughout its entire life cycle, from raw material extraction to disposal as well as to minimise its energy consumption contribution at the same time to the European Green Deal and Circular Economy strategies. In addition, the defence sector needs to quantify the inputs and outputs of its processes to monitor activities in order to reduce CO_2 emissions, waste accumulation, improve end of life management of discarded and bulky items and other impacts. This could be achieved through a detail material flow analysis (MFA) which will include data collection, data analysis, and interpretation.

Executive summary

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 circular economy initiatives,** to address emerging and future requirements. The **goal** is to provide **recommendations for EU defence decisionmakers 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* (European Union External Action, 2022), to address the links between defence and climate change. The key **objectives** of the study are the assessment of the environmental impact of the defence sector through LCA and MFA approach in the EU Member States MoDs.

This will be achieved through the following approach:

(i). Survey monkey audit which will be designed and send with the help of EDA to all the EU MoDs in order to identify:
- The level of knowledge about LCA and MFA in defence sector.
- If and where any defence sectors apply LCA and MFA and for which purpose.
- The level of environmental and energy impact of the defence sector.
- Strengths, weaknesses, opportunities and threats linked with the harmonisation of LCA and MFA implementation in the defence sector, as well as any gaps and potential obstacles and barriers to achieve an adequate monitoring and assessment strategy concerning environmental and energy impacts.

(ii). The development of a methodology to collect data from several sectors and to be used in LCA and MFA (Life Cycle Inventory Questionnaire).

(iii). Illustrative example of how LCA and MFA could monitor and control environmental impact and energy impact in the defence sector (e.g LCA of Budling office and/or MFA of Food and Beverage sector).

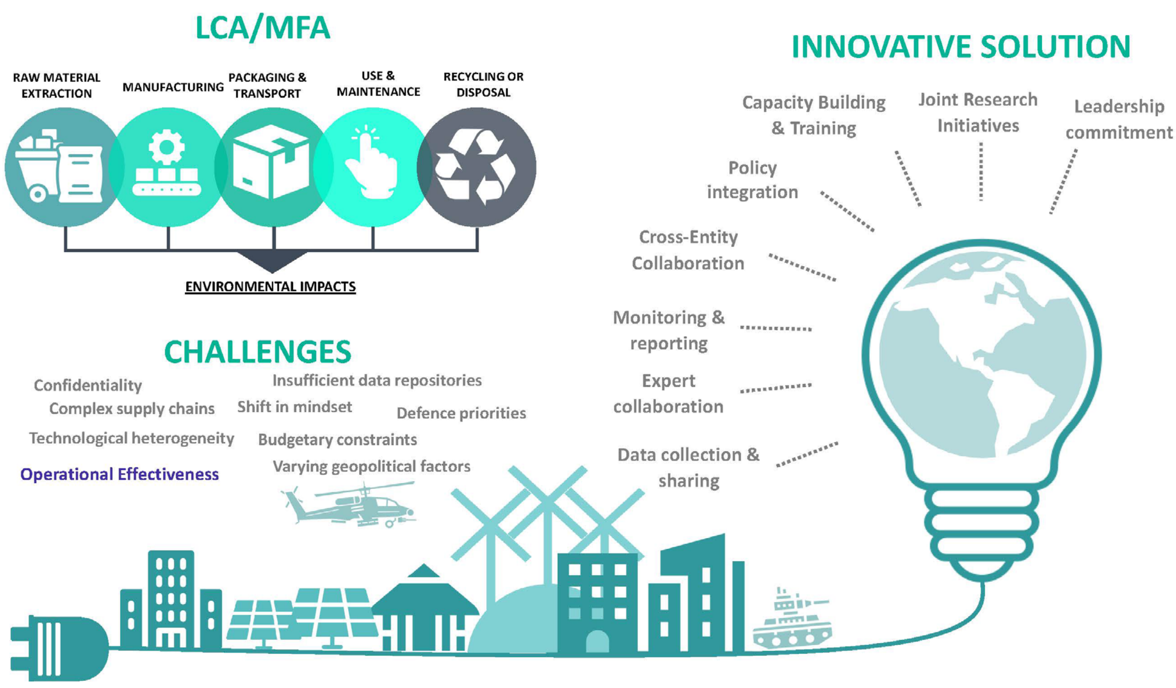
(iv). Define a list of educational material and develop new disciplines to help applying the LCA and MFA in the defence sector (a first-level educational material). A new curriculum will be designed and will include (a) syllabus (b) learning outcomes (c) references (d) relevant links for additional study (e) power point presentations (f) examples (g) interactive educational activities.

(v). Methodology will include the collection of relevant data through the PRISMA statement using international scientist platform e.g Scopus, Science Direct etc. Using International platform such as STATISTA, Eurostat etc., any relevant data related with energy consumption and other impacts from the Defence sector will be collected, given that these data are available.

The final study will include relevant information about what and how LCA and MFA can be established in the defence sector. In addition, it will include the results of the survey monkey as well as will provide details on how LCA and MFA could be used in a strategic level as a tool to help defence sector to assess its environmental and energy impact and how those can be monitor considering European Green Deal. The deliverables will include educational material as well as recommendations to support future work in addressing the identified barriers.

A Graphical Abstract that described the main study idea is presented in Figure 6.1 which indicated the operation effectiveness of the defence sector to adopt LCA and MFA with in its activities.

Figure 6.1. Graphical abstract described the operation effectiveness of the defence sector to adopt LCA and MFA (Figure created by the authors – ©)



6.1. Introduction

6.1.1. Introduction to the problem

The defence sector possesses a substantial capacity of materials and carries out several operations requiring high energy demands, thus severely affecting energy usage and the environment. Energy requirements of the military and defence sector may share similarities with other industries like manufacturing, construction, and telecommunications. However, their power demands necessitate enhanced ruggedness, durability, and exceptional reliability. Power equipment must operate at peak performance in various challenging climates and harsh terrains. Moreover, they must endure prolonged usage cycles with minimal maintenance. This applies to military-grade UPS systems, rugged UPS systems, defence generators, and power supplies specifically designed for naval defence purposes (Dale Power Solution, 2022). Within the defence sector, key factors (without limitation) contributing to its impact include the emission of greenhouse gases, the generation of noise pollution, the production of chemical and hazardous waste, the destruction of habitats, the contamination of water sources, and the management of end-of-life items.

Still, the defence sector constitutes a vital and critical area for the maintenance of safety and stability throughout social and governmental structures. Therefore, the defence sector cannot escape he accelerating and devastating effects of climate change impacting all other sectors of today's economy. From direct impacts of climate hazards (i.e. droughts, wildfire, storm damage) to indirect impacts due to the dependency of the sector on vulnerable entities operating critical energy infrastructure (i.e. hydropower, overheating cabling wire damages etc.), the defence sector must increase its resilience to climate change (European Commission, 2023).

This phenomenon is not entirely novel, as evidenced by historical data. From 1980 to 2020, across the 32 countries within the European Economic Area, weather and climate-related events resulted in total economic losses ranging from 450 to 520 billion EUR. Among these, hydrological incidents such as floods constituted more than 45% of the total, while meteorological events encompassing storms, lightning, hail, and mass movements accounted for approximately one-third. In terms of climatological occurrences, heat waves contributed to over 13% of the cumulative losses. The remaining portion of about 8% was attributed to droughts, forest fires, and cold waves combined. Notable among the most financially impactful events from 1980 to 2021 were the 2021 floods in Germany and Belgium, amassing almost EUR 50 billion in damages. Other significant incidents included the 2002 flood in central Europe (costing over EUR 22 billion), the 2003 EU-wide drought and heatwave (resulting in around EUR 16 billion in losses), the 1999 storm Lothar in Western Europe, and the 2000 floods in France and Italy (both exceeding EUR 13 billion), all calculated using 2021 values (Eurostat, 2022).

The energy sector, responsible for the production and distribution of energy, is exposed to various climate hazards (such as extreme weather events, droughts, heat waves, changing precipitation patterns and other) as well as is the source of around three-quarters of global greenhouse gas emissions. These hazards encompass droughts that impact hydropower generation and cooling water availability for thermal power plants, as well as damage caused by wildfires and storms to overhead cabling infrastructure (World Metereological Organisation, 2022).

Concurrently, the utilisation of fossil fuels remains a component of the energy mix, rendering this sector susceptible to climate change (which encompasses approximately 40% of the world's oil and gas reserves). Such susceptibility poses risks of severe health effects and environmental degradation. Moreover, projections indicate a potential multiplication of damage to critical infrastructure within the EU by over ten-fold by the close of this century, encompassing sectors like energy and transportation. Climate change has the potential to exacerbate the global security situation, thereby increasing the demand for both humanitarian and military assistance. Specific to the defence sector, according to the data collected by the European Defence Agency, (2019) on national defence related energy data of its 22 Member States (MS) Armed Forces, three main categories of energy consumption were identified: (a) electricity, (b) heating and (c) transport. The total electricity consumption in 2016 was almost 7 million MWh while, luckily, this value decreased by 8% by 2017 (6401587 MWh). Concerning heating, almost 50% of heating/cooling was performed using natural gas and almost 20% through fuel oil, for the total consumption of 13 million and 12 million MWh in 2016 and 2017 respectively. It is estimated that, 75% of energy used for heating resulted from fuel oil and natural gas respectively, posing a potential risk of dependency on non-EU countries (EBF, 2022). A total of 18 energy sources were utilised for heating purposes, varying across different regions from 9.21% in Southern Europe to 52% in Northern Europe. Lastly, kerosine for aviation made up 63% of fuel used for transportation (for a total of almost 21 million MWh), followed by diesel (19%) (References). An amalgamation of the three categories mentioned above, gave a net energy consumption of approximately 40 million MWh for the years 2016 and 2017. According to the report, the energy consumption of the 22 Member States armed forces equals that of a smaller EU Member State.

Concerning material usage (e.g beryllium, boron, dysprosium, germanium, gold, indium, magnesium, molybdenum, neodymium, niobium, praseodymium and other REEs, samarium, tantalum, thorium, titanium, vanadium, zirconium and yttrium), industrial based necessitates specialised high-performance processed materials to manufacture defence applications are necessary (European Commission, 2016).

According to the European Commission, (2016), 47 different alloys, compounds, and composite materials (such as Carbon-epoxy fibers, carbon fibers, Kevlar, etc.) that hold significance for the European defence industry. These materials possess exceptional properties (such as high durability, lightweight, high strength, high corrosion resistance etc.) and performance levels that cannot be easily substituted by readily available alternatives. As a result, their potential supply risk is significantly higher compared to the supply risk associated with the constituent raw materials. These unique properties lie in the mechanical, physical, electronic, magnetic/electromagnetic, and chemical attributes, as well as exceptional corrosion resistance. They play a crucial role in specific defence applications for instance high-performance alloys (containing niobium, vanadium, or molybdenum) utilised in military aircraft fuselages, the use of Beryllium known for being six times lighter and stronger than steel for lightweight alloys (i.e. fighter jets, helicopters, and satellites), Titanium-based alloys allowing for specific strength and excellent corrosion resistance while weighing only half as much as steel and nickel-based superalloys (i.e. aeronautic applications), carbon fibers for military aircrafts, strategic missiles and satellites due to dimensional stability, low thermal expansion, high strength and stiffness, low density and abrasion resistance and others (European Commission, 2016). The end-of-life treatment of composites is far more difficult due to the mixed nature of their structure. Hence, it is essential to foster innovation in the realm of disposing of composite materials at the end of their lifecycle. This is necessary to align these materials with the principles of a circular economy and to encourage companies to adopt value chain strategies that prioritise the use of premium recycled materials. Simultaneously, given the apparent complexity of disposing of composite materials compared to traditional ones, ongoing efforts are required to identify substitutes for these materials in their intended applications (Chatziparaskeva et al., 2022).

6.1.2. Aim of the study

The project aims to delve into the current state of impact assessment within the defence sector through the adoption of life cycle assessment (LCA) and material flow analysis (MFA) approaches in European Union Member States (EU MS). It is imperative for the defence sector to comprehend its energy and environmental ramifications, taking strides to mitigate them through the implementation of sustainable practices and technologies. By employing LCA, the defence sector should evaluate the comprehensive impact of its products and processes, encompassing the entire life cycle from raw material extraction to disposal, while simultaneously aligning with the principles outlined in the European Green Deal and Circular Economy strategies. Furthermore, the defence sector should quantitatively assess the inputs and outputs of its operations, enabling efficient monitoring and reduction of CO_2 emissions from several activities (such as buildings, storage rooms, maintenances etc.,), waste accumulation, and enhanced management of discarded and voluminous (bulk) items (e.g furniture, construction and demolition waste), among other impacts. To achieve this, a meticulous MFA must be undertaken, entailing comprehensive data collection, analysis, and interpretation.

6.1.3. Objectives of the study

The study has the following objectives:

1. Understanding of the level of knowledge about LCA and MFA in the defence sector, in order to identify the necessary knowledge to be transferred concerning the importance of energy and material flows monitoring, as well as environmental impact of defence sector operational life cycles.
2. Identifying if initiatives have been made concerning LCA and MFA methodologies within the defence sector and where, to pinpoint gaps and data acquisition possibilities for best results, assumptions and deliverables.
3. Identifying the real level (or a better estimate) of the existing impact of the defence sector onto the environment.
4. Identify strengths, weaknesses, opportunities, and threats linked with the harmonisation of LCA and MFA implementation in the defence sector, as well as any gaps and potential obstacles and barriers to achieve an adequate monitoring and assessment strategy concerning environmental and energy impacts.
5. Provide pathways and examples of how LCA and MFA can be used to monitor and mitigate environmental impacts and energy impacts of the defence sector.
6. Training of staff, necessary and/or interested parties on new disciplines for applying LCA and MFA in the defence sector.

6.1.4. Conceptual approach to the defence sector

The conceptual approach of this study has been to promote the dissemination of relevant information regarding LCA and MFA in the defence field, making the necessary tools and processes available to assess their environmental and energy impact. Hence, a specific methodology was designed, which has already been extensively detailed throughout this document, consisting of the following steps:

- **Select relevant information.** Determining which information, within the current development trends in LCA and MFA, is most relevant and applicable to the defence domain. For this purpose, several sources of information were taken into consideration, including (but not limited to) material of the EU MoDs, made publicly available on their websites, materials already published by EDA in the context of CF's activities or EnE CapTech's activities and state of the art concepts obtained among EU Tools for Innovation and Monitoring. Furthermore, using PRISMA statement (Preferred Reporting Items for Systematic Reviews) and Meta-Analysis (www.prisma-statement.org) several relevant papers and research related with LCA and MFA in the defence sector were extract.
- **Collection of relevant information** through a questionnaire. The objective of the questionnaire was to gather defence LCA and MFA information and data publicly available to enable EDA to realise the level of the implementation of LCA/MFA in defence activities as well as how one can use LCA/MFA to assess the environmental impact of the institution, organisation or structure as well as their energy impact. The questionnaire (see section 4 Methodology) was sent to all EU defence agencies through the support of EDA and the results were analysed.
- **Development of educational material** that offers information on LCA and MFA to the defence sector. The platform, which has already been developed and is currently stored on ISDEFE local servers, has been made available on the EDA website through the ECP and presents an online profile per each MoD respectively (the platform will be published following the approval of the involved MoDs).
- **Fine-tuning.** EDA IT constantly collaborates with ISDEFE on its proposal to make the necessary adaptations, in order to upload it to the EDA servers.
- **Process the information received,** so that it fits the selected parameters of relevance. To this end, ISDEFE studied the information and presented its results to EDA during progress review meetings.
- The last phase of the study will consist of **sharing this information** with the MoDs, thus providing visibility.

6.1.5. What is LCA

Since the beginning of the 21st century, the interest in LCAs has increased strongly. This is reflected in the wider application of this methodology. In addition, the implementation of LCA is further encouraged by incorporation in recommendation authorities and the increased use of LCA on policy level (Dossche et al., 2017). For example, in this context the IPP (Integrated Product Policy) has been developed by the EU (Commission of the European Communities, 2001). During 2002, UNEP (United Nation Environment Programme) with the collaboration of SETAC (Society for Environment Toxicology and Chemistry) launched an International Life Cycle Partnership, known as Life Cycle Initiative. This partnership enables users globally to put life thanking into effective practices.

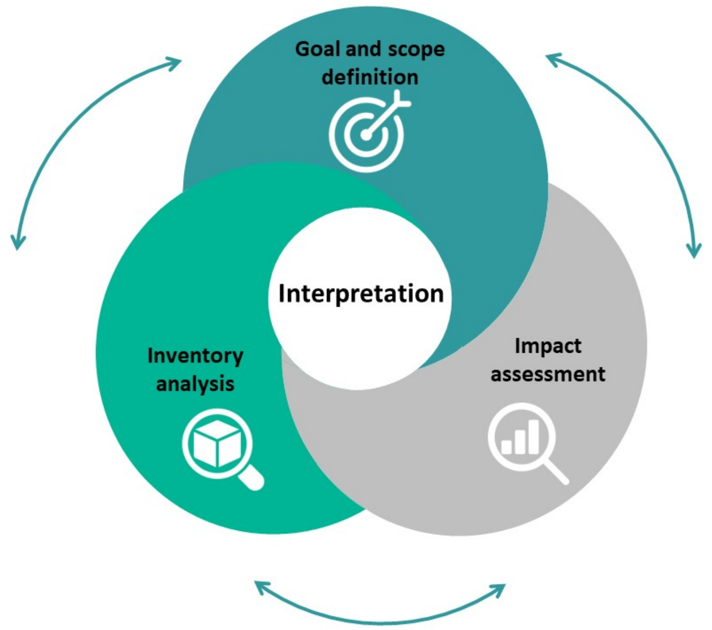
In order to keep track and monitor the environmental burdens from different systems, adequate monitoring and quantification of environmental implications is vital. Throughout the life cycle of a product, service or system, from raw material acquisition to production, end of life treatment, recycle and final disposition, LCA is a standard procedure which can address environmental and energy impacts of each process within a given system (i.e. use of resources, carbon footprint, energy demand etc). LCA has advanced rapidly over the last thirty years from a basic energy analysis to a full environmental assessment, life cycle costing, and social-LCA. More recently, life cycle sustainability analysis has been introduced, expanding the scope of investigation of environmental evaluation. LCA is directly involved in the creation and enhancement of products, planning and strategies, environmental impact assessment, environmental performance, public policy formulation and other. It has been used in the past in many different areas of environmental burdens including, but not limited to, industry, agriculture, wastewater treatment, urban planning etc (Ioannou-Ttofa et al., 2016; UNECE, 2021; Verdi et al., 2022). It has been used for the monitoring of carbon dioxide emissions, for estimating the impact of climate change of energy crops as well as for circular economy.

By conducting and LCA, different scenarios within the same system can be compared, enabling decision-makers to identify the most environmentally friendly options. LCA is an environmental analysis method that examines the total life cycle of a process, system or product spotting their potential impacts to the environment (Tsangas et al., 2020; Zorpas, 2020). It is standardised and addresses the environmental aspects from the acquisition of the raw material, through production, use, end-of-life treatment, recycling and final disposal of a product (Banti et al., 2020). The general standard in the context of LCA, ISO 14040:2006, and ISO 14044:2006 describe and specify respectively the principles and the framework as well as the requirements and the guidelines for LCA. According to ISO 14040:2006 (ISO, 2006), there are four phases (**Figure 6.2**) that should be followed for a study:

- Firstly, the goal and scope of the study must be defined including the determination of the functional unit (FU), the system boundaries and the level of the analysis. The functional unit (FU) reflects a marketable product measured and explicitly specified to allow for mathematical normalisation as well as for simpler comparison and measurement. FU should be defined very accurate since all the inputs are calculated per FU. To enable fair and equivalent comparison of two products each system should thus be composed according to the exact same FU. In the context of comparability, attention should also be given to other requirements, such as a closer look at the system boundaries and allocation principles (Dossche et al., 2017).
- The life cycle inventory (LCI): Throughout the LCI, all necessary data for the system under study are collected from all inputs and outputs life cycle. To accomplish the objectives of the particular study, LCI analysis phase entails the essential input/output of data with regard to the examined system. In this phase it is vital to work with accurate data since the accuracy of the results of the LCA strongly depends on LCI data (Dossche et al., 2017).
- The life cycle impact assessment phase (LCIA) that aims to gather information for LCI results by assessing the impacts, to identify their environmental importance. Through LCIA will evaluate potential environmental impacts and used resources based on the data of the LCI phase and depending on which impact assessment methods is used. Basically, there are two types of methods in conducting an impact assessment:

   a. The problem oriented (or midpoint) methods which are considered as a point in the cause-effect chain (environmental mechanism) of a particular impact category, prior to the end point. To nuance the midpoint results characterisation factors can be calculated to reflect the relative importance of various specific emissions or extractions in the LCI.
   b. The damage-oriented (or endpoint) methods (LCA studies that demands a combination of impact categories will often acquire endpoint approach).
- Furthermore, during the life cycle interpretation phase, the results of the inventory and impact assessment phase are summarised and discussed, and conclusions and recommendations are formed in accordance with the goal and scope. During the interpretation (fourth phase), information from the LCI analysis results is gathered for the impacts to be assessed. This phase draws conclusions and provides recommendations.

Figure 6.2. Phases to follow for an LCA based on ISO 14040 (Figure created by the authors-©)



LCA tools are widely used in wastewater treatment environmental analysis aiming to improve the environmental performance of goods and services, including products belonging to the agri-food sector (Tsangas et al., 2020), quarries (Goudouva et al., 2018; Goudouva and Zorpas, 2017) and finally they are considered as highly important tools for environmental impact assessment (Chen and Huang, 2019).

LCA has also been used to quantify the environmental impact of wastewater treatment plants (WWTPs). LCA is deemed useful in the evaluation of WWTP technologies and processes as it captures trade-offs along different categories of environmental concern (i.e. water use, energy consumption, emissions etc.). It serves as a useful decision-making support tool to examine alternative scenarios of operation alongside and during strategic planning of the wastewater sector (Corominas et al., 2020). As the defence sector may have and/or operate WWTPs, LCA is very useful to assess the impact as well as to optimise the operation of WWTPs.

In addition, LCA was widely used to measure environmental and energy impact in construction sector. As the defence sector has too many buildings to construct, manage, and maintain LCA is useful tool to realise and understand how energy and other impacts can be monitored in order to reduce GHGs. According to many researchers (Dossche et al., 2017; Tait and Cheung, 2016). The dependency of construction activities on substantial quantities of raw materials and high energy consumption is direct. Opting for materials with elevated embodied energy levels leads to initial high energy consumption during the building production phase, while also dictating future energy consumption for meeting heating, ventilation, and air conditioning needs. Within this context, buildings account for 40% of global raw material extractions, equivalent to 24% of these extractions. In the EU alone, buildings amount for 4.8 tons of mineral extractions per capita. Specifically in Spain, each square meter of habitable residence amounts for 2.3 tons of 100 different necessary materials (referring only to the materials used during the construction phase). The energy invested in manufacturing specific materials for one square meter of necessary construction materials equals the energy produced from burning over 150 liters of petrol. Each square meter constructed results in an emission of 0.5 tons of CO_2 and an energy consumption of 5754 MJ, encompassing only material-related impacts. The contribution of major building materials to primary energy demand and CO2 emissions in a Spanish standard block of flats is evident, with commonly used materials like steel, cement, and ceramics bearing a substantial impact. Structural materials often account for more than 50% of the building's embodied energy (Zabalza Bribián et al., 2011).

Furthermore, considering existing research on LCA of buildings, embodied energy in materials and LCA ranges from 9% to 46% of overall energy consumption over a building's lifetime for low energy consumption buildings, and from 2% to 38% for conventional buildings. Typically, the average lifespan of a building is 50 years, with exceptions of 30 years and longer (75 to 100 years) in some cases. Different studies indicate varying proportions for the embodied energy in materials, with energy in the usage stage generally ranging from 80% to 90%, and less than 1% allocated to energy for end-of-life treatments. These disparities arise due to diverse buildings, materials, lifespans, and geographic and climatic conditions. Varied approaches and simplifications are taken to perform LCA for building materials (Zabalza Bribián et al., 2011).

The production phase encompasses the utilisation of energy and resources to extract raw materials, transport these materials to manufacturing facilities, and ultimately create the final building products. Moving on to the construction phase, this involves transporting materials to the construction site and utilising energy to operate construction machinery, provide auxiliary construction materials, and manage the disposal of any generated construction waste. Transitioning to the utilisation phase, it entails the consequences of occupying a building throughout its lifespan. These consequences arise from lighting, heating, water consumption, as well as the use of materials for maintenance, repairs, and replacements. As for the end-of-life phase, it covers the dismantling and disposal of the building (The Carbon Leadership Forum, 2019).

The construction sector has a huge responsibility on the consumption of natural resources, on the use of energy and on the production of waste due to construction and demolition activities. Therefore, it plays a primordial role in Sustainable Development. The use of energy in buildings is usually related to the energy requirements for the heating and cooling of the building over its operation stage, usually known as operational energy. This issue had been intensively addressed over the last years and major EU directives were put into practice leading to considerable reductions in the operational energy of buildings.

The new Construction Products Regulation (CPR) provides harmonised rules for marketing construction products in the EU (Official Journal of the European Union, 2011). It requires construction products to have CE marking and a declaration of performance if they are to be placed on the market in the European Economic Area. In addition, the proposed CPR construction works must satisfy basic requirements for an economically reasonable working life as well as, an additional basic requirement on sustainability was introduced: the sustainable use of natural resources which is in line with SDG 12 (Zorpas, 2020). In this case CPR clarify that "*The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following: (a) reuse or recyclability of the construction works, their materials and parts after demolition; (b) durability of the construction works; (c) use of environmentally compatible raw and secondary materials in the construction works*."

Through LCA of buildings (European Commission et al., 2018) the efficiency use of resources in buildings is understood as a minimisation of the amount of natural resources used throughout the life cycle of the building. This entails the promotion of materials with recycled contents (input side), materials with high durability and materials with reuse and/or refurbish, and/or re-construct and/or recycling and/or material recovery potential (output side).

Considering that the defence sector has too many buildings especially for administrative purpose, those buildings require energy that will cover lighting, colling and heating. Defence sector demands for energy security. Taking this into consideration the decarbonisation of the defence building sectors may achieved through PV panes and the use of batteries for energy storage and saving. There are many studies indicated how through LCA, peripheral components for the overall environmental impacts of a home storage systems (HSS) such as batteries from Lithium, could optimised the buildings energy impacts (Jasper et al., 2022). Furthermore, there are many Governments that promotes HSS with numerous incentives. For example, in Germany a sharp increase in annually installed systems has been observed in the recent years (Kairies et al., 2019; PV magazine, 2021). At the same time also raised concerns about the environmental impacts related to the entire life cycle of these systems are expressed. Jasper et al., (2022) indicated that the total greenhouse gas emissions of the HSS are 84 g CO_2eq/KWh of electricity delivered over its lifetime in a residential PV application, or 31 g CO2eq/KWh over lifetime when excluding the use-phase impact. The peripheral components contribute between 37% and 85% to the total gross manufacturing impacts of the HSS, depending on the considered cell chemistry and the impact category. Typically, peripheral components include the battery management system, power electronics and cooling i.e., everything that is not battery cells and housing. LCA tools can optimised the operational effectiveness of the peripheral components for the entire defence building sector. In any case, through LCA, the entire battery storage system could be monitor and optimised as these systems includes (Hiremath et al., 2015; Le Varlet et al., 2020; Ryan et al., 2018).

- Battery modules (composed of battery cells, a module housing, some control electronics and optionally an active or passive cooling system).
- A system control unit (mainly active electronic components such as printed wiring board, microprocessors, and display).
- Power electronics (composed of printed wiring boards, contactors and passive electronic components).
- Thermal regulation (fans or other forced cooling).
- Housing and cabling.

6.1.6. What is MFA?

Material flow analysis (MFA) is a systematic evaluation of material flows and stocks within a defined system in both spatial and temporal dimensions. It establishes connections between the sources, pathways, and ultimate sinks of materials (Brunner and Rechberger, 2004). It refers to the monitoring and analysis of physical flows of materials into, through and out of a given system (usually the economy) and is generally based on methodically organised accounts in physical units. It analyses the relationships between material flows, including energy, human activities – including economic and trade developments – and environmental changes (OECD, 2008).

Levels of application and functions MFA can be applied to a wide range of economic, administrative or natural entities, studying the flows of materials within the global economy or within the economy of a region or a country, within a territory, a municipality or a city, within a natural unit, such as a river basin or an ecosystem, within an economic activity or an industrial unit such as a firm or a plant. At each of these levels, MFA helps understand the flows of natural resources and materials, their shifts, and their economic and environmental implications. It helps locate the sources of environmental stress, identify risks of supply disruptions, identify opportunities for efficiency and productivity gains, and formulate ways to manage, control and reduce the adverse environmental impacts of resource use. This is of value in many policy areas and business strategies, especially in a context of population growth, economic and technological changes, with pressures to use resources in a way that is both economically efficient and environmentally effective (Cui, 2022; Yang et al., 2023).

For example, MFA can be applied to understand the flow of waste materials within a Military Base waste management system. The analysis would involve quantifying the inputs of various types of waste (e.g., municipal solid waste, green waste, food waste, industrial waste, hazardous, electrical waste etc.) into the Military Base, tracking the collection and transportation of waste to different treatment facilities (e.g., recycling centers, incinerators, landfills, composting), and estimating the outputs (e.g., recycled materials, energy recovery, disposal, reused, remanufacture etc.). This analysis can help MoDs and waste managers identify opportunities to improve waste diversion rates, optimise recycling efforts, and reduce waste sent to landfills.

Another example, MFA is used to analyse the material flows within a specific maintenance process of defence vehicles. The MFA analysis would **involve tracking the input materials, such as steel, plastic, glass, and electronic components, used to assemble the vehicle.** The **output would include the number of vehicles that are ready to be used, the scrap generated, and any recycled materials used in the maintenance process.** This analysis can help identify potential material efficiency improvements, optimised the maintenance process, to adopt waste reduction strategies, and opportunities for recycling or reusing certain materials in the whole process.

An MFA study can in principle cover any possible relevant set of materials at various levels of detail, from the complete collection of all resources and products flowing through the system under analysis to groups of materials at various levels of detail and to particular products. It can also be applied to particular materials or even single chemical elements that raise specific concerns as to the sustainability of use of the original natural resource, as to the environmental implications of their use or as to their economic or trade implications (OECD, 2008).

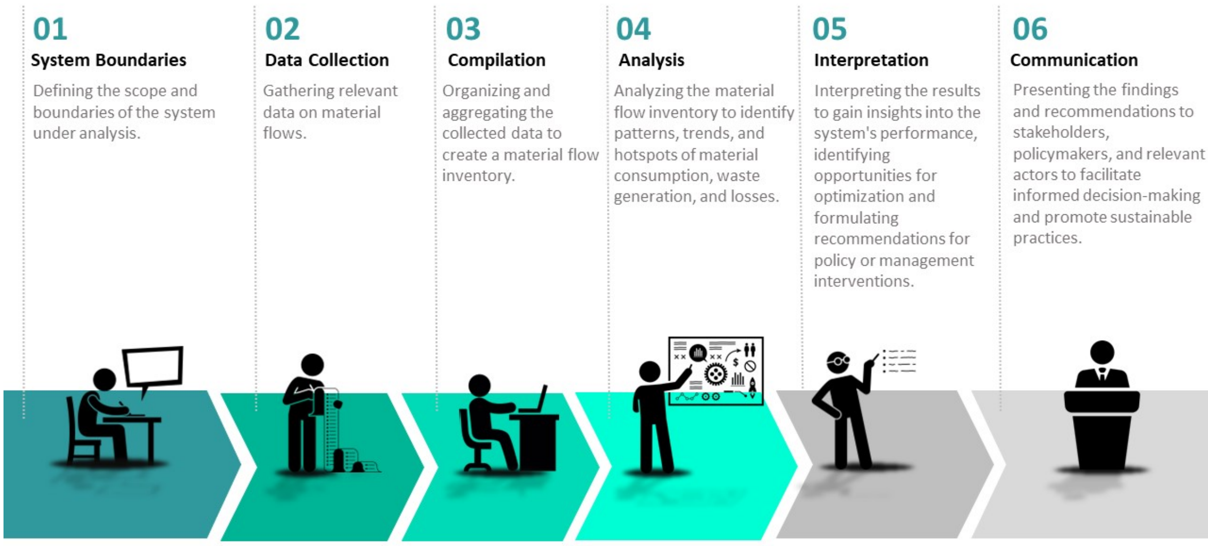
MFA operates on the principle of the conservation of matter, enabling the assessment of inputs, stocks, and outputs through a straightforward material balance. This characteristic makes MFA an appealing decision-support tool for resource management, waste management, and environmental management (Brunner and Rechberger, 2004).

The principle described above refers to mass balancing and the first law of thermodynamics. MFA uses the principle of mass balancing to study how materials and energy flow through the economy and the environment within countries and among countries. It is because raw materials, water and air are extracted from the natural system as **inputs**, transformed into products and finally re-transferred to the natural system as **outputs** (in the form of waste and emissions). **The accounting concepts involved are founded on the first law of thermodynamics** (called the law of conservation of matter), **which states that matter (mass, energy) is neither created nor destroyed by any physical process** (OECD, 2008).

MFA has been applied in various fields and sectors, including environmental management, sustainable development, waste management, industrial ecology, and resource efficiency (Corona et al., 2019; Kennedy et al., 2007; Millette et al., 2019; OECD, 2008). It has been used at different scales, ranging from local to national and global levels. The methodology of MFA typically involves (**Figure 6.3**) the following steps:

(i). **System Boundaries:** Defining the scope and boundaries of the system under analysis, very much like an LCA, including the specific materials and processes to be studied.
(ii). **Data Collection:** Gathering relevant data on material flows, such as extraction rates, production volumes, imports, exports, consumption, and waste generation.
(iii). **Compilation:** Organising and aggregating the collected data to create a material flow inventory, which quantifies the material flows within the system.
(iv). **Analysis:** Analysing the material flow inventory to identify patterns, trends, and hotspots of material consumption, waste generation, and losses. This can involve calculations of indicators like material efficiency, recycling rates, and environmental impacts.
(v). **Interpretation:** Interpreting the results to gain insights into the system's performance, identifying opportunities for optimisation, and formulating recommendations for policy or management interventions.
(vi). **Communication:** Presenting the findings and recommendations to stakeholders, policymakers, and relevant actors to facilitate informed decision-making and promote sustainable practices.

Figure 6.3. MFA methodology approach (Figure created by the authors – ©)



In addition to the previous examples some other relevant to defence sector that directly related with MFA are:

(1) Ammunition material flow analysis

In this case, MFA is used to analyse the flow of ammunition throughout the military supply chain. It involves tracking the production, procurement, distribution, and consumption of different types of ammunition used by the armed forces. The analysis would help identify inefficiencies in the supply chain, potential stockpile imbalances, and opportunities for waste reduction and recycling of certain components. It could also lead to better inventory management, ensuring an adequate supply of ammunition while minimizing excess or obsolete stockpiles.

(2) Military vehicle material flow analysis

MFA can be applied to study the material flow within the lifecycle of military vehicles, such as tanks, armoured personnel carriers, and aircraft. This analysis involves tracking the raw materials used in manufacturing, the maintenance and repair processes, and the eventual disposal or decommissioning of vehicles. By quantifying material inputs and outputs, the defence sector can identify opportunities to improve vehicle design for longevity and recyclability, optimise maintenance practices to minimise waste, and explore the potential for remanufacturing or reuse of vehicle components.

(3) Material flow analysis of military bases

MFA can be used to analyse the material flow within military bases or installations. This includes assessing the consumption of resources like fuel, water, food, and building materials. Additionally, the analysis would examine waste generation, recycling efforts, and waste disposal practices within the base. By conducting such an analysis, the defence sector can identify opportunities for resource conservation, waste reduction, and the implementation of sustainable practices in military operations.

6.2. Context

6.2.1. Study relevance to CF SEDSS III the Transversal Group

The scope of the transversal working group is specific and introduced to fill a gap between the other existing groups. The transversal group aim to enhance collaboration and address cross-cutting areas of mutual interest of the three working groups, such as the innovative energy technologies, energy-related policy and management as well as financing mechanisms and funding instruments including current and emerging opportunities.

Through the Transversal Group there are three transversal areas (**Policy and management observatory; Technology, research** and **Innovation hub** as well as **Financing and funding gateway cell**) that are strongly related with existing study:

- **Policy and management observatory:** to focus primarily on the energy management policy dimension aiming at helping the MoDs to assist the defence sector in establishing policies, strategies, processes, roadmaps, methodologies and tools to improve energy management and performance as well as cultivating green defence energy culture.
- **Provided explanation:** The adoption of LCA and MFA from the MoDs will enhance the thematic transversal area on Policy and Management as both LCA and MFA could be used to assess, improve, monitor, and validate energy management and performance by controlling any environmental impact and at the same time to cultivate greener culture and green attitude between the defence sectors.

In addition, LCA is closely related to the energy management policy dimension, as it provides valuable insights and data to support the development and implementation of energy management policies. LCA is a systematic and comprehensive approach used to evaluate the environmental impacts associated with all stages of a product or process in the defence sector.

The energy management policy dimension (That the Transversal Group is targeting) focuses on strategies and actions aimed at optimising energy use, improving energy efficiency, and reducing greenhouse gas emissions. LCA plays a crucial role in this context by providing a holistic perspective on the energy and environmental implications of various activities, products, or services that exist and applies in MoDs.

With out limitation LCA is related to the energy management policy dimension through the following activities

a. **Identifying hotspots:** LCA helps identify the stages of a product's life cycle that have the most significant energy consumption and environmental impacts. This information allows policymakers to prioritise efforts and target interventions in areas where the greatest improvements can be made.
b. **Energy efficiency assessment:** LCA assesses energy efficiency throughout the entire life cycle of a product or process, including energy inputs and outputs at each stage. Policymakers can use this data to design energy efficiency programs and set energy performance standards for the defence sector activities were applicable.
c. **Policy impact assessment:** LCA can be used to evaluate the potential impact of proposed energy management policies before implementation. Policymakers in the defence sector can simulate various scenarios and understand the likely outcomes of different policy choices on energy consumption, greenhouse gas emissions, and other environmental factors.

d. **Setting environmental targets:** LCA provides a scientific basis for setting realistic and measurable environmental targets. By understanding the life cycle energy consumption and emissions associated with different products and processes, policymakers in the defence sector can establish ambitious yet achievable goals to improve energy efficiency and reduce environmental impacts.
e. **Promoting renewable energy:** LCA can help policymakers in the defence sector to understand the comparative environmental benefits of using different energy sources (e.g., fossil fuels, renewables). It supports the development of policies that encourage the adoption of renewable energy technologies, which can lead to lower overall life cycle greenhouse gas emissions.
f. **Supporting circular economy:** LCA is indispensable for assessing the environmental implications of recycling, reusing, or remanufacturing processes. Policymakers in the defence sector can promote circular economy principles by incentivising practices that minimise energy consumption and waste generation across the product life cycle.

- **Technology, research and innovation hub:** to address issues, coordinate activities, collect best practices and raise awareness on innovative and smart energy technologies such as intelligent metering system, blockchain, artificial intelligence, digitalisation, big data, sensors, energy management networks, cybersecurity, etc.
- **Provided explanation:** The adoption of LCA and MFA from the MoDs will enhance the thematic transversal area on Technology, Research and Innovation Hub as trust build measures will be created in order to share relevant, accurate and transparent data to run LCA model between Member states. Hence, a common strategy among the member states will be established. Without limitation best practices on how MoDs already monitored and controlled environmental and energy impacts will be shared through a common platform that should be developed.

In addition, LCA may provide essential insights and data for sustainable development, informed decision-making, and promoting eco-friendly technologies. LCA may contribute to technology, research and innovation Hubs through the following channels:

a. **Sustainable technology development:** LCA is a valuable tool for assessing the environmental impacts of new technologies during their development and throughout their life cycles. Technology, Research and Innovation Hubs can use LCA to compare the environmental performance of different technologies and guide researchers in designing more sustainable solutions.
b. **Eco-design and green innovation:** LCA encourages eco-design principles, where environmental considerations are integrated into the innovation process from the outset. By evaluating the environmental impacts of different design choices, Technology, Research and Innovation Hubs can foster green innovation that minimises resource consumption, energy use, and waste generation.
c. **Policy and regulation support:** LCA provides scientific evidence to support the development of policies and regulations that promote sustainable technologies. Technology, Research and Innovation Hubs can use LCA data to advocate for the adoption of eco-friendly technologies and influence policy decisions towards more sustainable practices.
d. **Identifying research priorities:** LCA helps identify areas with the highest environmental impact within a product's life cycle. Technology, Research and Innovation Hubs can use this information to prioritise research efforts, focusing on technologies or processes that have the most significant potential for environmental improvement.
e. **Carbon footprint reduction:** LCA allows Technology, Research and Innovation Hubs to assess the carbon footprint of technologies and/or process in the defence sector. By understanding the emissions associated with different activities, researchers can implement carbon reduction strategies and contribute to climate change mitigation efforts.
f. **Circular economy advancement:** LCA supports the development of circular economy practices by evaluating the environmental benefits of recycling, remanufacturing, and reusing technologies. Technology, Research and Innovation Hubs can promote circular economy initiatives by encouraging the adoption of technologies with lower life cycle environmental impacts.

g. **Life cycle thinking integration:** LCA encourages a life cycle thinking approach, which considers the entire life cycle of products/services and technologies, from raw material extraction to end-of-life disposal. Technology, Research and Innovation Hubs can use this approach to develop holistic and sustainable solutions that address potential environmental trade-offs across the life cycle.
h. **Environmental labelling and certification:** LCA data can be used to provide environmental labelling and certification for technologies, helping MoDs Procurement office to make informed decisions about the environmental impacts of their choices. Technology, Research, and Innovation Hubs can develop certification programs based on LCA findings to promote environmentally friendly technologies.

- **Financing and funding gateway cell:** where the Agency will apply its internal methodology "IdentiFunding for Energy in Defence" to review or identify existing and new financing mechanisms or other funding instruments to support the implementation of defence-energy related topics.
- **Provided explanation:** The adoption of LCA and MFA from the MoDs will enhance the thematic transversal area on Financing and Funding Gateway Cell by providing the opportunity.

6.2.2. LCA / MFA contribution to defence environmental policy goals

The EU aims to contribute to the global effort for climate change mitigation through the reduction of greenhouse gas emissions associated with defence activities. This includes the promotion of energy efficiency, transition to low-carbon technologies and adoption of renewable energy sources in defence operations. LCA can be used to monitor and assess the environmental performance of defence systems over their operational life. By identifying areas of improvement and analysing the potential benefits of alternative technologies or practices, LCA can guide efforts toward continuous environmental improvement in the defence sector (Hermann et al., 2007; Myhre et al., 2013).

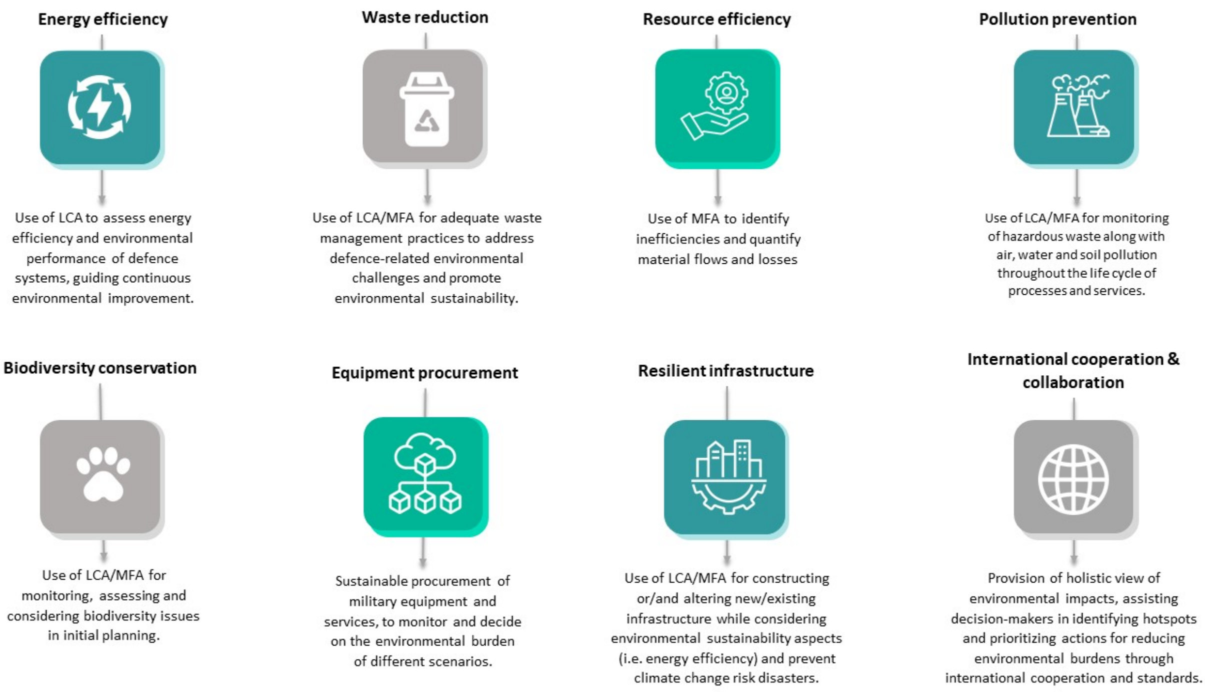
At the same time, resource efficiency is to be improved in defence systems to minimise material consumption and optimise production processes, simultaneously promoting circular economy principles when possible. This can be clearly illustrated through various policies, legislations and strategies of the EU, including but not limited to the European Green Deal, the Circular Economy Action Plan, Waste Framework Directive and other (European Commission, 2021, 2019; Official Journal of the European Union, 2008) Conclusively, this includes waste generation reduction, increase in recycling and reuse practices, as well as other circular economy practices (e.g. remanufacture, refurbish etc.) while also minimizing the use of scarce resources in defence operations. Additionally, the EU emphasises on the prevention and control of pollution (air, water, soil) arising from different sectors, including defence activities (e.g. industrial emissions directive 2010/75/EU, water policy 2000/60/EC, air quality directives and strategies etc.) (Official Journal of the European Communities, 2000; Official Journal of the European Union, 2010).

Policies aim to reduce the discharge of hazardous substances, limit water and soil contamination and promote responsible waste management practices within the defence sector. Through the use of both LCA and MFA, inefficiencies in material use within the defence sector can be identified and material flows and losses can be quantified (Zorpas, 2020). MFA specifically can be used to pinpoint areas where material consumption can be minimised, waste reduced, and recycling or reuse opportunities exploited. This can lead to improved resource efficiency and reduced environmental impacts. Interlinked with this, MFA can contribute to supply chain control, by identifying vulnerabilities and mapping material flows and dependencies. Both LCA and MFA can assist in developing effective waste management strategies within the defence sector. By monitoring and analysing material flows and waste streams, LCA and MFA can identify opportunities for waste reduction, recycling, and recovery (Corona et al., 2019).

Furthermore, the EU recognises the importance of biodiversity conservation and natural ecosystems. Defence environmental policies aim at minimizing the negative activities of the defence sector on biodiversity (e.g. habitat destruction, marine and waterborne pollution, soil toxicity etc.) by incorporating biodiversity considerations into land use planning, military training exercises and infrastructural development. Defence infrastructure and facilities are expected to be resilient to climate change impacts. As the EU encourages defence organisations to assess and adapt their infrastructure to minimise vulnerability to extreme weather events, sea-level rise, and other climate-related risks, carefully crafting and altering existing or new infrastructure must be of vital importance. LCA and MFA can be used to both monitor and analyse infrastructure as well as climate related risk scenarios, to minimise forthcoming disaster and mitigate environmental burden arising from poor architecture and insufficient environmental considerations (i.e. low energy efficiency) (Geyer et al., 2010).

At the same time, sustainable procurement practices in defence acquisitions, involves the consideration of environmental factors when selecting defence equipment and services to lower environmental impact and meet sustainability criteria. As LCA methodology is used to evaluate the environmental impacts of a product, process, or system throughout its entire life cycle, from raw material extraction to end-of-life disposal, it can provide significant aid in the procurement and design of defence equipment options. By considering aspects such as energy consumption, emissions, resource use and waste generation, LCA can help identify the most environmentally friendly options (Esteve-Turrillas and de la Guardia, 2017). Moreover, EU activities engage in international cooperation and collaboration to address defence related environmental challenges including best practices, exchange of information, harmonisation of standards promoting environmental sustainability (i.e. ISO 14001) in global defence operations (Heras-Saizarbitoria et al., 2020). Overall, key aspect when using LCA and MFA in the defence sector for the fulfilment and synchronisation of the sector with the environmental policies and strategies of the EU, is the provision of a holistic view of environmental impacts, allowing decision-makers to identify hotspots and prioritise actions for reducing environmental burdens. By quantifying the environmental benefits and trade-offs associated with different strategies, LCA can support informed decision-making in defence environmental policy (Zorpas et al., 2021) (**Figure 6.4**).

Figure 6.4. Using LCA/MFA to fulfil key goals of environmental policies in the defence sector (Figure created by the authors – ©)



6.3. Problem analysis

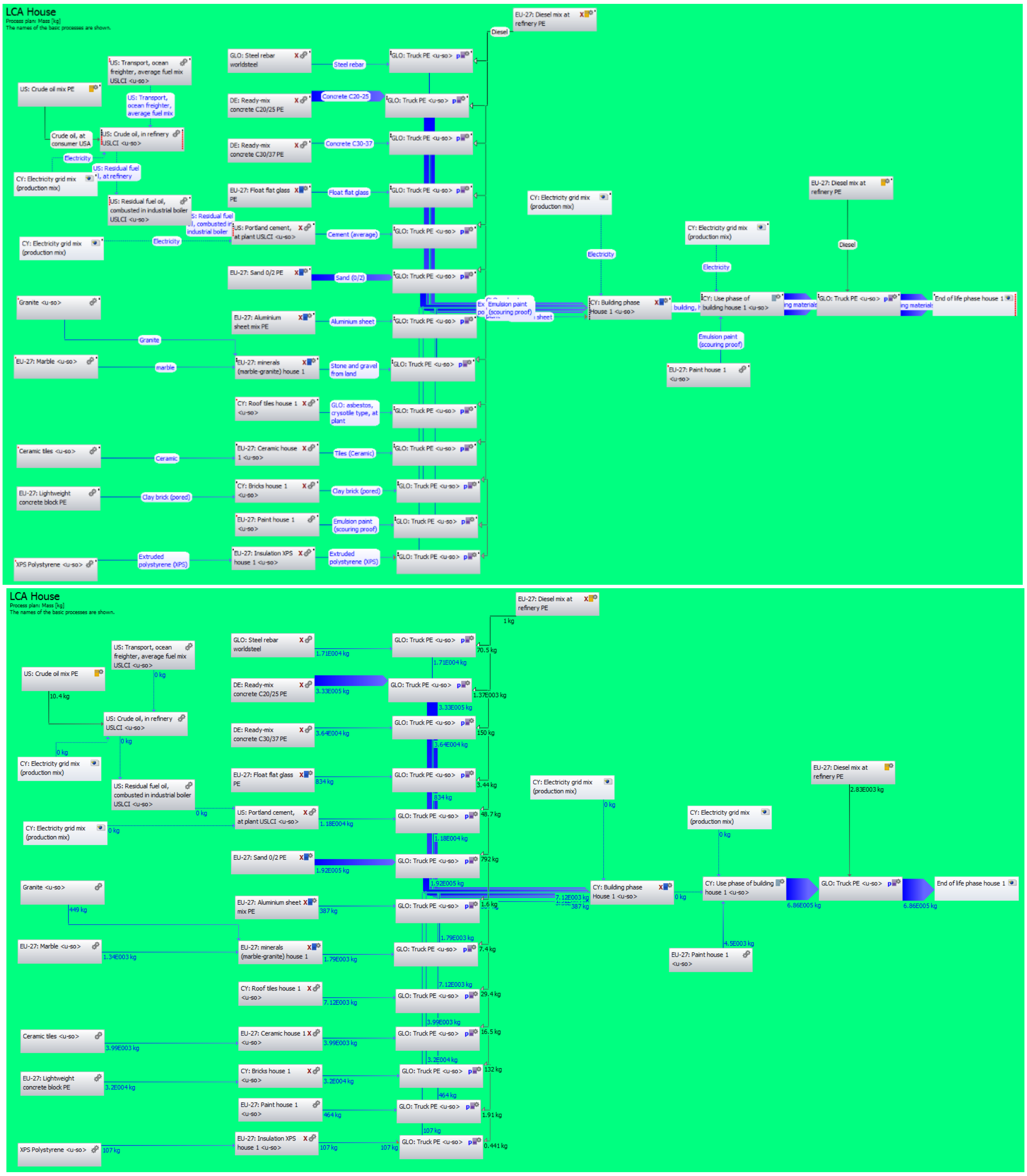
6.3.1. Gap identification

The development and implementation of a pan-European harmonised defence LCA and MFA methodologies is deemed of outpost importance for the smooth transition of the sector to a more sustainable model. However, several obstacles (such as data availability and accessibility, complexity of working system) and barriers (such as regulatory hurdles, lack of expertise, cost concerns) need to be address, concerning both direct and indirect limitations to data acquisition, prioritisation and cost efficiency (Lozano Gómez, 2022). As EU member states have different defence priorities, budgets and military-industrial complexes, harmonising LCA and MFA concepts would require aligning these diverse national interests, which may be challenging due to varying geopolitical factors and defence strategies. At the same time, there is severe lack of accurate data and transparency in the sector, both due to insufficient data repositories concerning environmental aspects but also confidentiality of data. However, conducting comprehensive LCAs and MFAs requires access to reliable data on the environmental impact and energy impact of military equipment and operations. Such data may be lacking or not readily available across EU countries while defence establishments often prioritise secrecy and national security, which can hinder the transparency needed for effective analysis (Lozano Gómez, 2022). For example, it is off important to develop a common methodology based on LCI) and/or SWOT analysis and/or multi-criteria analysis based on Analytical Hierocracy Process (AHP) in order to assess, collect, and share data between defence sectors in EU. These will help to prepare a blueprint light agreement through building trust measures between member states in order to convince defence sectors to share best practices considering the management of environmental issues (such as food waste, organic waste, fashion and textile waste, end of waste equipment, construction and demolition waste etc), energy issues arise from buildings, vehicles and other related activities. Through LCI defence sector will be able to collect relevant data helpful to run LCA and MFA. For example, **Table 1** provide the necessary information needed to assess environmental and energy impact from a defence WWTP of equivalence population of 1000 inhabitants. In addition, **Figure 5 indicates the flowchart and philosophy** of an LCA/ LCI of a building similar to any defence building. In addition, **Table 6.1** and **Figure 6.5** showcase that the related data that are needed to calculate energy impact, MFA, environmental impact cannot be in the sphere of the "Top Secret" strategy but consist of data that can be shared between MoDs to be used to assess their impact on the environment.

Table 6.1. LCI for WWTP

Element	Units per FU	WWTP
Influent	m^3	1
Bulky screen total electricity	kWh	0.0731
Screenings and floam transport	Kg*km	0.0002
Screenings and floam	L	0.01
Milling electricity	kWh	
Sand	Kg	0.026
Sand collection total electricity	kWh	0.00728
Sand	Kg	0.026
Sand transport	Kg*km	0.52
Microscreenings total electricity	kWh	
Microscreenings	Kg	
Total aeration treatment electricity	kWh	0.42048
Sludge	m^3	0.1424
Q sludge out	m^3	2.2784
Biogas	m^3	0.1008
Produced energy	kWh	0.048
Effluent	m^3	0.92
Lorry	Items	3

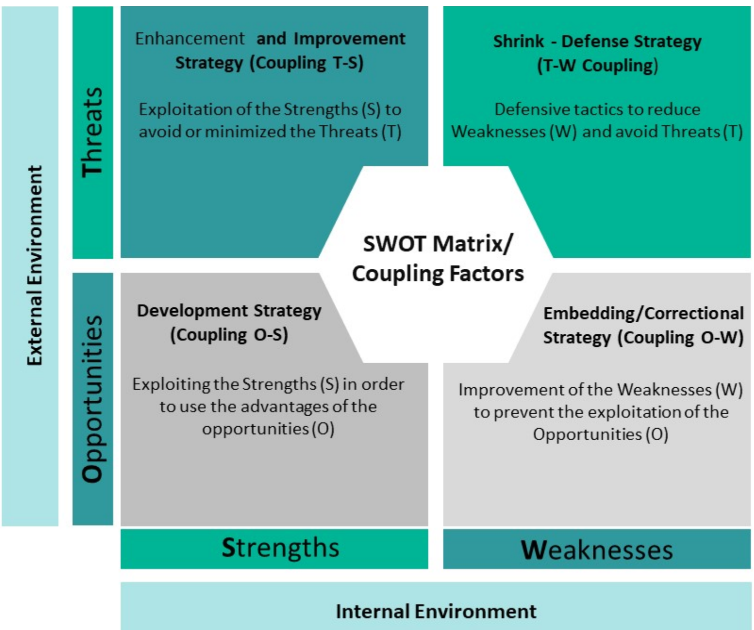
Figure 6.5. **LCI and LCA from a typical house/building may be applied to any defence building (mainly for administrative purposes. (Figure created by the authors – ©)**



6.3.2. SWOT analysis

Through the SWOT analysis which consists of a strategic approach tool that combines the strengths and weaknesses of an organisation, process, territory or sector with the study of opportunities and threats in its environment (Symeonides et al., 2019), the defence sector will be in position to decide whether the collected data create threats or benefits. SWOT analysis derives its name from the initials of the words strengths (S), weaknesses (W), opportunities (O), and threats (T). Strengths are positives and weaknesses are negatives related to the system internal aspects. Opportunities are external factors that have a positive interaction with the system and the negative effects of the system environment represent threats to the system (Srdjevic et al., 2012). According to Islam and Mamun, (2017) SWOT analysis is an effective tool, able to support policymakers in all levels. SWOT analysis is broadly used in energy planning related research. For example, Fertel et al., (2013) performed a SWOT analysis of the energy and climate policies of Canada to analyse policy coherence between federal and provincial/territorial strategies. The method has also been used in combination with PESTLE (or PESTEL i.e. Political, Economic, Social, Technical, Environmental, Legal) analysis, to analyse the possibilities and the challenges of implementing renewable energy (Islam and Mamun, 2017). The method is also applied in non-academic analysis e.g. is presented for Argentina Oil & Gas sector (BMI Research, 2017) related with energy. Many researchers (Tsangas et al., 2019; Tsangas and Zorpas, 2018a, 2018b) used SWOT analysis to assess the hydrocarbon energy sector as well as the energy resources from Cyprus Energy Sector. The interpretation of the results of the evaluation of the PESTEL – SWOT formed sustainability indicators leads to the general observation, that the hydrocarbons sector in Cyprus could be sustainably developed. An effective SWOT analysis assumes an extensive definition of the internal and external context of the examined sector. The internal and external factors should be well defined prior to the SWOT analysis. In these framework, defence sector strengths, weaknesses, opportunities and threats should be obtained by an extensive recording of the sector context. The outline of each context factor (Symeonides et al., 2019) should base on the review of primary and secondary data collected and gathered from academic literature as well as other data sources such as government, national or international organisations websites, reports etc. Review of the internal and external environment data leads to a consequent SWOT matrix. The PESTLE analysis is an analytical tool for assessing the impact of external situations on a project (Srdjevic et al., 2012; UNICEF, 2015). The method used in this study to identify S, W, O and T s by the context (Internal and External) review is briefly presented in **Figure 6.6**. For each pillar we have identified **S**trength and **W**eakness of the internal environment as well as **O**pportunity and **T**hreats for the external environment in order to acknowledge the policy and the strategy that the existing system must followed:

Figure 6.6. SWOT matrix (Figure created by the authors – ©)

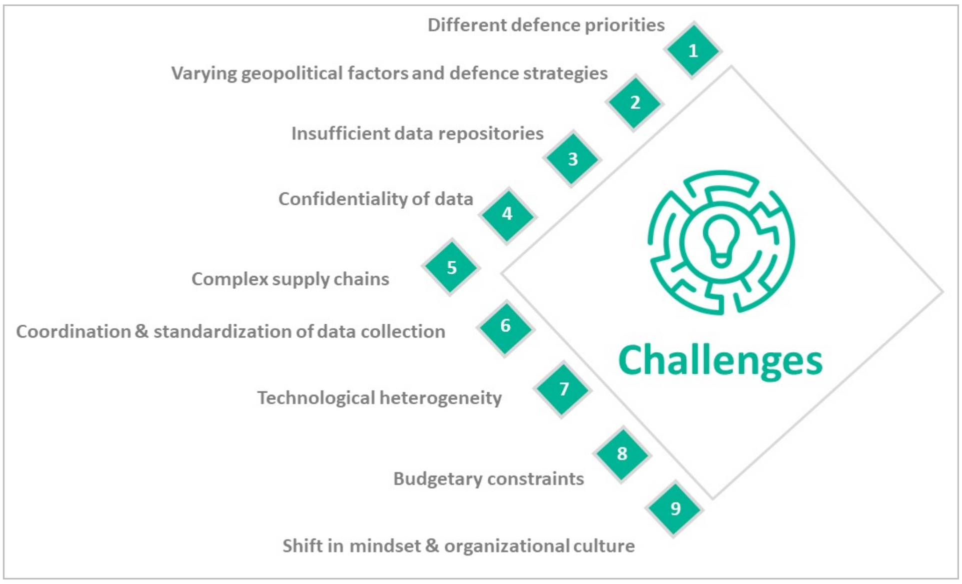


Simultaneously, defence equipment often involves complex supply chains with numerous subcontractors and suppliers. Obtaining data on materials and processes at each stage of the supply chain can be difficult, especially if there are proprietary technologies or classified information involved. Coordinating and standardising data collection across multiple stakeholders can pose a significant challenge while technological heterogeneity is a major issue that will hinder or better delay the correct monitoring and assessment through LCA and MFA. This is due to the wide range of military equipment, developed by various manufacturers and using diverse technologies. This technological heterogeneity makes it challenging to compare and evaluate environmental and energy impact consistently (Briem et al., 2019).

This heterogeneity arises due to the complex and specialised nature of defence equipment, which can encompass everything from aircraft and naval vessels to ground vehicles and electronics. Due to the vast differences between defence technologies, different environmental footprints are at hand. Assessing the environmental impact of an aircraft is in no means similar to the environmental impact of a ground vehicle in terms of functional units, system boundaries (i.e. manufacturing, operation, end-of-life) as well as the LCI. These can vary significantly due to variations in resource type and consumption, emissions and waste generation (Benitez et al., 2021; Mahashabde et al., 2011). At the same time, a possible inconsistency in data availability and accuracy for different technological equipment can lead to discontinuation in the "depth" of analysis for LCA and MFA (Weidema et al., 2013). Conducting LCA and MFA requires a significant amount of data on various inputs, processes, and outputs throughout a product's lifecycle. However, due to the classified and proprietary nature of defence technologies, obtaining accurate and comprehensive data can be challenging. Manufacturers may be hesitant to share detailed information, especially if it involves sensitive technologies. Furthermore, defence equipment often involves complex supply chains with several subcontractors and suppliers, thus making it very difficult to identify the components and environmental profile of each equipment part and the equipment. This complexity makes it difficult to track the flow of materials and energy accurately across the entire supply chain. Adding to this issue, defence equipment is often customised to meet specific military requirements which can lead to unique designs and manufacturing processes. This can lead to unique design features and manufacturing processes for each piece of equipment. Such customisation makes it harder to create standardised assessment methodologies that can be uniformly applied across different equipment types (Briem et al., 2019). This creates issues like lack of consistency in assessment as well as lack of comparability and benchmarking.

Important aspect when it comes to the crucial monitoring of environmental burdens of the sector constitutes budgetary constraints. As defence budgeting is typically allocated for military readiness and operational capacities, environmental and energy considerations are not and cannot be priority for all military units across different EU member states. It is without doubts and any limitations that defence sectors considered energy security rather than energy impacts as any defence facility should not run out of any kind of well know energy source with the fossil fuel to be upon priority (IEA, 2023). Prioritising investment in LCA and MFA initiatives may face resistance if it is perceived as diverting resources from core defence capabilities. However, adequate funding and resource allocation would be essential for successful implementation and is only achieved through substantial understanding of both long term economic and environmental benefits of such initiatives. Moreover, concerning political alignment and transnational cooperation, coordinating policies and regulations among EU member states can be a complex process. Establishing a harmonised defence LCA and MFA concept would require agreement and alignment on environmental goals, energy goals, methodologies, and implementation strategies and thus, overcoming political differences and achieving consensus could be a significant barrier. Interconnections with political alignment, cultural and organisational habits vary across different nations. By default, defence organisations have unique cultures, traditions, and operational priorities. Integrating environmental and energy considerations into their decision-making processes may require a shift in mindset and organisational culture as well as to follow and or develop other more flexible procedures. Raising awareness, building capacity, and fostering collaboration between defence entities and environmental and/or energy experts as well as with academia would be necessary.

Figure 6.7. Challenges and barriers for the smooth implementation of LCA and MFA in the defence sector (Figure created by the authors – ©)



However, achieving harmonisation across diverse defence industries, military doctrines, and procurement practices would be a considerable undertaking. It would require standardising data collection methods, assessment frameworks, and reporting formats to ensure comparability and compatibility among different countries and stakeholders. Still, addressing these obstacles would necessitate a multi-stakeholder approach involving defence ministries, research institutions, defence industries, environmental organisations, and policymakers at national and European Union levels. Strong leadership, coordination, and long-term commitment would be crucial to overcome these barriers and realise the benefits of a pan-European harmonised defence LCA and MFA concept (**Figure 6.7**).

6.3.3. Target group

When referring to mitigating climate change and promote sustainable development practices among different sector, indirect effects benefit all members of society due to the fact that, climate change and environmental performance knows no boundaries (Zorpas et al., 2021). Limiting the understanding of beneficial outcomes from optimising sustainable practices in the defence sector, is one of the main areas that need alterations in terms of mindset (Papamichael et al., 2023). However, directly affected groups of such mitigation measures and monitoring methodologies are the communities that mostly have impact, the power of decision making, and the ones directly affected by the sustainable practices monitored and analysed (**Figure 6.8**). For instance, defence Ministries and Military Organisations are responsible for military procurement, operations, and sustainability. They would benefit from the study by gaining a comprehensive understanding of the environmental and energy impact of their activities, equipment, and operations, enabling them to make informed decisions, optimise resource use, and reduce their ecological footprint. Similarly, defence Contractors and Suppliers, meaning companies involved in defence manufacturing and supply chains, could align their processes and products with harmonised LCA and MFA standards and requirements. This would enhance their competitiveness in the European defence market and enable them to demonstrate their commitment to environmental sustainability. Furthermore, policymakers on an EU and national levels would benefit from the study by obtaining evidence-based information to develop and implement policies related to defence, environment and sustainable development. It would help them align defence strategies with environmental objectives and promote harmonisation of practices across member states (European Commission, 2023; Zorpas et al., 2021).

As an important aspect of all sustainability initiatives in the EU, the employment of LCA/MFA methodologies in the defence sector can align with the markers and goals set out by the European Green Deal. Acting as the steppingstone for today's society, the European Green Deal is a comprehensive policy framework set out for climate-neutrality by 2050 by promoting sustainable growth. Using LCA/MFA can enhance environmental sustainability by monitoring and reporting on the environmental impact of defence equipment and infrastructure, from raw material extraction to disposal. By quantifying energy use and efficiency, resource consumption, emissions and waste associated with the sector, LCA can identify opportunities for environmental footprint as well as carbon emissions in time for 2050 (Christoforou et al., 2016; European Commission, 2019).

At the same time, the identification of inefficiencies in resource use can both highlight areas of improvement as well as create gateways for circular economy concepts, as needed through the Circular Economy Action Plan (CEAP) (European Commission, 2021). Bringing employed or disposed equipment back into the loop of defence infrastructure and manufacturing can be both a cost efficient and resource efficient strategy. Through the use of LCA/MFA, these opportunities can be pinpointed by analysing the entire lifecycle of defence equipment, optimised and then reverted back into the loop in a circular concept with minimum or optimal resource waste/use. Binding into this, the European Green Deal promotes the transition towards circularity, where products are designed to be durable, repairable, and recyclable. LCA can help assess the potential for extending the lifespan of defence equipment, considering factors like repairability, remanufacturing, and recycling. By designing products with circular principles in mind, the defence sector can contribute to reducing waste and promoting sustainability.

Moving out of the main area of interest, Environmental Organisations and Activists advocating for sustainability and reduction of environmental impacts will have the opportunity to obtain valuable data and insights to assess the ecological consequences of military activities and advocate for policy changes, resource optimisation, and environmentally friendly practices (such as renewable energy, sustainable buildings, recycling, remanufacturing and other). Correspondingly, researchers and academia will have a plethora of data and opportunities for further analysis, to enable for the contribution of experts in the field concerning the defence sector. This could facilitate the development and/or improvement of methodologies and technologies and best practices for LCA and MFA. Of course, as mentioned above, in a chain reaction arising from calculated moves and strategic planning, the general public and future generations will have the opportunity to reduce environmental and energy impacts of military activities and contribute to the overall sustainability efforts, preservation of ecosystems, and a healthier planet for future generations (Nita et al., 2022).

Figure 6.8. Target groups and the key benefits from LCA and MFA implementation in the defence sector (Figure created by the authors – ©)

6.3.4. State-of-the-art practices in defence

One of the biggest issues concerning the implementation of LCA/MFA in the defence sector is the substantial lack of data available regarding energy, emissions, raw material usage and waste management and or treatment (such as textile, end of life equipment, waste waters, Food Waste, demolition waste, hazardous waste, explosive waste etc.) etc. As analysed in detail in section 4 (v) below, when scanning through different research portals (e.g. SCOPUS) the available references regarding the defence sector in regard to sustainability are limited to near zero. It is at the same time a logical outcome, due to the confidentiality and "top secret" mentality of defence, hindering though the development and upgrade of the sector to a more independent and efficient powerhouse in terms of energy security and raw material usage. Big obstacle and considerable factor when considering both the release of data and the implementation of environmental strategies in the sector (e.g. Circular Economy) is the **operational effectiveness of military activities**. Such barriers, hinder the creation of an internal repository of data, along with sharing success stories and best practices amongst MoDs.

The following questions were set and discussed with the research team in order to assess and define any other obstacles and barriers regarding the existing state of the art and management practices:

- Are you familiar with the following definitions?
  - LCA.
  - MAF.
  - Circular economy.
  - European Green Deal.
  - ISO 14001 (Environmental Management System).
  - EMAS (Environmental Management Audit Scheme).
  - Sustainability (Sustainable Development).
  - SDGs (Sustainable Development Goals).
  - ESG (Environmental – Social – Government).

- What are the existing practises that are applied and used to collect data regarding any of the above?
- Did you apply LCA and/or MFA and for what proposed?
  - If yes can you share the results.
  - If yes what kind of software did you used.
  - If yes.
- Did you apply any environmental management system e.g ISO 14001 and/or EMAS and/or any other equivalent?
  - If yes which standard.
  - If yes how many years are certified.
  - If yes can you share flow chats of the proposed activity that an EMS was applied as well as quantitative data regarding the main environmental issues and impacts? (for example what kind of waste are been produced, how many waste are peen produced per year and in what quantities, how you managed those waste per category, are you established any internal management method or you are using subcontractors, how you control you energy demands and what kind or energy are you use and for what purpose).
- Do you apply any internal training programme for skills development regarding environmental education (if yes can you share some titles as well as can you share how many was participants and how often you do this training)?
- Do you do any energy audits of your buildings?
- Do you collaborate with (a) external consultant and for what purposed (b) with research institute and which (c) with university and which?
- Do you have any internal committee responsible for the Environmental and Energy Issues. (If yes can you mentioned how many are they, what are the level of their knowledge regarding energy and environmental issues as well as how often your discussing)?

However, at the end the research team of this study decided to use only the questions indicated in section 6.4 (Methodology), as they wanted to avoid and confusion in the MoDs.

6.4. Methodology

6.4.1. Addressing objectives and gap

The main objective of the proposal is to investigate the current state of defence sector impact assessment using LCA and MFA approaches in the EU MoDs. The following approach will be employed to achieve this objective:

(i) Audit

Survey Monkey platform or other similar will be used to design and export a survey with the assistance of the EDA and distributed to all EU defence sector entities. This survey will aim to identify and recruit the following data:

i. The level of knowledge about LCA and MFA within the defence sector. This will be done to identify the level of knowledge regarding, LCA, MFA, environmental performance and impact, sustainability concerns, quantification of data and other.

ii. The extent to which LCA and MFA are being applied in the defence sector and for what purposes. This will be done to establish the gap(s) in the defence sector regarding the quantification of environmental impact of processes and services. Simultaneously, this will paint a better picture for the differences between various MoDs to give both general guidelines and knowledge regarding LCA and MFA methodologies, but also personalise the transfer of knowledge to the needs of each individual ministry.

iii. The environmental and energy impacts of the defence sector. This will be crucial to recruit the necessary data for carrying out the LCA and MFA approaches. The level of detail in which these data will be provided, will be directly proportional to the level of detail and accuracy of the models. This will involve the creation of a Life Cycle Inventory Questionnaire.

iv. Strengths, weaknesses, opportunities, and threats associated with the harmonisation of LCA and MFA implementation in the defence sector, as well as any existing gaps, potential obstacles, and barriers to achieving an effective monitoring and assessment strategy for environmental and energy impacts.

Table 6.2 indicates the relevant asked questions to the MoDs in member states in order to realise the existing knowhow on LCA/MFA. The questionnaire was sent to Agencies through EDA and they were asked to provide their inputs before the end of September 2023.

Table 6.2. Relevant asked questions

	Yes	No	I don't know	If yes provide an example (100 words)
Q1: Is circular economy being applied to your agency?				
Q2: Have your agency used life cycle assessment or material flow analysis to identify energy efficiency or raw material usage?				
Q3: Please answer the following questions to the best of your knowledge:				
3.1 we know the energy impact of my agency				
3.2 we know the numerical energy impact of my agency				
3.3 we have energy impact as a priority				
3.4 we are willing to use LCA/MFA to find out and optimise energy and environmental impact and material usage of our agency				

Q2: How well do you know the following terms? Please reply using the scaling of 1 (I don't know the term at all) to 5 (I know the term very well)

	1 (I don't know the term at all)	2 (I don't know the term but I have heard of it)	3 (I have heard of the term)	4 (I know the term)	5 (I know the term in depth)
Circular Economy					
Industrial Symbiosis					
Life Cycle Assessment (LCA)					
Material Flow Analysis (MFA)					

Q3. In your opinion, please provide 3 strengths that arise from quantifying the energy impact of your agency?

Q4. In your opinion, please provide 3 weaknesses that arise from quantifying the energy impact of your agency?

Q5. Are you willing to share data to be used for LCA and/or MFA in order monitor your Energy and/or Environmental Impact?

- Yes.
- No.

(ii) Illustrative example

In order to create a common understanding and inclusivity for those players unfamiliar with the concepts of LCA and MFA, an illustrative example will be provided to demonstrate how LCA and MFA can be utilised to monitor and control environmental and energy impacts within the defence sector. For instance, a case study could involve conducting an LCA of a building office or an MFA or the Food and Beverage sector.

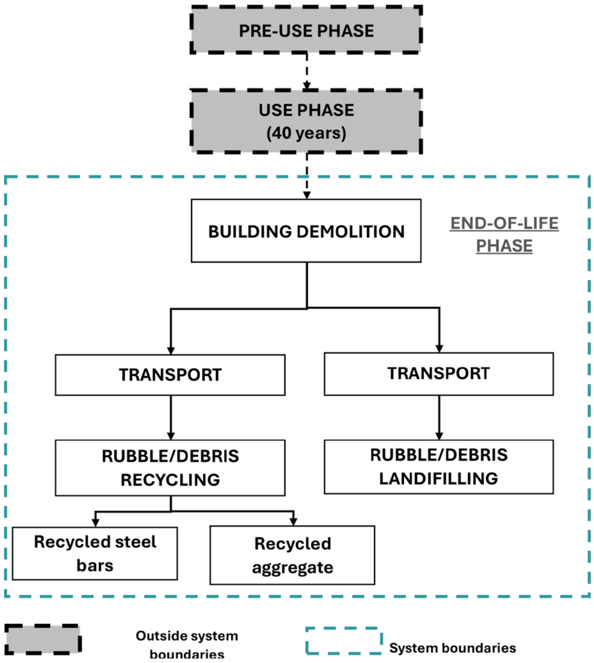
For example, a typical LCA that is directly related with defence sector activities and summarises the environmental and energy impact is the following:

For the LCA of buildings, Blengini, (2009), conducted an LCA in a residential area of Via Fratelli Garrone, Turin, Italy. The building chosen was erected in 1965 and demolished in 2004, giving it a 40 years lifetime. In this regard, the author wanted to evaluate the environmental impact of different stages in its lifecycle, from the pre-use phase (from the extraction of raw materials until the building was operational), to the operational phase (40 years of use) and the demolition. For simplicity, **only the demolition phase of the building was illustrated** and summarised below. Therefore, according to the methodology, the LCA steps defined by ISO 14040 are as follows:

Step 1. Goal and scope

The goal of the LCA was to analyse the relative contribution of the demolition phase to the overall energy consumption and environmental impacts of an existing residential block of flats, the identification of environmental impacts and benefits of demolition and rubble recycling, assessment of end-of-life scenarios and assessment of recycling potential of building materials. The functional unit (FU) used was 1 m^2 net floor area. In particular, the authors used this FU relative to one year period. The boundaries of the system as illustrated in **Figure 6.9**, including (only) the end-of-life phase (demolition, transport of waste to either recycling or landfilling, recycling, and landfilling) of the building. The impact categories chosen were Gross Energy Requirement (GER) in megajoules (MJ), Global Warming Potential (GWP) in kg CO_2(eq), Ozone Depletion Potential (ODP) in g CFC11(eq), acidification potential (AP) in mol H^+, eutrophication potential (EP) in g O_2(eq) and photochemical Ozone Creation Potential (POCP) in g C_2H_4(eq).

Figure 6.9. System boundaries of system under study (Figure created by the authors – ©)



Step 2. LCI

Th demolition of the building was performed using blasting technique by placing explosive charges on the shell basement. The transport of rubble and debris was done using a truck or train, according to the route chosen (landfilling or recycling). The data collected can be presented only nominally with units in **Table 6.3**.

Table 6.3. LCI of system under study for the demolition of the building

Operation	Units
BUILDING DEMOLITION	
Electricity (diamond wire, disk equipment)	MJ
Electricity (drilling)	kWh
Explosives	Kg
Detonating cord	Kg
Excavation	m^3
Damping heap creation	m^3
RUBBLE/DEBRIS PROCESSING	
Hydraulic hammer (secondary on site demolition)	m^3
3 Hydraulic loaders (rubble mixing, rubble loading, steel scrap loading)	m^3
Truck	Tons-km
Train	Tons-km
Jaw crusher & magnetic separator	kWh

Step 3. Impact assessment

According to the six impact categories chosen, the impact assessment of the demolition phase is presented in **Table 6.4**. For context, as the research of Blengini, (2009) included the pre-use and use phase apart from the demolition explored in this illustrative example, the results for all three phases are included.

Table 6.4. **Impact assessment for the system under study. The grey columns represent the pre-use and use phase that was excluded from this illustrative example but were included in the study of Blengini (2009). For context, they have also been provided below**

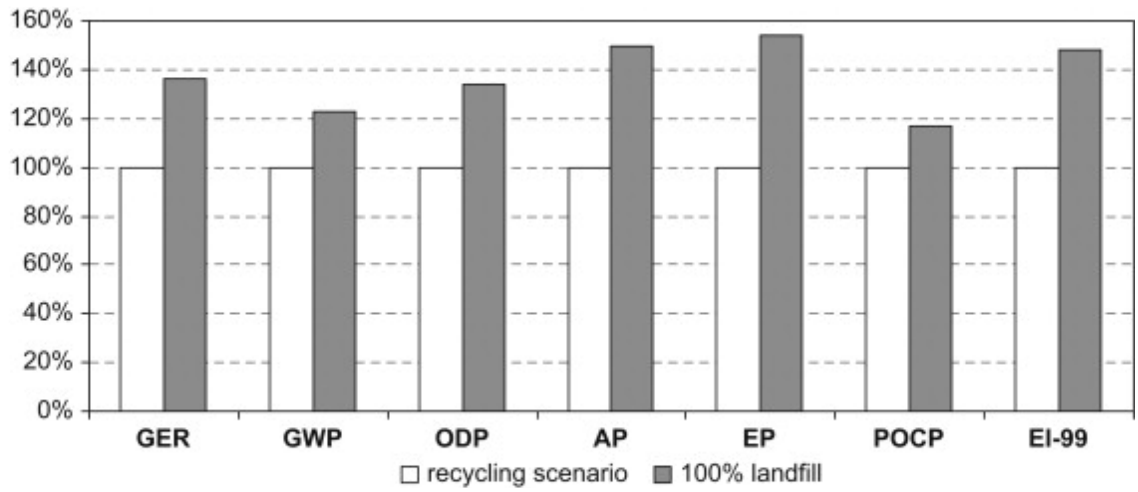
Impact category	Unit per FU (m2)	Pre-use phase	Use phase	End-of-life phase	Total life cycle
GER	MJ	90.8	928.1	-20.3	998.6
GWP	Kg CO_2(eq)	7.7	60.2	-1.1	66.8
ODP	mg CFC11	2.0	29.6	-0.3	31.3
AP	Mol H+	1.5	17.3	=0.4	19.4
EP	g O_2	215	3333	-47	3502
POCP	mg C2H4	79.2	865.6	-2.2	942.7

Step 4. Interpretation phase

It's evident that the primary contributors of significance are the materials concrete and steel reinforcement bars. Their respective proportions vary between 29.4% to 71.4% and 2.9% to 39.4%. Concrete takes the lead in terms of its impact on global warming, ozone layer depletion, eutrophication, and photo-smog. On the other hand, steel plays a central role in energy consumption and acidification (Blengini, 2009).

To gain a deeper comprehension of the scale and relative significance of effective end-of-life management for buildings, an alternative disposal scenario was examined. In this context, after employing methods such as controlled demolition and on-site size reduction, the debris was assumed to be completely deposited in landfills. The outcomes of this approach are depicted in **Figure 6.10**, with the comparison specifically focusing on the initial use and end-of-life stages. It's clear that if no recycling of debris takes place, there are no positive environmental advancements. Consequently, the potential for recycling is forfeited, leading to a rise in life cycle impacts—excluding the operational phase of the building—by percentages ranging from 17% to 54% (Blengini, 2009).

Figure 6.10. Impact analysis of the illustrative examples (Blengini, 2009)



(iii) Educational material

A list of educational materials will be compiled, and new disciplines will be developed to assist in the application of LCA and MFA in the defence sector. This educational material will be designed as a first-level resource and will include:

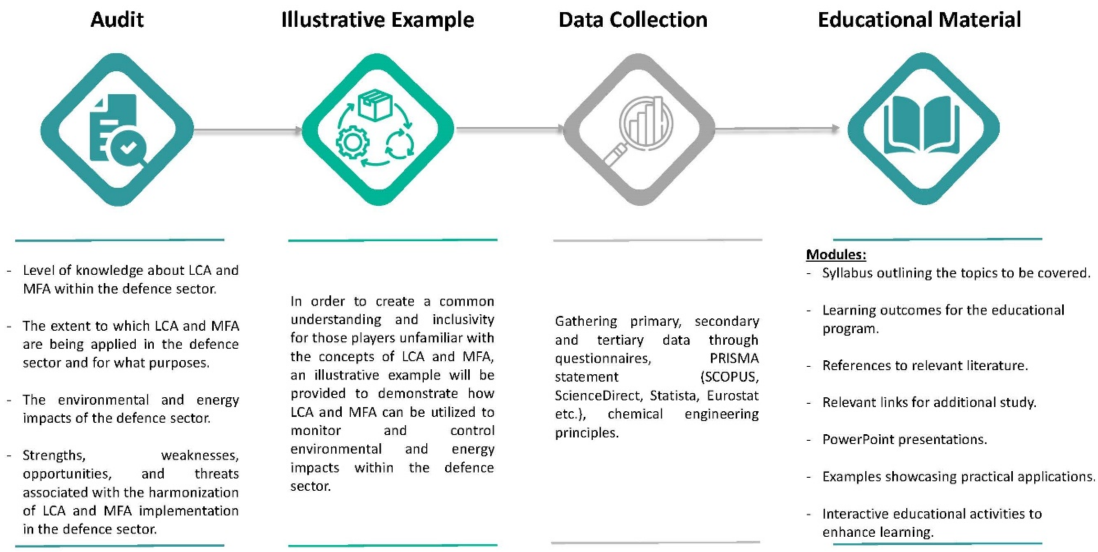
- Syllabus outlining the topics to be covered.
- Learning outcomes for the educational program.
- References to relevant literature.
- Relevant links for additional study.
- PowerPoint presentations.
- Examples showcasing practical applications.
- Interactive educational activities to enhance learning.

(iv) Data collection methodology

The methodology will involve gathering primary (from the questionnaires to be completed concerning on the field data), secondary (data collected using PRISMA statement methodology for recruiting relevant literature and existing research on the matter) and tertiary (using scientific calculations where data are not available like mass and energy balance, thermodynamics etc.) data. For secondary data acquisitions, the PRISMA statement will recruit literature from international scientific platforms such as Scopus and Science Direct. Additionally, data related to energy consumption and other impacts from the defence sector will be collected using international platforms like STATISTA and Eurostat, provided that such data is available.

By employing this comprehensive approach, the proposal aims to enhance understanding, establish a robust methodology, provide practical examples, and develop educational resources for the implementation of LCA and MFA in the defence sector within the EU Member States (**Figure 6.11**).

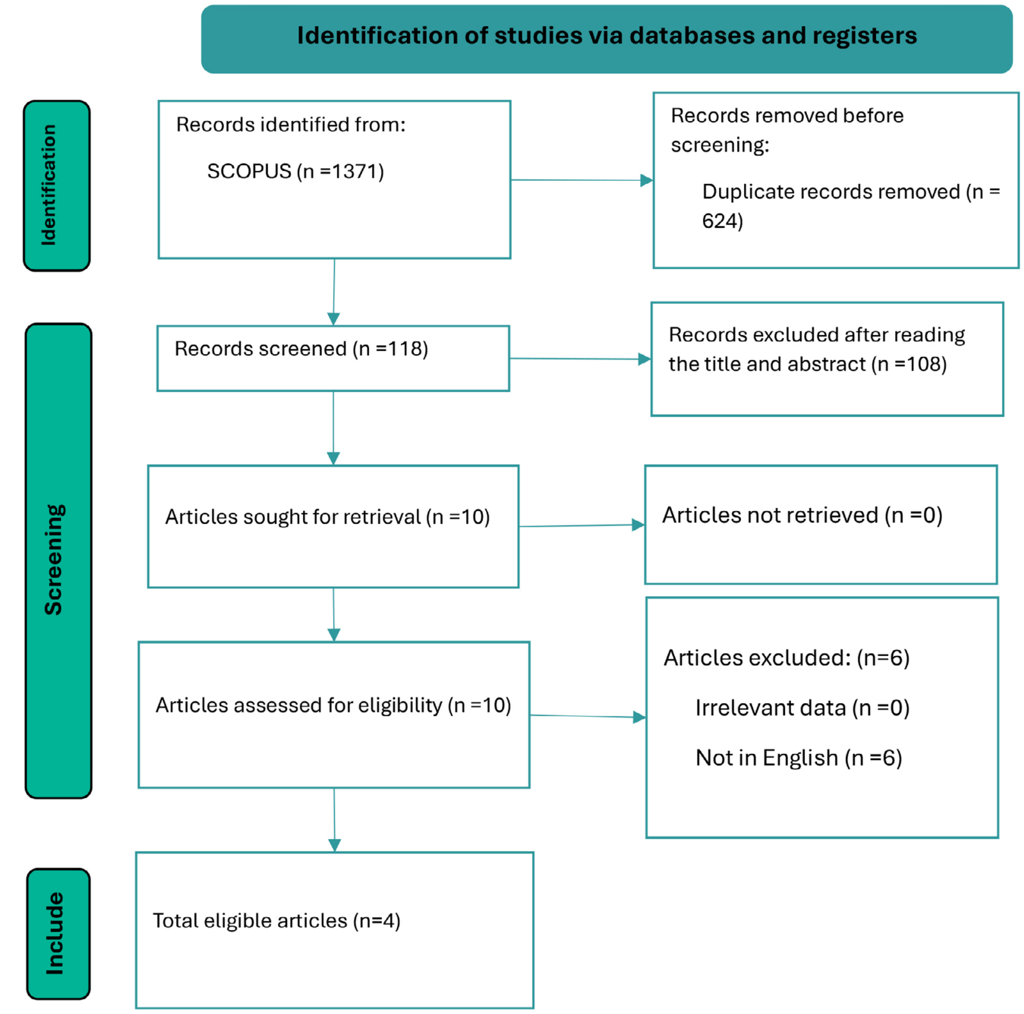
Figure 6.11. Methodology to be followed for the current study (Figure created by the authors – ©)



(v) Literature review based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) declaration

The examination of existing literature employed the PRISMA approach (Preferred Reporting Items for Systematic Reviews and Meta-Analysis), as detailed on the PRISMA website (www.prisma-statement.org). The execution of the intended literature review adhered to the PRISMA methodology, comprising 27 distinct pathways that encompass the clearly defined stages of a systematic review. This process entails setting eligibility criteria and identifying relevant information sources, exploring strategic approaches, conducting a selection procedure, and ultimately synthesising findings and data (Ortiz-Martínez et al., 2019; Tricco et al., 2018). As far as the authors are aware, this is the inaugural utilisation of the PRISMA methodology to compile all the studies conducted in the exploration of metabolic processes. The graphical representation of the PRISMA 2020 flowchart for systematic reviews, tailored specifically to encompass searches of databases and registers for this study, is displayed in **Figure 6.12**.

Figure 6.12. PRISMA statement (Figure created by the authors – ©)



The eligibility criteria that had been applied consist of inclusion and exclusion criteria. The inclusion criteria cover:

a. Research related with all the existing applied methods of LCA in defence sector.
b. Research related with all the existing applied methods of MFA in the defence sector.
c. Articles published from 1980 to current.
d. Research mentioning comprehensive outcomes and/or information.

The exclusion criteria involved:

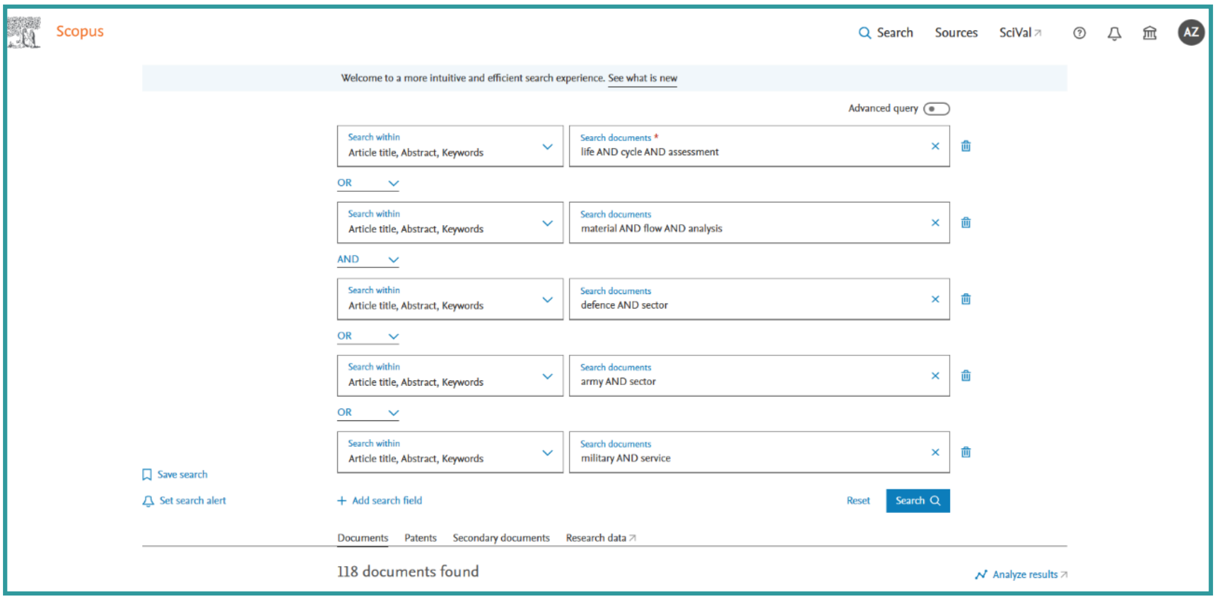
a. Narrative reviews.
b. Not related to the effectiveness of the proposed research.
c. Available papers in other language than English.

The information sources were completed for works published from inception to December 1980. The data base of Scopus webpage was used and the keywords that had been used were chosen in a meeting held by the authors of this research studies (see Acknowledgments also), since the authors are experts in the field (short CVs of the research team is included after the Acknowledgements).

As Scopus database option search were "**title, abstract, keywords**" the following combinations had been applied: *LCA* **OR** *MFA* **OR** *Life Cycle Assessment* **OR** *Material Flow Analysis* **AND** *Defence Sector* **OR** *Army sector* **OR** *military service*.

The review team comprises the authors, aiming to implement strategies that mitigate the likelihood of random errors and biases throughout the research process. This involves screening titles and abstracts to identify potentially relevant materials, taking into consideration predefined inclusion and exclusion criteria. Any disparities regarding the inclusion or exclusion of specific documents were addressed through extensive deliberations among the authors. From 1371 records initially identified using the keywords mentioned above in separate binary patterns (i.e. *LCA* **AND** *Defence sector*, *MFA* **AND** *defence sector* etc.), **118** references were extracted from Scopus (as shown in **Figure 6.13**). These references underwent a cross-check using Mendeley software to identify any potential instances of duplicated studies. In cases where the authors had uncertainties about whether a particular paper met the inclusion criteria, full papers were acquired for further evaluation. Consequently, the proposed list of references was also scrutinised to detect any conceivably relevant papers; however, no additional studies were found to fulfil this criterion.

Figure 6.13. Data extraction from Scopus (photo obtained by the authors)



Data extraction was accomplished by the authors (**Figure 6.13**). The Authors accomplished the data extraction (data items) of the 118 nominated papers for which data were examined containing those related to the publication of the paper (corresponding author/s country, year of issued, name of journal), results and discussions.

However, the majority of those 118 papers related directly or indirectly with the defence sector were focuses mainly on:

- Health systems.
- Security systems.
- Cyber security.
- Behaviour systems.
- Data driven assessment analysis.
- Risk modelling.
- Process optimisation.

Very impressive was the fact that:

i. There was not any paper directly related with the concept of LCA in defence sector.
ii. There was not any paper directly related with the concept of MFA in the defence sector.
iii. There were two papers indirectly related with defence sector (a) carbon footprint of electronic products (Vasan et al., 2014) and (b) perform an environmental footprint analysis of total consumption, capital investment, and capital consumption in the United States (Berrill et al., 2020).
iv. There were two papers related with the circular economy concept.

Therefore, form the 118 papers identified, only 4 were eligible regarding LCA, MFA and the concept of raw material usage in the framework of circular economy.

The 1st one from Janikowski, (2020) analysis the existing economic situation, referred to as the circular economy, of the armed forces during peacetime. This economic approach is often indicated as the target model in civilian areas and activities within the "European Defence Action Plan." The analyses carried out in this study demonstrate that some European armed forces, including the Polish one, realise circular economic requirements, namely creation of closed loops of material flow, slowing resources flow and using fewer materials. Some of these economic principles are typical for the military sector, such as "outdated" ammunition in civilian use. The above findings demonstrate the transformation towards a circular economy in the armed forces during peacetime.

The 2nd one from Ferreira et al., (2019) was dealing with circular economy approach to military munitions. Ammunition that has reached its end of life or become obsolete is considered hazardous waste due to the energetic material content that must be decommissioned. One of the technologies to dispose of ammunition involves the use of incinerators with sophisticated gas treatment systems; however, this disposal process has important limitations in terms of incinerator capacity, energy requirements and high costs. This article assesses the potential primary energy avoided and environmental benefits arising from the valorisation of energetic material from military ammunition by incorporating it into civil emulsion explosives, as an alternative to destructive disposal.

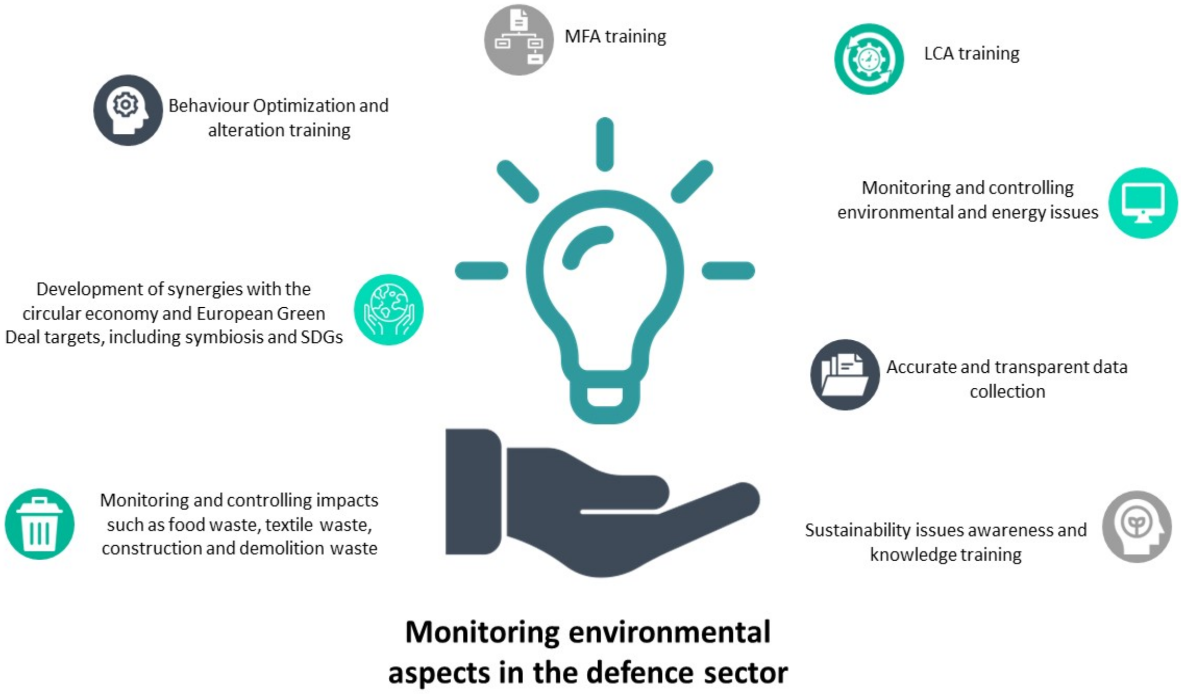
The results indicated the necessity to encompass the LCA and MFA in the defence sector as a tool to assess their environmental and energy impacts in order to achieve any operational effectiveness.

6.4.2. Idea to application

The study (**Figure 6.14**) is situated in the spectrum from "idea to application" as aim to develop a trust environment between the defence sector within the EU member states in order to establish through Internet of Things (in the future, using additional metaverse environment) a common platform that will:

- Train the entire defence sector in the era of environmental aspects.
- Train the entire defence sector in the era of life cycle assessment.
- Train the entire defence sector in the era of material flow analysis.
- Train the entire defence sector on how will collect accurate and transparent data.
- Train the entire defence sector on how will monitor and control its environmental and energy issues.
- Train the entire defence sector on how will monitor and control impacts such as food waste, textile waste, construction and demolition waste.
- Train the entire defence sector to interconnect and developed synergies with the circular economy and European green deal targets including symbiosis and SDGs.
- Train the defence sector on the Behaviour Optimisation.

Figure 6.14. Idea to application approach (Figure created by the authors – ©)



6.5. Solution implementation

The solution implementation is targeting to the full implementation of LCA and MFA in the defence sector. The outcome of the **findings and recommendations** should help defence sector to **gain an understanding of the importance of applying of the LCA – MFA options** at the following four levels:

Strategic level

Consider the **LCA and MFA** as a **tool** to achieve defence environmental policy goals relating to **energy** resources, as well as aligning with the European Green Deal.

Provided Clarification: Adoption of LCA and MFA will give to the defence sector the operational effectiveness that they need to assess their energy and environmental impact, reducing at the same time the consumption of natural resources and increase sustainability. In addition, a specific strategic approach or a policy should be clearly linked to the organisation's larger policies/objectives in the sustainability, climate and energy domains. In addition, will help the defence sector to redefine their roles and responsibilities within an organisation, including lines of reporting, how actions will be evaluated/monitored/assesses/validated, and ambition increased over time. This will cover without limitation and goal of the defence sector in terms of emissions control, energy security and savings, sustainable resource use and other impacts management.

Operational level

Explore the **LCA and MFA specific options** for the defence installations and/or activities.

Provided Clarification: The operational effectiveness will also cover the prioritisation of the defence sector targets in order control their Environmental and Energy Impacts. The "Green military services" will be an ambitions target based on the monitoring of the energy and environmental impacts of any MoDs.

Once priorities and targets have been set, an assessment of the current energy and environmental impacts e.g MoDs Buildings, Energy Storage, etc. should be undertaken, gaps identified, and appropriate staff training put in place. This may also involve revisions to job descriptions, workflows and qualification and promotion frameworks. Examples may include:

a. Changes in energy efficiency reporting.
b. Continuous monitoring of LCA/MFA models.
c. Annual sustainability or environmental impact reports to ensure the consistency of the methodologies employed.

Tactical level

Propose a **common EU methodological approach** on how to better integrate impact assessment from defence installations and/or activities.

Provided Clarification: defence sector may need a common approach on how will monitor and assess energy and environmental impacts. This will establish lines of communication between several actors and department. For example, procurement office with stakeholders and or client to ensure that all the provided services in the defence sector will follow green and sustainable approach as well as emphasis will be given to greener product that produced less CO2 emission and consume less energy.

Development of a new discipline

Through a specific curriculum that it will include LCA (ANNEX I) and MFA (ANNEX II) proposed methodologies which can be used as a first level educational material.

Provided Explanation: The proposed educational material (ANNEX I and II) will aim

- To educate MoD's staff so that they have more holistic understanding of the MAF and LCA, given the sustainable development requirements.
- To educate MoD's staff to be able to handle environmental tools such as LCA in order to assess Decence Sector environmental and energy impacts.
- To educate MoD's staff so that they are able to fully develop strategic development plans with emphasis on environmental and energy impacts.
- The intended learning outcomes are divided in 6 pillars as indicated in **Figure 6.15**.

Figure 6.15. Learning outcomes from the proposed curriculum (Figure created by the authors – ©)

Knowledge	• Critical thinking and critical knowledge on LCA and MFA • Development of knowledge in matters of LCA and MFA to assess Environmental Impact Assessment through softwares (e.g OpenLCA). • Development of critical knowledge to monitor energy impacts
Comprehension	• To understand the concept of energy security and energy impacts • To understand the concept of environmental impacts • Understanding the concept of Energy Efficiency in the construction sectors • Understanding of concepts related to Materials Flow Analysis
Application	• Identification of the level of Life Cycle Analysis (LCA). • Preparation of Environmental Impact Assessment and Life Cycle Analysis Studies.
Analysis	• Analysis of the characteristic of LCI and the requirement to measure environmental and energy impact through LCA and MFA • Analysis of the technical criteria for LCA / MFA
Synthesis	• Analysis of the flowchart from several Defence activities that potentially could be used to apply LCA and MFA • Development of monitoring procedures
Evaluation	• Evaluation of the LCA and MFA methods to assess environmental and energy impact

However, there are certain barriers and risk that should be clarified to achieve the full implementation of LCA and MFA in the defence sector. Using SWOT analysis (**Table 6.5**) we defined strengths, weakness, opportunity, and threats. The proposed strategy will help the defence sector to achieve any operational effectiveness towards low carbon society.

Table 6.5. SWOT analysis for the implementation of MFA and LCA in the defence sector

External Factors			
OPPORTUNITIES		**THREATS**	
O1	To turn defence sector into green philosophy	T1	The "Top secret" philosophy will not import data
O2	To change the attitude of the civil society for the defence sector	T2	Too much bureaucracy in MoDs
O3	To develop new skills for the existing staff in MoDs	T3	Limited educated staff in the era of LCA / MFA
O4	To develop confidence building measures between MoDs in EU	T4	Frequent key personnel transfers
O5	Adoption of organisation policies and common strategy in MoDs	T5	The absent of motivations
O6	Integration with sustainability, climate and energy policies	T6	The absent of common EU strategy
O7	Pilot demonstration projects	T7	Veto from MoDs at political level to share date
Internal Factors			
STRENGTHS		**WEAKNESSES**	
S1	Operational effectiveness to defence sector to control energy and environmental impact	W1	There is no obligation to measure energy and environmental impact in the MoDs
S2	To monitor GHGs from defence buildings	W2	There is no well-known logistics to control the existing practices
S3	To monitor energy saving	W3	Until now there is no blueprint focused on the circular economy strategy and/or energy and/or environmental impact assessment
S4	The knowhow will improve the process for the selection of green products and services	W4	There is no specific target (or agreement) between MoDs to reduce GHGs
S5	Settings of targets and priority categories	W5	Lack of political commitment and guidance
S6	Long term sustainability	W6	Expected results not appropriately estimated (underestimated / overestimated)
S7	Common blue print strategy for member states	W7	Carbon footprint of the future activities may be high and could not be measure

According to Symeonides at al., (2019) the strategies that arise from **Figure 6.6** (section 3.2) are the following:

i. **Development Strategy (O-S), (Growth/Expansion).** It applies when there are many opportunities and the organisation is in a position to use, apply and exploit those advantages in order to expand its activities. Usually, the targets set includes: to increase sales, penetrate into new markets, produce new products and develop new business.
ii. **Embedding / Correctional Strategy (O-W).** It applies when opportunities exist, but the organisation has internal weaknesses and is not in a position to use those opportunities. Main target is the internal stability of the current situation and gradually to improve the existing weaknesses to be able to implement a development strategy, giving priority to existing customers, improved product quality, correct processing, and reduced costs.
iii. **Enhancement / Improvement Strategy (T-S).** It applies when the organisation face several threats but has internal forces and procedures to face those threats and turn the organisation into a stable "path".
iv. **Shrink / Defence Strategy (T-W).** It applies when Treats exist, but the organisation can face them and aim to correct unprofitable activities, reduced employees, search for new markets and possibly diversify of the products.

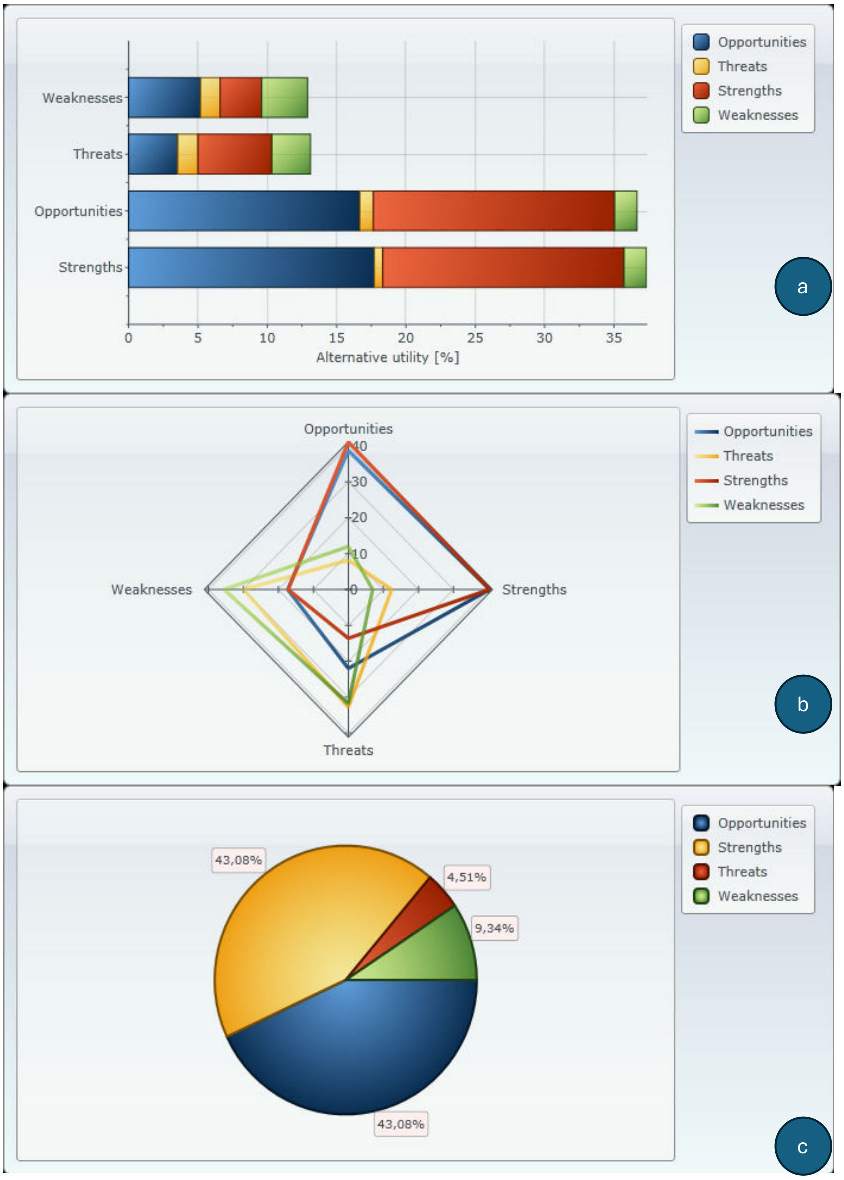
The choice strategy to be followed, depends on the image presented by the SWOT matrix (**Table 6.6**). The Development Strategy is chosen when "O-S" prevails, that is, there are many opportunities and at the same time the organisation has several possibilities and advantages for their exploitation. In contrast, when "W-T" prevails, that is when there are several threats from the external environment and the organisation does not have internal forces or any competitive advantage to deal with them, then the Shrink Strategy is chosen. Based on the same logic, the "T-S" Enhancement Strategy is selected when there are many external threats, but the organisation has the benefits to address them or the "O-S" Correction Strategy, when there are opportunities, however the organisation is characterised by many weaknesses and is not able to face and exploit them.

Table 6.6. SWOT corelated matrix table

THREATS	T7		✔	✔		✔	✔	✔	✔		✔		✔		
	T6	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	T5	✔					✔	✔	✔		✔			✔	✔
	T4	✔	✔	✔	✔	✔	✔	✔	✔				✔	✔	✔
	T3	✔	✔	✔	✔	✔	✔							✔	✔
	T2													✔	✔
	T1	✔	✔	✔	✔	✔	✔	✔						✔	✔
OPPORTUNITIES	O7		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	O6	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	O5	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	O4	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	O3	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
	O2						✔						✔		
	O1	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
SWOT MATRIX		S1	S2	S3	S4	S5	S6	S7	W1	W2	W3	W4	W5	W6	W7
	STRENGTHS								WEAKNESSES						

In the SWOT matrix (**Table 6.5**), a pairing of findings, linking opportunities with the associated strengths (O-S), opportunities with weaknesses (O-W), threats to related strengths (T-S) and threats with the weaknesses (T-W). The numbering of the SWOT analysis findings (**Table 6.5**) corresponds to the SWOT Corelated Matrix **Table 6.6**. As demonstrated in Table 10, there were 37 correlations between Opportunities/Weaknesses (O-W), 37 correlations between Opportunities/Strengths (O-S), 32 correlations between Threats/Strengths (T-S) and 24 correlations between Threats/Weaknesses (T-W). Moreover, **Table 6.6**, indicates that the management system under examination has the option to select one of the three Strategies: (i) for O-S Development, (ii) Enhancement /Improvement T-S or (iii) Embedding/Correctional O-W. The O-W, Correctional Strategy slightly overrides the other two. As the T-W, Shrinking Strategy is clearly less in number cannot be an option. In the present situation, the system under study does not face financial sustainability problems and could lead the management system to collapse or shrink strategy. This is also indicated and from the sensitive analysis **Figure 6.16b** while **Figure 6.16a clearly indicated the operational effectiveness of the defence sector to apply LCA and MFA to monitor environmental and energy impacts as the provided strengths and opportunities are higher than the threats and the weaknesses.**

Figure 6.16. (a) Multicriteria analysis (b) Sensitive analysis (c) weight criteria (Figure created by the authors – ©)



6.6. Recommendations and way ahead

Once the project in its original conception can be considered completed and its objectives have been met, the next action to be undertaken should be to keep sharing this information with the MoDs involved thus giving it as much visibility as possible. This phase may involve holding more specific events where stakeholders can provide feedback. It is expected that, because of the publication, cross-interests, collaborative projects between countries, synergies and ultimately a flow of information will be generated.

The next steps should also be to ensure even greater participation by Member States. 23 countries responded positively to the request to provide information, and this is a very promising start. The recemented actions are summarised in the following **Table 6.7** as well as in the following **Figure 6.17** which presents an overview of the actions.

Figure 6.17. Overview of the actions Figure created by the authors – ©)

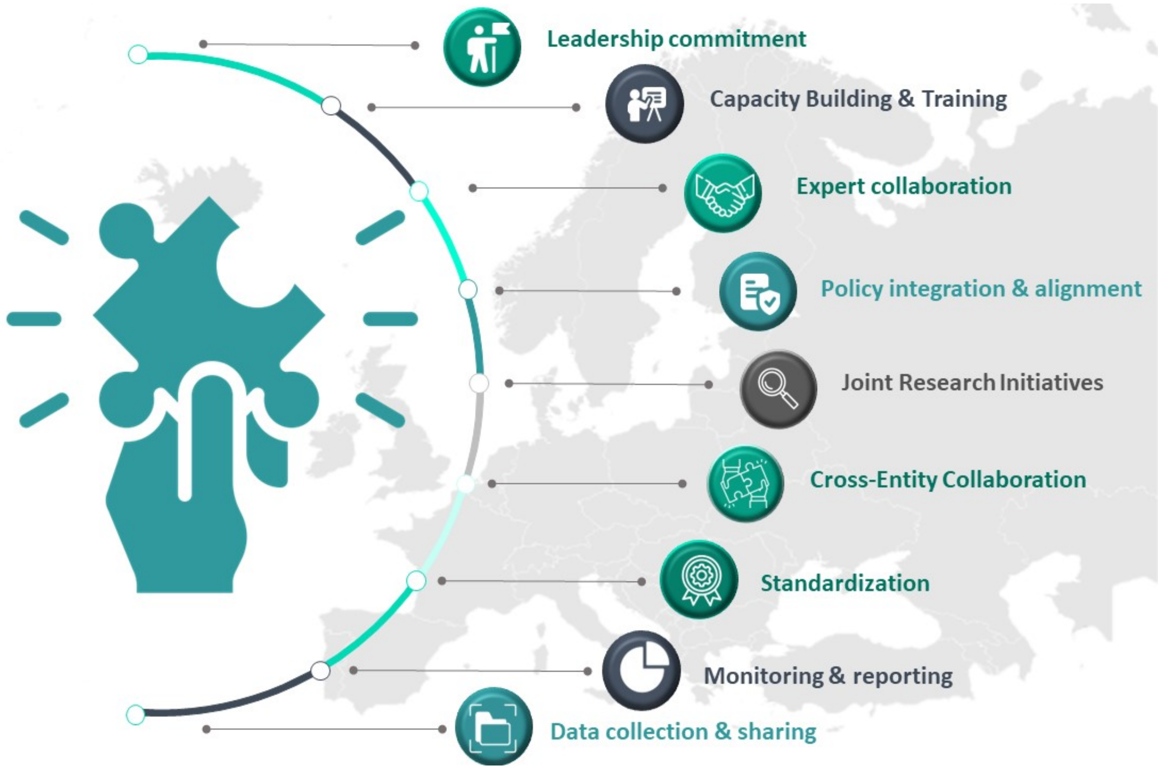


Table 6.7. Recommended actions

Action	Innovation Solution – Elaboration
Capacity Building and Training	Provision of training programmes and workshops to defence personnel in order to enhance LCA/MFA understanding both in methodology and importance, in order to effectively incorporate sustainability considerations into their planning.
Standardisation	Development of standardised guidelines for the conduction of LCA/MFA specific and personalised to the defence sector, to ensure consistency in methodology and results.
Expert collaboration	External collaboration with environmental experts like environmental stakeholders, research and academia to provide advisory support for LCA/MFA implementation, in order to overcome technical challenges for accurate results.
Data collection & sharing through an information exchange platform	Establish data collection protocols to streamline the gathering of relevant data for LCA/MFA. Information sharing between defence entities has to be a priority as confidentiality is a big obstacle to LCA/MFA implementation. The creation of a centralised platform for sharing best practices, case studies and success stories related to environmental impact assessments will aid MoDs in the learning process amongst each other.
Policy integration and alignment	Integrate LCA/MFA methodologies into existing defence policies and strategies in order to create a holistic and smooth decision-making process.
Cross-Entity Collaboration	Facilitate collaboration between different European MoDs to develop a unified approach towards environmental impact reduction for a harmonised pan-European Strategy.
Joint Research Initiatives and pilot projects	Invest in joint research projects and initiative pilot projects focusing on LCA/MFA in the defence sector, to address specific challenges, gather practical insights and develop innovative solutions.
Leadership commitment	Secure high-level leadership commitment from each participating MoD to ensure the implementation of the harmonised strategy and the allocation of necessary resources.
Monitoring and reporting mechanisms	Develop mechanisms to monitor the progress of LCA/MFA implementation of the harmonised strategy by regular reporting and performance metrics.

Conclusion

While prioritising investments in LCA and MFA initiatives for defence may initially face opposition due to concerns about resource diversion from core defence capabilities, it is crucial to recognise the indispensability of adequate funding and resource allocation for their successful implementation. This requires a deep comprehension of the substantial long-term economic and environmental advantages that such initiatives can offer. The challenges related to political alignment and transnational cooperation within the EU member states cannot be underestimated. The establishment of a harmonised defence LCA and MFA framework demands consensus on environmental goals, energy objectives, methodologies, and implementation strategies. Overcoming the barriers posed by differing political stances and achieving agreement stands as a significant obstacle in this endeavour. The diverse interplay of political alignment, cultural nuances, and organisational practices across nations introduces complexities that necessitate careful consideration.

In the context of defence, unique organisational cultures, traditions, and operational priorities are the norm. The integration of environmental and energy considerations into decision-making processes mandates a profound shift in mindset and organisational culture. Adapting to more flexible procedures, whether by following existing ones or developing new approaches, becomes imperative. To pave the way forward, several key actions are paramount. Raising awareness among defence entities about the multifaceted benefits of LCA and MFA initiatives is vital. Building capacity within these organisations to comprehend and embrace these concepts can facilitate their adoption. Equally important is fostering collaboration between defence entities, environmental and energy experts, and academia. This collaborative approach can bridge the gap between traditional defence practices and the demands of sustainable and environmentally conscious decision-making.

Surmounting the challenges tied to resource allocation, political alignment, and cultural adaptation requires a strategic and multidimensional approach. To overcome barriers in LCA/MFA integration, capacity-building through training, standardised guidelines, collaboration with experts, efficient data collection, and policy integration are essential. In terms of developing a harmonised strategy, cross-entity collaboration, policy alignment, an information exchange platform, joint research initiatives, and securing leadership commitment are crucial elements. The options for implementing these recommendations encompass pilot projects, capacity-building workshops, policy framework development, collaborative research funding, monitoring mechanisms, stakeholder engagement, and policy advocacy. Successful execution will rely on phased implementation, stakeholder dedication, and continuous evaluation, thereby allowing strategies to adapt based on real-world results. Ultimately, these recommendations pave the way for a more ecologically sustainable approach to defence planning and activities, contributing to a greener future.

By recognising the long-term advantages, aligning political will, and encouraging collaboration, the integration of LCA and MFA initiatives within defence can not only enhance environmental stewardship but also promote a more resilient and forward-thinking defence establishment.

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Annex I – LCA curriculum

LIFE CYCLE ASSESSMENT

Description

The course aims to provide knowledge on life cycle assessment and how it can be used in the defence sector in order to assess the environmental and energy impacts of difference processes within a given system. LCA is directly involved in product development and enhancement, planning and strategy, environmental impact assessment, environmental performance, public policy formulation, and other activities.

Different scenarios within the same system can be examined using LCA, allowing decision-makers to identify the most environmentally friendly approaches. By LCA, the defence sector should evaluate the comprehensive impact of its products and processes, encompassing the entire life cycle from raw material extraction to disposal, while simultaneously aligning with the principles outlined in the European Green Deal and circular economy strategies.

The course will emphasise how the life cycle assessment is carried out and how the outcomes could be used to assess the environmental and energy impacts of defence sector.

Learning outcomes

Knowledge:

- Critical thinking and critical knowledge on LCA.
- Development of knowledge in matters of LCA to assess environmental impact assessment through softwares (e.g OpenLCA).
- Development of critical knowledge to monitor energy impacts.

Comprehension:

- To understand the concept of energy security and energy impacts.
- To understand the concept of environmental impacts.
- To understand the standard requirements of ISO 14040:2006 and ISO 14044:2006.
- Understanding the concept of energy efficiency in the construction sector.

Application:

- Identification of the level of LCA.
- Identification of the level of a strategy through LCA.
- Apply different scenarios to find the optimum solution through LCA.
- Preparation of environmental impact assessment and LCA.

Analysis:

- Analysis of the characteristic of life cycle inventory (LCI) and the requirement to measure environmental and energy impact through LCA.
- Analysis of the technical criteria for LCA.

Synthesis:

- Analysis of the flowchart from several defence activities that potentially could be used to apply LCA.
- Development and use of key performance indicators.
- Development of monitoring procedures.

Evaluation:

- Evaluation of the LCA method to assess environmental and energy impact.

Basic concepts:

- Life cycle assessment.
- Environmental impacts.
- Energy impacts.
- Environmental impact assessment.
- Life cycle inventory.
- 14040:2006.
- ISO 14044:2006.

Literature to be considered

Chen, Z., Huang, L., 2019. Application review of LCA (life cycle assessment) in circular economy: From the perspective of PSS (Product Service System). Procedia CIRP. https://doi.org/10.1016/j.procir.2019.04.141

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Annex II – MFA curriculum

MATERIAL FLOW ANALYSIS

Description

The course aims to provide knowledge on material flow analysis and how it can be used to monitor and analyse the physical flows of materials into, through and out of a given system and also how it can be used to evaluated relationships between material flows, including energy, human activities and environmental changes.

The course will emphasise on how the material flow analysis is carried out with the aim to understand the flows of natural resources and materials, their shifts, and their economic and environmental implication. Furthermore, through the training programme, focus will be placed on the approach of recognising the inputs and outputs in different activities of defence sector such as waste management system, and how this analysis can help to identify opportunities to improve waste diversion rates, optimise recycling efforts, and reduce waste sent to landfills.

Learning outcomes

Knowledge:

- Critical thinking and critical knowledge on MFA.
- Development of knowledge in matters of MFA to assess environmental impact assessment.

Comprehension:

- To understand the concept of energy security and energy impacts.
- To understand the concept of environmental impacts.
- To understand MFA methodology approach.

Application:

- Identification of the level of a strategy through MFA.
- Apply different scenarios to find the optimum solution through MFA.
- Preparation of MFA.

Analysis:

- Analysis of the requirement to measure environmental and energy impact through MFA.
- Analysis of the technical criteria for MFA.

Synthesis:

- Analysis of the flowchart from several defence activities that potentially could be used to apply MFA.
- Development and use of key performance indicators.
- Development of monitoring procedures.

Evaluation:

- Evaluation of the MFA method to assess environmental and energy impact.

Basic Concepts:

- Material flow analysis.
- Environmental impacts.
- Environmental impact assessment.
- Input flow, output flow.

Literature to be considered

Brunner, P.H., Rechberger, H., 2004. Practical handbook of material flow analysis. Int. J. Life Cycle Assess. 9, 337–338. https://doi.org/10.1007/BF02979426

OECD, 2008. Measuring material flows and resource productivity Volume I. The OECD Guide. Available online: https://www.oecd.org/environment/indicators-modelling-outlooks/MFA-Guide.pdf

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7. Strategic pathways for advancing the defence energy transition

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Abstract

This concluding chapter outlines the strategic pathways and final reflections from Phase III (2019-2024) of the Consultation Forum for Sustainable Energy in the Defence and Security Sector (CF SEDSS). It emphasises the importance of integrating sustainable energy practices into the defence sector to enhance energy efficiency, resilience, and autonomy, aligning with the EU's climate neutrality goals by 2050. Key initiatives discussed include the establishment of an EU-led Competence Centre on Climate Change, Security, and Defence, and the launch of the European Defence Sustainable Energy Profiles (EDESEP) platform. These initiatives are designed to foster collaboration, standardise best practices, and support the defence sector's transition to sustainable energy models. The chapter concludes by highlighting the critical role of the European Defence Agency, the European Commission, and MoDs in driving this transition, ensuring that defence operations contribute to global efforts in combating climate change while maintaining operational effectiveness and readiness.

7.1. Introduction

The content of this chapter and the publication as a whole is the result of extensive research conducted by external experts under the auspices of the European Defence Agency (EDA) and the supervision of the CF SEDSS project management team. The CF SEDSS management team, alongside the Forum's working groups, has meticulously defined the scope and objectives of these studies, ensuring that the findings and outcomes directly address existing gaps and barriers while meeting the EU and the MoDs expectations. The studies have provided recommendations and identified gaps that require further research, technical support, specialised expertise, and unwavering political commitment to be resolved effectively.

The research conducted within Phase III of CF SEDSS represents a pioneering effort, marking a significant advancement since the project's inception in 2015. This phase has proven highly beneficial, introducing new research, findings, and recommendations that empower MoDs to coordinate more effectively with industry, research, and technology organisations. These collaborations are essential for identifying synergies, bridging existing gaps, and implementing sustainable energy models that reduce energy consumption while enhancing both efficiency and resilience.

This publication serves as a vital resource for driving the energy transition within the defence sector. It offers practical tools, strategic insights, and policy recommendations that are particularly valuable for MoDs across the EU. The publication equips MoDs with the knowledge needed to align their operations with the European Green Deal while maintaining military readiness and energy security. Its value lies in its comprehensive approach, addressing both current challenges and future requirements for integrating sustainable energy practices within defence operations.

The detailed analysis of energy efficiency trends, green public procurement, energy storage systems, offshore renewable energy, and life cycle assessment provides actionable insights for MoDs. These insights support the implementation of energy-efficient technologies and the integration of renewable energy into defence infrastructure. By following these recommendations, defence entities can significantly reduce their carbon footprint, enhance energy security, and contribute to broader climate goals. Implementing these recommendations will ensure compliance with both EU and national regulatory frameworks and position MoDs as leaders in the global shift towards sustainable defence operations.

7.2. Key recommendations for defence energy transition

7.2.1. Energy efficiency and buildings performance

MoDs should prioritise the adoption of energy-efficient technologies and practices within their facilities. This includes retrofitting existing buildings with modern, energy-saving systems and integrating renewable energy sources such as solar and wind into new construction projects. By adopting a life-cycle costing approach, rather than focusing solely on upfront costs, MoDs can achieve long-term benefits that extend beyond immediate financial savings, leading to more sustainable and resilient infrastructure.

7.2.2. Green Public Procurement (GPP)

GPP is underscored as a critical tool for promoting sustainable practices within the defence sector. MoDs are encouraged to develop and implement GPP policies that are closely aligned with their strategic goals, ensuring that all procurement processes take into account environmental impacts and energy efficiency. Regular training for procurement personnel, coupled with collaboration across the EU to standardise GPP criteria, are crucial steps in embedding sustainability into defence procurement practices.

7.2.3. Energy storage systems

Selecting appropriate energy storage solutions is vital for supporting the integration of renewable energy in defence operations. A forward-looking strategy involves developing and utilising software tools to identify optimal storage systems, considering factors such as energy density, operational costs, and environmental impact. These tools will enable MoDs to make informed decisions that enhance both energy security and operational efficiency.

7.2.4. Offshore renewable energy installation and defence systems coexistence

To facilitate the coexistence of offshore renewable energy projects with defence activities, MoDs should invest in research and simulation programmes that assess the impact of these projects on military operations. Identifying suitable areas for renewable energy development without compromising national security and defence operational effectiveness is crucial. This requires transparent and effective dialogue between the defence sector and public and private stakeholders to ensure mutual benefits.

7.2.5. Life Cycle Assessment (LCA) and Material Flow Analysis (MFA)

Integrating LCA and MFA into defence planning is essential for comprehensively evaluating the environmental impact of defence operations. The publication recommends establishing standardised guidelines and fostering collaboration with environmental experts to enhance the accuracy and effectiveness of LCA and MFA. These tools will enable MoDs to make more informed decisions that align with sustainability goals while maintaining operational readiness.

7.3. Implementing strategic steps to drive the defence energy transition

In this section, we introduce two innovative concepts developed within the CF SEDSS and further refined with insights from external experts. Implementing these ideas is expected to significantly advance the defence energy transition in a more structured and coherent manner over the long term while fostering greater collaboration between the defence sector and civilian communities, including both public and private stakeholders. The EU's commitment to climate neutrality by 2050 requires full societal engagement, and the defence sector must not lag behind. On the contrary, defence should play a pivotal role as an enabler of this transition, ensuring its adaptation to the evolving energy landscape while enhancing its operational effectiveness, competitiveness, and resilience.

7.3.1. Establishing an EU-led competence centre on climate change, security, and defence[133]

a) Addressing critical energy and security challenges

Reducing energy demand and enhancing energy resilience are crucial for the armed forces to maintain high levels of readiness and sustainability. Improving energy efficiency can unlock substantial human and financial resources, allowing the defence sector to reallocate these savings to other critical needs. Despite various ongoing initiatives at the national and EU levels, these efforts often need to be more cohesive and, at times, overlapping. Achieving the necessary levels of energy efficiency, resilience, and sustainability cannot be accomplished by any single member state acting alone. Instead, a network of strategic partners must be leveraged. Strategic autonomy in energy does not imply reliance solely on domestic resources but rather having access to a diversified array of options within the European energy ecosystem, including its defence dimensions. Implementing sustainable energy models in defence and diversifying energy supplies are crucial to enhancing resilience against security challenges and reducing dependency on non-EU energy sources. As the EU advances toward a resilient Energy Union and aims to become the first climate-neutral continent by 2050, the role of the defence sector in this transition is increasingly critical.

Securing strategic energy autonomy for European defence necessitates fostering collaboration among MoDs, sharing best practices, and developing collaborative projects. The EU must expand its research capabilities and capacities to achieve a critical mass by leveraging the competencies of its member states and relevant networking centres. Establishing a suitable mechanism, such as a competence centre, that provides comprehensive, systematic, and structured support is essential for enabling MoDs to address defence energy-related challenges effectively. This centre would be pivotal in underpinning the policy and decision-making processes of MoDs, enhancing energy efficiency, and ensuring coherence in achieving the EU's energy and climate objectives.

b) Comprehensive research and findings

To address this gap, the CF SEDSS, in Phase III, initiated a research study that was further developed within the Forum with support from an external contractor. The initial findings were reviewed by the European External Action Service (EEAS), which subsequently included in its first EU Climate Change and Defence Roadmap[134], issued in November 2022:

133. The authors would like to express their deep appreciation to Mr. Patrice Lefeu, who implemented this study on behalf of the EDA and CF SEDSS.
134. EUROPEAN EXTERNAL ACTION SERVICE (europa.eu).

- The Commission services, in cooperation with EEAS and EDA, will assess the feasibility of establishing a suitable mechanism to act as the EU's repository, observatory, and research platform. The mechanism could aim at assisting national authorities (e.g., EU Ministries of defence, Interior, Energy, Environment, etc.) in reducing energy consumption, increasing energy efficiency, and thereby contributing to the implementation of the EU's climate and energy targets.

In response to this call, the EDA conducted a comprehensive research study as part of the CF SEDSS. The findings, presented in November 2022, were subsequently included in the EEAS Joint Progress Report on Climate Change, Defence, and Security (2020-2022)[135]. The report underscored the need to support the policy and decision-making processes of MoDs to enhance energy efficiency, resilience, and autonomy, while aligning with the EU's climate neutrality goals by 2050. It also emphasised the importance of accelerating cross-border cooperation, including fostering civilian and military collaboration in the energy and climate change domains, generating significant economic savings, and reallocating resources to military priorities.

Against this backdrop, the European Commission and the High Representative have committed to exploring ways to support Member States, both individually and through enhanced civilian-military cooperation, in line with the objectives of the Strategic Compass and the European Green Deal. This commitment aligns with the EU Joint Communication on the Climate and Security Nexus[136], which states:

- …a new Climate and Defence Support Mechanism will be set up between relevant Commission services, the EEAS and the EDA to work with Member States to identify gaps and collaborative opportunities in areas such as the development of skills, sharing or conducting research and studies, developing green standards, data gathering, developing methodologies or technical concepts, enhancing incentives and promoting collaborative projects.

c) Strategic importance of establishing an EU-led competence centre on climate change, security, and defence

Based on the analysis conducted within the CF SEDSS, the research from the contracting study[137], and further reflection, it is evident that a Competence Centre—currently lacking in the EU context—could play a catalytic role in harmonising existing and future defence energy initiatives across the EU. This Centre is envisioned as a repository and research platform that facilitates data sharing, best practices, and provides tools to accelerate cross-border cooperation, project development, and financing. The Centre's focus is anticipated to be on **five vital interrelated areas**:

I. Data collection and reporting

- Provide a comprehensive and analytical overview of the energy performance of defence buildings, transportation, equipment, and non-tactical vehicles through reliable, consistent, and comparable data.
- Analyse and report data collection and reporting at the EU level and across MoDs to evaluate vulnerabilities, assist in future policy-making, and identify collective responses.
- Collaborate with EDA and Eurostat to provide transparent and reliable information in an aggregated form, valuable to policymakers, investors, stakeholders, local and national authorities, and researchers.

135. progress report public.pdf (europa.eu).
136. JOIN_2023_19_1_EN_ACT_part1_v7.pdf (europa.eu).
137. assessment-of-suitable-mechanisms.pdf (europa.eu).

II. Best practice and knowledge sharing

- Create a standardised terminology database among all relevant EU defence stakeholders to ensure consistent definitions (e.g., "energy resilience," "energy security," "sustainable energy").
- Share best practices and knowledge with MoDs on improving energy efficiency, utilising renewable energy sources, and increasing the resilience of critical energy infrastructure.
- Deliver analysis on the implications and opportunities of implementing energy-related legislation and policies in the defence sector, functioning as a support tool for MoDs when reporting to the European Commission (e.g., National Climate and Energy Plans – NCEPs).
- Disseminate knowledge and best practices to raise awareness of the impact of climate change and environmental risks on defence.
- Raise awareness of the vital role that defence can play in increasing energy resilience and supporting the EU's efforts to reduce greenhouse gas emissions and build a greener, safer future.

III. Education and training

- Coordinate with EDA to structure the permanent and continuous delivery of relevant energy courses (e.g., Defence Energy Management Course – DEMC).
- Collaborate with the European Defence and Security College (ESDC) to introduce dedicated courses/training on transitioning defence ministries to sustainable energy models.
- Partner with universities, agencies, and organisations like the UN and NATO to enhance MoDs' opportunities to improve their sustainable energy knowledge through training and education.

IV. Funding and financial opportunities

- Provide updated information on funding and financing opportunities (e.g., leveraging EDA's existing tools, such as the European Funding Gateway for Energy in Defence).
- Support the development of defence energy-related project ideas by identifying available funding opportunities.
- Offer tailored support to MoDs in preparing applications for European-level funding.

V. Multinational projects and research

- Enable MoDs to build capacity to respond to existing and emerging energy demands and challenges related to climate change and environmental risks.
- Translate defence energy data into customised tools and products to assist decision-makers in boosting resilience and energy-climate adaptation measures.
- Assist MoDs in identifying opportunities for multinational collaboration and projects, such as EDA's ad-hoc CAT A or B projects, PESCO, CF SEDSS, and EDA EnE Capability and Technology Group, EDA Operational Budget.
- Stimulate research and innovation to deliver concrete solutions for energy and climate adaptation, fostering collaboration with civilian and industrial communities to overcome national resource and expertise limitations.

d) Impact and future prospects

Establishing the proposed Competence Centre would significantly enhance the EU's defence energy resilience and autonomy, aligning military energy practices with broader EU climate neutrality goals by 2050. It would also accelerate cross-border cooperation, potentially generate economic savings, and enable the reallocation of resources to military priorities. It is essential to highlight that the EU Centre would support MoDs in applying the EU's energy policy and legislative framework through EU funding and tailored technical expertise—an area distinct from NATO's Climate Change and Security Centre of Excellence.

Creating an EU-led Competence Centre on Climate Change, Security, and Defence represents a strategic advancement in integrating defence energy practices with the EU's climate goals. By fostering collaboration, knowledge sharing, and innovation, this Centre could play a pivotal role in driving the defence sector's energy transition, contributing to the EU's overarching aim of achieving climate neutrality by 2050. The CF SEDSS has identified this gap in the EU context, and the EU has committed to exploring further opportunities. Given the volatile geopolitical environment, including energy challenges and the cascading effects of climate change, the EU must provide long-term support to MoDs to ensure their defence energy transition and climate adaptation align with the European Green Deal and the objectives of climate neutrality by 2050.

7.3.2. Launching the European Defence Sustainable Energy Profiles (EDESEP)[138]

Addressing key gaps in defence energy sustainability

The creation of the European Defence Sustainable Energy Profiles (EDESEP) is an innovative initiative conceptualised during CF SEDSS Phase III. EDESEP aims to advance the defence energy transition by providing comprehensive and actionable data to MoDs and relevant stakeholders. This platform is designed to address common energy and climate change considerations, foster collaboration across the defence sector, and enhance energy resilience. EDESEP emerged from recognising that while the EU is committed to decarbonisation and energy sustainability, the defence sector's energy activities still need to be more cohesive and reported. The platform is conceived as a collaborative virtual resource, aggregating and presenting the best sustainability practices from EU MoDs and strategic partners. By showcasing replicable initiatives, EDESEP seeks to provide visibility to successful efforts, benefiting all members in terms of sustainability, efficiency, and resilience.

Comprehensive research and implementation of EDESEP

Reflecting the above gap, the EEAS Joint Progress Report on Climate Change, Defence, and Security (2020-2022) has recognised the need to improve the information exchange between Member States on the various energy-related activities in the ministries of defence. In this respect, it has invited the EDA to launch a European Defence Sustainable Energy Profiles platform. This digital platform compiles and showcases notable energy sustainability efforts and activities based on inputs from the MoDs, thus giving visibility to successful initiatives from which other members can benefit. Responding to this call, and considering the lack of accessible, aggregated data on defence sustainable energy models, the CF SEDSS has conducted a research study[139] with the support of an external contractor to fill this gap by creating a dynamic exchange platform. This platform will:

- Foster communication, synergies, and cooperation among EU Member States.
- Prevent redundancies and overlaps in energy initiatives.
- Identify areas for improvement in energy consumption and production.
- Highlight potential dependencies of EU armed forces on external energy sources.
- Optimise the use of resources by strengthening multilateralism and partnerships.

The EDESEP will be an interactive web platform dedicated to information sharing across four key areas:

I. **Sustainability, Energy Efficiency, and Buildings Performance.**
II. **Utilisation of Renewable Energy Sources in the Defence Sector.**
III. **Resilience of Defence-Related Critical Energy Infrastructure.**
IV. **Crosscutting Topics:** Energy management policies, innovative technologies, funding, and financing opportunities.

138. The authors would like to express their deep appreciation to Mr. David Bretones, who implemented this study on behalf of the EDA and CF SEDSS.
139. eu-defence-sustainable-energy-profiles.pdf (europa.eu).

Impact and next steps for EDESEP

EDESEP is aligned with the EU's broader goals of becoming the first climate-neutral continent by 2050. By making critical energy information readily available, the platform will support decision-makers and stakeholders in the defence sector. EDESEP promotes a structured approach to understanding and enhancing the energy resilience and autonomy of MoDs, contributing significantly to the EU's climate and energy objectives.

The successful implementation of EDESEP will require sustained collaboration between the EDA, the European Commission, and the EEAS. This platform represents a unique tool within the European defence landscape, offering an opportunity to bolster defence energy resilience and reduce dependencies on non-EU energy sources. By aligning with the European Green Deal, EDESEP will help ensure that the defence sector plays a crucial role in achieving climate neutrality by 2050. Continued support and optimisation of this platform will be vital to its success, facilitating cross-border collaboration, project development, and the flow of critical information. The EDA will place significant efforts into Phase IV of the CF SEDSS to ensure this platform's successful launch and implementation.

7.4. Outlook and reflections on the future of defence energy and sustainability

The future of defence operations hinges on the successful integration of sustainable energy practices. As the defence sector adapts to new environmental realities, it must assume a leadership role in transitioning to a climate-neutral economy to ensure competitiveness. The recommendations provided in this publication lay the groundwork for a resilient, energy-secure defence infrastructure and capabilities that align with the EU's climate objectives. By embracing innovation and digitalisation and fostering cross-sector collaborations, MoDs can ensure their operations remain robust and sustainable amidst emerging challenges. The European Defence Agency and the European Commission, in coordination with MoDs and relevant stakeholders, are pivotal in preparing the defence sector for the evolving energy landscape. This preparation involves enhancing operational readiness and effectiveness and ensuring that defence operations contribute to broader sustainability and climate resilience goals.

As we move forward, it is essential that the defence sector remains at the forefront of the energy transition. By implementing the strategic initiatives outlined in this publication, MoDs will not only achieve compliance with EU regulations but will also position themselves as leaders in the global effort to combat climate change. The pathway ahead requires a clear vision, unwavering commitment, and collaborative effort. The EU defence sector, supported by robust policies and innovative practices, has the potential to set a global benchmark for sustainable defence operations, driving the change needed to secure a greener, safer, and more sustainable future.

Given that the armed forces are considerable energy consumers, predominantly reliant on fossil fuels, there is a significant opportunity to enhance resilience by incorporating more sustainable sources into their energy mix. This shift involves expanding the use of renewable energy, integrating sustainability into daily operations, and designing infrastructure that is resilient to the impacts of climate change. Securing adequate funding, fostering a cultural shift towards sustainability, and investing in the upskilling and reskilling of personnel are critical measures. These actions are essential to prepare defence personnel for the post-2030 landscape, ensuring they are equipped to manage evolving challenges effectively. Furthermore, given the armed forces' sizable contributions to global greenhouse gas emissions, they have a unique responsibility—and opportunity—to take significant steps in reducing their environmental impact. The EU's objectives to achieve net-zero emissions by 2050 and enhance the energy resilience and readiness of the armed forces demand that the defence sector transitions to more sustainable energy models.

The CF SEDSS, representing the largest European defence energy community in its third phase, has proven to be a key platform for MoDs and relevant stakeholders to share knowledge and promote collaborative research and innovation in sustainable energy. Throughout Phase III (2019-2024), the Forum has successfully implemented its objectives, making a positive impact on the efforts of MoDs to address energy-related considerations and advance climate change adaptation. Since its inception, the forum has generated over 50 innovative project ideas, 20 research studies, and overarching guidance documents, complete with roadmaps, to enable the further development of EU and national policies and practices aimed at reducing energy consumption and addressing climate change challenges.

This publication reflects a portion of the substantial work carried out by the Forum, focusing on identifying gaps and presenting solutions for enhancing energy efficiency and resilience within the defence sector. Initiatives and proposals such as improving energy efficiency, increasing the use of renewable energy, encouraging behavioural changes among military personnel, and implementing pilot projects leveraging AI to optimise energy use and promote green public procurement principles can significantly advance the defence energy transition. Equally important are efforts to electrify transport within defence facilities and integrate hydrogen fuel technology into logistics vehicles. Additionally, the Forum has emphasised developing unified energy performance assessments across European defence installations and incentivising the renovation of defence buildings to meet nearly zero-energy standards.

Overall, the CF SEDSS has been instrumental in advancing the defence energy transition and climate change adaptation, securing nearly EUR 10 million in energy-related funding from the European Commission. A key success of the Forum has been conceptualising the Symbiosis (Offshore Renewable Energy for Defence) project, which received EUR 2 million contribution under Horizon Europe. The Symbiosis project, designed to promote the coexistence of defence activities and renewable energy initiatives, is considered a multiplier effect of the Forum's broader efforts. Furthermore, the outcomes of the Forum have supported several other initiatives, such as the EDA's relevant work strands, such as the Energy and Environment Capability and Technology Group and the Incubation Forum on Circular Economy.

The successful work and progress of the Consultation Forum was recognised in the June 2019 Council Conclusions and again in June 2020, when the Council of the EU invited the High Representative to propose actions addressing the links between defence and climate change. The EU Climate Change and Defence Roadmap, issued in November 2020, included specific actions for the Consultation Forum and recognised its role in enhancing energy efficiency and resilience in the defence sector while contributing to the European Green Deal. The mid-term review of the Roadmap highlighted the Forum's efforts in developing concrete solutions for sustainable energy models within the defence sector, increasing resilience and operational efficiency in the face of climate change. The Forum's work also significantly contributes to key actions of the June 2023 EU's Joint Communication to address the climate-security nexus. Additionally, the project's work and impact have been acknowledged in the EU's Offshore Strategy, the Action Plan on Synergies between Civil, Defence, and Space Industries, and the EU's Action Plan on Military Mobility. This recognition and the substantial contributions of the Forum highlight not only the significant impact of its work but, more importantly, the critical role that the defence sector can play in driving the energy transition and adapting to climate change.

The EU's goal to cut greenhouse gas emissions by 55% by 2030 is ambitious and necessitates active engagement from all sectors. With its strategic focus on enhancing energy resilience, the defence sector is well-positioned to contribute meaningfully to this objective. The active participation of defence experts in the CF SEDSS, alongside policies that integrate climate change and security, underscores a solid commitment to this cause. The energy and environment category under the European Defence Fund and the prospect of a dedicated EU-led Competence Centre on Climate Change, Security, and Defence, as advocated by the Forum, further highlight this dedication. Without compromising operational effectiveness, the defence sector can significantly contribute to a more sustainable and resilient future.

In light of the volatile situation in both the defence and energy landscapes, the next phase of the CF SEDSS will be crucial. The project's fourth phase will further enhance the EDA's vital role in assisting MoDs in strengthening energy resilience and autonomy. As the defence sector continues to navigate the complexities of the energy transition, its actions will play a pivotal role in shaping a secure and sustainable future for Europe. The groundwork laid by the CF SEDSS and its stakeholders not only serves as a foundation for future progress but also as a beacon for other sectors to follow in the pursuit of climate neutrality and energy resilience.

Editors

Dr Constantinos Hadjisavvas, with 25 years of experience in defence and policy formulation, has significantly contributed to military development, defence energy transition, and climate resilience at the European Defence Agency (2014-2024). He led key EU-funded projects, such as the Defence Energy Consultation Forum—Europe's largest defence energy network—and the Symbiosis project, which promotes a symbiotic co-existence between defence and renewable energy. His background includes advisory roles at the Cyprus Ministries of Defence and Foreign Affairs, the Cyprus Permanent Representation to the EU, the Cyprus National Guard, and the African Union Mission in Sudan. A graduate of the Hellenic Army Academy, he holds a PhD and BA in Political Science (University of Cyprus), a Master's in International Conflict Analysis (King's College London), and an advanced degree from the European Security and Defence College. His contributions to European and international forums underscore his expertise in defence resilience.

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Dr Antonis A. Zorpas (see section on editors)

Dr Constantinos Hadjisavvas (see section on editors)

Maja Kuzel (see section on editors)

List of acronyms

Acronym	Explanation
A-CAES	adiabatic compressed air energy storage
AIS	Automated Identification System
BACS	Building Automation Control Systems
BEV	Battery electric vehicle
BIM	Building Modelling Information
CBAM	Carbon Border Adjustment Mechanism
BSH	Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency)
Cas	Competent Authorities
CAD	Computer Aided Design
CAES	Compressed air energy storage
CAPEX	Capital expenditures (CAPEX) are funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment
CEAP	Circular Economy Action Plan
CEI	Critical Energy Infrastructure
CF SEDSS	Consultation Forum for the Sustainable Energy in the Defence and Security Sector
CINEA	Climate, Infrastructure and Environment Executive Agency
COM	Commission
COTS	Commercial of the Shelf
COP	Contingency of Parties
CSDP	Common Security Defence Policy
DEMC	Defence Energy Manager's Course
DETI	Defence Energy Efficiency Tools & Implementation Indicators
DG	Directorate-General
DG ENER	Director General for Energy
EDA	European Defence Agency
EDCAS-SF	Energy Data Collection Analysis and Sharing Support Frame
EDF	European Defence Fund
EEAS	European External Action Service
EED	Energy Efficiency Directive
EEZ	Economic Exclusive Zone
EIB	European Investment Bank
EMS	Environmental Management System
EnMS	Energy Management System
EnPIs	Energy Performance Indicators
ENTSO	European Network of Transmission System Operators
EP	European Parliament
EPBD	Energy Performance Buildings Directive

EPCs	Energy Performance Certificates
EPC	Energy Performance Contracting
EPD	Environmental Product Declaration
ESCOs	Energy Saving Companies
ESS	Energy Storage Systems
ETS	Emissions Trading Scheme
EU	European Union
EUMS	European Union Military Staff
FESS	Flywheel energy storage systems
GPP	Green Public Procurement
GHG	Greenhouse Gases
GW	Gigawatt
GWP	Global Warming Potential
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
IEA	International Energy Agency
IFF	Identification Friend or Foe
IRENA	International Renewable Energy Agency
ISO	International Standardization Organization
JRC	Joint Research Centre
KPIs	Key Performance Indicators
LAES	Liquid Air Energy Storage
LCA	Life-cycle assessment/Life-cycle analysis
LCC	Life-cycle costing
LCoE	Levelised Cost of Energy (a commonly agreed calculation methodology in the industry)
Li-S	Lithium-Sulphur
LMP	Lithium-metal-polymer
LTRS	Long-Term Renovation Strategies
LTRS	Long-Term Renovation Strategy
MoD	Ministry of Defence
MS	Member States
MSP	Maritime Spatial Planning (activity) or Maritime Spatial Plan (product)
MWh	Megawatt per hour
NaS	Liquid Sodium (Na) and Sulfur (S)
NATO	North Atlantic Treaty Organisation
NCI	National Critical Infrastructure
NCO	Non-Commissioned Officer
NCPs	National Competent Authorities
NDA	Non-Disclosure Agreement
NECP	National Energy and Climate Plan
Ni-NaCl	nickel (Ni), sodium chloride (NaCl)

Ni-Cd	Nickel-cadmium
NTD	Naval Team Denmark
NZEB	Nearly Zero Energy Buildings
OEM	Original Equipment Manufacture
O/M	Operations/Missions
OPEX	An operating expense (OPEX) is an expense required for the day-to-day functioning of a business. In contrast, a capital expense (CAPEX) is an expense a business incurs to create a benefit in the future
ORE	Offshore Renewable Energy
PCM	Phase Change Materials
PCP	Pre-commercial procurement
PCRs	Product category rules
PHES	Pumped heat electrical storage
PV	Photovoltaic
RED	Renewable Energy Directive
REEB	Roadmap Energy Efficiency and Buildings
RES	Renewable Energy Sources
SCs	Supercapacitors
SEU	Significant energy consumers
SHS	Sensible heat storage
SMART	Specific Measurable Achievable Relevant Time-bound
SME	Small or medium-sised enterprise
SMES	Superconducting magnetic energy storage
SOC	Sophisticated Organised Crime
SPP	Sustainable Public Procurement
SRI	Smart Readiness Indicator
TED	Tenders Electronic Daily
TES	Thermal energy storage
ToR	Terms of Reference
TTW	Territorial Waters
UXO	Unexploded Ordnance
WG	Working Group
WG1	Working Group 1 (of the CF SEDSS)
WG-2 RES	Working Group 2 on Renewable Energy Sources
WTG	Wind Turbine Generator

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