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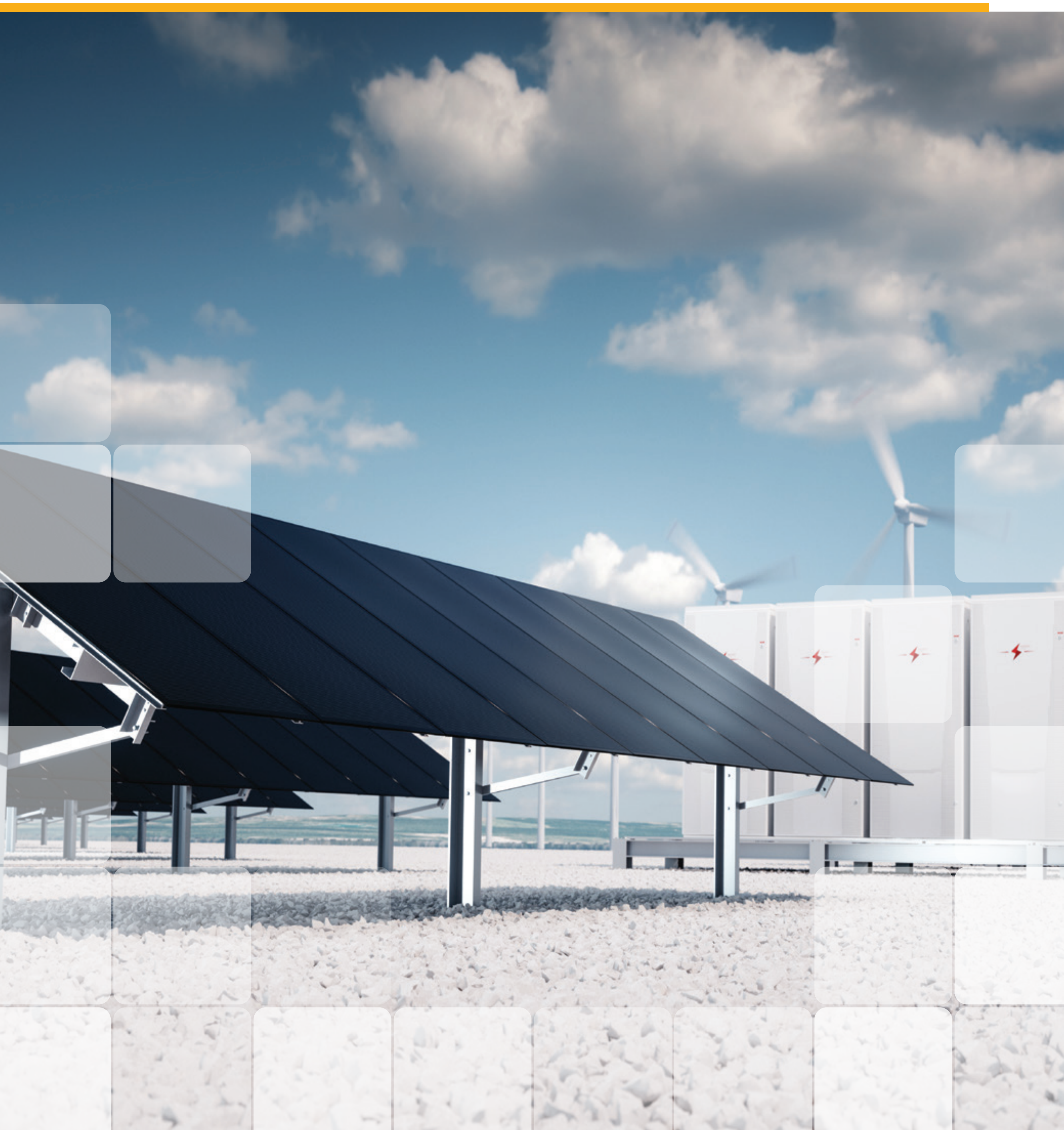
ENERGY HIGHLIGHTS



ACKNOWLEDGEMENTS

The NATO ENSEC COE would like to thank the following organisations for their contribution to the study by providing some information and materials: Estonian Ministry of Defence, Finnish Defence Forces, French Ministry of the Armed Forces, Georgian Ministry of Economy and Sustainable Development, German Federal Ministry of Defence, Hellenic Air Force, Hellenic Ministry of National Defence, Italian Ministry of Defence, Latvian Ministry of Defence, Lithuanian Ministry of National Defence, Norwegian Defence Estates Agency, Polish Military Inspection of Energy Economy, Swedish Armed Forces and U.S. Department of Energy.

The authors would also like to thank Ms. Giulia SIGNORELLI for her contribution to the proofreading phase of the project report during her internship at the NATO ENSEC COE.

Content

Energy efficiency and renewable energy solutions in NATO and PfP countries' military operations

FINAL REPORT OF THE STUDY

JULY 2021, VILNIUS, LITHUANIA

Lead Author:
Ana GOGORELIANI
NATO Energy Security Centre of Excellence, Doctrine and Concept Development Division,
Representative of the Ministry of Economy and Sustainable Development of Georgia

Co-Authors:
Fabio INDEO[*]
Analyst, NATO Defense College Foundation, Italy

Teimuraz PULUZASHVILI[**]
Senior Engineer Designer, Georgian state Military Scientific-Technical Center "DELTA", Georgia

EXECUTIVE SUMMARY

The growing demand for energy around the world and related climate change issues have been forcing various sectors, including the military sphere, to move towards more sustainable development. Military force capabilities continue to be heavily dependent on energy sources and their supply routes. It is recognized that the success of current Land, Air and Naval operations at any location requires the use of a vast amount of energy daily, mainly traditional fuels, and significantly increased consumption during the war. Considering various factors, including the fact that most of the energy sources consumed by the armed forces of NATO nations to ensure security come from outside NATO member states, countries recognize energy security as part of their overall security and strive to improve its parameters.

The development of the combat environment causes increased energy consumption and, consequently, an increased level of dependence on imported energy, accompanied by an increased impact on the environment. The main cause for it is the integration of additional energy-consuming equipment to improve military operational capabilities. Thanks to innovations, defence systems are moving towards integrating more electric-based technologies, and the readiness to provide the energy needed for such technologies will likely become the determining factor in the balance of future forces. Some amount of manned military equipment is expected to transition into unmanned and be controlled remotely. Such a shift in the warfighting environment will also affect both the mix of required energy sources and their supply routes.

In order to meet the energy demands of the anticipated future warfighting environment and at the same time mitigate expected environmental impacts, it is necessary to implement effective energy optimization mechanisms. It means introducing advanced technological and non-technological smart energy solutions without reducing military operational capabilities.

The massive development and introduction of innovative technologies require more investments in people, equipment, and installations, which need an improved intercommunication between the military and civilian sectors. In this process, relationship platforms can play a positive role by enabling an exchange of views on development constraints and future perspectives regarding military energy.

To achieve sustainable defence, at first, as an effective tool, all national decision-making bodies need to declare their visions and long-term plans through appropriate policy and strategy documents. Despite numerous activities towards sustainable defence undertaken by NATO, its member states and some PfP countries, the process is still at an early stage. It requires more active involvement from each country. At this stage, unfortunately, not all NATO and PfP countries express concrete readiness through dedicated policies and other relevant documents. In addition, countries focus mainly on installation energy but not on operational energy, which is a major determinant of the battlefield capabilities of the armed forces.

Using best practice sharing platforms, countries have the opportunity to take into account the experience-based innovative and sustainable energy solutions of other countries and develop new solutions to improve the energy efficiency and sustainability of military operations that can enhance military capabilities while managing risks.

Considering the successful but not widespread experiences of NATO and several PfP countries, there are several essential technological and non-technological tools that can be used to promote energy optimization, for example: the adoption of relevant policies, strategies and other related legal documents to ensure the standardisation of energy management initiatives and to provide a comprehensive regulatory framework within which military branches and departments can coordinate their efforts in accordance with national and international laws and requirements; the development of comprehensive approaches that allow the armed forces to collect energy consumption data from all military branches to develop a unified, coordinated EnMS plan and assess the impact of energy reduction in the military sector; the raising of awareness of energy issues among military personnel to implement an EnMS that promotes the adoption of greener behaviors in the armed forces; the appointment of energy managers during military operations and at defence installations to identify, implement and maintain efficient measures aimed at reducing energy consumption for promoting energy efficiency without jeopardizing mission capabilities or reducing the quality of life of personnel; implement education and training practices to raise awareness of military personnel about how energy affects missions and capabilities focusing on the importance of behaviour change; the development of Sustainable and Green Procurement in the acquisition of military equipment, services and systems to achieve greater efficiency, resilience and adaptability; the introduction of the practice of Energy Performance Contracts to upgrade energy efficiency of military bases and buildings through energy performances guaranteed by the private sector. The most expensive and, at the same time, most effective tools identified in the process of reaching sustainable defence within NATO and several PfP countries are the development and introduction of innovative smart energy technologies, such as: fixed and deployable renewable plants and hybrid power generation systems to utilize inexhaustible, free, non-polluting, local energy, that increases the independence and flexibility of the armed forces and saves the budget; fixed energy storages to power systems by absorbing power during periods with low demand and injecting power during periods with high demand; advanced mobile energy storages to ensure the armed forces' energy powering during long-term mobile missions; stationary smartgrids for fixed bases and mobile ones for contingency bases to create more efficient, reliable, and resilient systems and effectively integrate a growing amount of intermittent energy sources like solar and wind into the grid; energy management systems to control generators, maintain storages and manage demand to meet operational requirements and energy use patterns; sustainable energy-powered, hybrid-powered and energy-efficient technologies to increase the utilization of sustainable, mainly renewable energy sources, decrease dependence on fossil fuels, increase the forces' resilience and, at the same time, minimize the environmental footprint; also, the development of alternative fuels and the gradual replacement of traditional fuel sources by alternative fuels taking into account certain natural limitations.

Despite the steps taken forward, most of such smart regulatory mechanisms and advanced technologies that support sustainable defence are just rare examples and are still not widely introduced in the military forces.

In order to effectively transform the current military energy mix into more sustainable ones by using the above-mentioned and other advanced tools at different scales, it is recommended to perform a cost-benefit analysis of various possible long-term development scenarios, both at the national and NATO levels. Through such analysis, it will be possible to determine the approximate maximum that the military forces can do to achieve sustainable defence without reducing capabilities. It will also be possible to select the most effective scenario and determine further appropriate steps.

As energy transition issues are one of the most significant challenges and potential tools for improving the capabilities of the Armed Forces, it should be integrated into the full range of defence policies, strategies, plans and activities of NATO (among them into the NDPP) and its member states, including in the processes of equipment procurement; which should be followed by a monitoring, evaluation and reporting process. In addition to integrating the issue into the various national and international regulatory documents, there is also a need to develop dedicated policies, strategies, plans and other related measures on military operational energy. Planning should involve current and future military land, navy, and air operational and non-operational activities covering both short-term and long-term periods. The process should ensure the adaptation of already developed technological and non-technological approaches and the implementation of research and training projects to find and develop new smart energy solutions.

1. INTRODUCTION

Due to the high dependence of military force effectiveness on the uninterrupted supply of energy resources to perform their tasks under different weather conditions and over various geographical locations, energy matters require various kinds of smart technological and non-technological solutions.

The report represents the study project conducted by the NATO ENSEC COE, within the Italian MoD and French MoD initiative, which provides a comprehensive overview of the best examples of implemented and planned solutions of energy efficiency and renewable energy performance within the military land, naval and air operations of NATO and several PfP countries. By sharing the best existing EE and RE solutions and future development visions, the paper aims to support NATO and PfP nations in improving their knowledge about EE and RE matters in the military field to reduce negative environmental impacts and defence expenditures, as well as to improve resilience and security of the military forces.

In the first phase of the project, to select the best energy solutions implemented by the countries, 22 countries were chosen within NATO and PfP, based on the information available online: NATO ENSEC COE's members, 8 NATO and 2 PfP countries. However, taking into account the information available online as well as the information provided (considering the language barrier, mainly English and Italian sources were used), the study focuses mainly on the following 12 countries: Canada, Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Spain, Sweden, the United Kingdom, and the United States.

It also includes some examples from other countries. The principle of selecting countries is based on the implemented, ongoing and planned activities of nations in the field of military operational energy transformation and information on their activities available at the national and international levels. Because the focus area of the study is operational energy required for training, moving, and sustaining military forces and weapons platforms for military operations, it does not include those and other countries' smart solutions related only to installation energy despite the availability of information.

In order to support the achievement of sustainable energy security in the defence sector, by raising awareness of this issue, the paper provides an overview and recommendations on the following topics, focused on operational energy: energy demand tendencies and future expectations in the military sector; energy efficiency and renewable energy regulations in the military field and their effectiveness based on countries' experiences; best practices of Energy Management System and their potential for reducing energy, especially traditional fuel, consumption in the military field; the best examples of existing and promising smart energy production, storage, distribution and energy consumer technologies used in the different military branches. It also provides a short overview of the future plans of 12 countries regarding operational energy.

2. THE ROLE OF THE MILITARY FORCES IN A GLOBAL SUSTAINABLE ENERGY SECURITY[1]

For centuries, the geographical map of energy sources has played a crucial role in the world's geopolitical situation. The development of countries and the relationship between them often depend on energy issues. It often becomes a reason for tension. As a positive effect, energy is one of the drivers of innovation in the world. Still, at the same time, it requires lots of effort to use its potential considering environmental issues; because sustainable development - a development that meets present needs without compromising the ability of future generations to meet their own needs - is one of the major global goals and responsibilities of today's world.[1]

To achieve more stability, unions and countries seek to diversify energy sources, routes and suppliers, which is one of the main components of energy security, but innovation is the best tool that changes the shape of a geographical map of commercially usable energy sources. The main problem of global energy security is the growing dependence on fossil fuels, which are located in some of the most unstable parts of the planet; which is also a challenge for global sustainable development. It is widely acknowledged that through the years, the emissions of GHGs from human activity have become an additional cause of global warming. Climate change is becoming a cause of more extreme weather events with severe implications for infrastructure, property, health and nature. To achieve global sustainable development, a united effort to limit climate change is required, but in the process, it is necessary to take into account the environmental, social and economic aspects of sustainability. One of the best ways to limit climate change is lowering the use of fossil fuels and increasing clean energy instead, especially in the field where energy demand is significantly high; which at the same time increases energy security. The military sector is one of the top energy consumers and GHG emitters. Military operations, both inside and outside the country, often have a significant impact on the environment, as oil-based fuels are the dominant energy source for aircraft, ships and land vehicles, as well as for providing electricity and heating, not only for deployed forces but also for base installations. From another perspective, energy is a fundamental enabler of military capability; it is essential to the Land, Air and Naval Forces' combat capability. Energy, most often fuel and electricity, is critical for the success of military operations. It must be available in the home country and abroad, over great distances, under different weather conditions, and across air, land, and sea, often against determined adversaries.

However, climate change as a national security issue is a challenge for the future military forces as well, because it has potential impacts on the military forces' built and natural infrastructure, missions and operational plans. It affects the daily running of military installations and military

[1] Sustainable energy security is defined as "the provisioning of uninterrupted energy services in an affordable, equitable, efficient and environmentally benign manner".

forces' activities due to changes in the natural characteristics of the area of operations and the limitation of the available energy and water resources. High temperature could also undermine the operational capabilities of military missions by affecting the health of soldiers. Additionally, climate change might affect the emergence and spread of infectious diseases, which, in turn, might also influence the Army's capabilities. It also influences people's quality of life, including access to water and food, which is one of the main reasons for migration and also, for wars between nations.

Therefore, on the one hand, the growing consumption of energy and, on the other hand, the mobilization of lots of human, material and financial resources in the military forces create the military sphere as a sector with huge potential to play one of the leading roles in global security and sustainable development. Accordingly, considering energy security and environmental issues is a critical element of the military forces' main task, including achieving lower energy consumption, limiting the amount of waste and reducing impacts on the surrounding land, air and marine ecosystems. For this reason, the situation requires the integration of sustainability aspects into all activities of the military forces as components of their daily work.

2.1. ENERGY AS A FUNDAMENTAL ENABLER FOR MILITARY FORCES EFFECTIVENESS

There are many different military operations and missions worldwide operating under various environmental conditions. NATO is an active and leading contributor to peace and security in the international arena. Currently, NATO is leading operations in Afghanistan, Kosovo and the Mediterranean. It also carries out training missions in Iraq, peacekeeping missions on the African continent to support the African Union, and air police missions in its airspace. About 20,000 military personnel are engaged in NATO operations and missions worldwide, often managing complex ground, air and naval operations in all types of environments.[2] The effectiveness of each operation depends on the quality of people and products. It directly depends on the availability of resources such as energy and water, as well as on the resiliency of installations, weapon systems and personnel.

To improve operational capabilities, energy is critically important. It is a fundamental enabler for the sustainment of every military mission and operation. Energy powers bases and platforms; it ensures the effective fulfillment of the military forces' tasks. The troops need a vast amount of

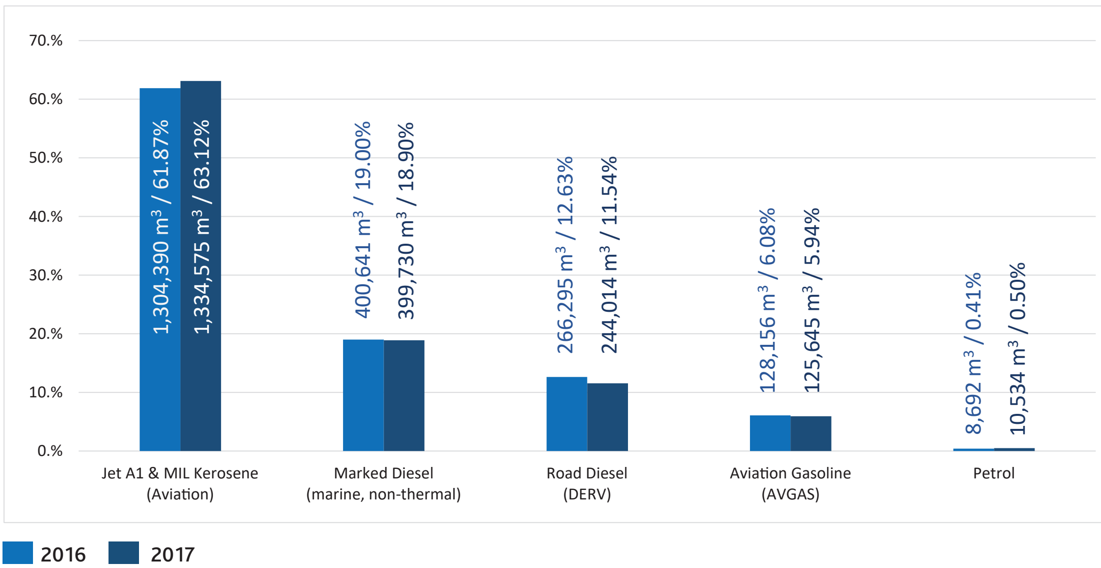


Figure 1: Energy consumption for transport by the armed forces of the 22 EDA member states, 2016 - 2017
Source: EDA [3]

energy to ensure operations on a day-to-day basis. It is even more required during operations against an enemy. At the tactical level, a lack of energy can constrain the endurance of army units and limit flexibility and freedom of action. Both mounted and dismounted forces rely on a predictable resupply of fuel and batteries, which exposes soldiers to tactical risks, and limits commanders' options.

In 2016, the total energy consumption of the armed forces of the 22 EDA member states (of which 17 are member states of NATO) amounted to 41 339 GWH and in 2017 - 40 266 GWH. Most of the energy consumed, 52% on average, was spent on transportation, 32% for heating, and electricity amounted to 17%. Transportation fuel was almost entirely composed of emission emitter traditional fuels, and 63% of it amounted to Aviation fuel. For heating purposes, 18 different energy sources were used, but 75% of the total consumption was covered by fuel oils and natural gas. The share of sustainable energy sources used by the armed forces for heating purposes was a very small percentage. EU and NATO armed forces are moving towards more sustainable defence energy models; but given the scarcity of defence energy data (only two years' collected data exist), the trend is not yet visible.[3]

Considering EDA's data, one study estimates that the carbon footprint of EU military expenditure in 2019 was about 24.8 million tCO_2 e, which is equivalent to the annual emissions of approximately 14 million average cars.[4]

According to different characteristics, priorities, and opportunities, military energy can be divided into operational and installation. For example, the U.S. has a separate definition for each of them. According to the law of the U.S., they consider operational energy as the energy used in military operations, in direct support of military operations, and in training to support unit readiness for military operations. It is defined as "energy required for training, moving, and sustaining military forces and weapons platforms for military operations." It includes energy used by tactical power systems and generators, as well as by weapons platforms themselves. Traditionally, the scope of operational energy of the U.S. excludes nuclear energy used for the propulsion of the Navy's aircraft carriers and submarines, as well as the energy used for military space launches and operations. According to the same law, installation energy is the energy used to heat and cool buildings, provide electricity, and power non-tactical vehicles. In many ways, installation energy supports warfighter requirements through secure and resilient sources of commercial electrical energy, and where applicable, energy generation and storage to support mission loads, power projection platforms, remotely piloted aircraft operations, intelligence support and cyber operations.[5,6] The content of Canada's definition of Operational Energy is almost the same: the energy required for training, moving and sustaining military forces and weapons platforms for military operations.[7] Something similar is found in the case of the Netherlands: energy required by operational units for training, preparing for combat readiness and national and international operations.[7]

The UK has a slightly different definition: Operational Energy is the energy that is used to generate and sustain military capabilities. They also use the name "Capability Energy" instead of "Operational Energy" to reflect the explicit link between energy and military capabilities. They define Capability Energy as the energy required to train, deploy, sustain, recover and recuperate fighting forces and support elements worldwide, now and in the future. This definition excludes the energy required to power domestic utilities, largely, but not exclusively, in the strategic bases, which remains the responsibility of the UK DIO. In addition, this does not include nuclear energy as it falls within the nuclear portfolio and the Defence Nuclear Executive Board's responsibilities. They also divide Capability Energy into the energy used for business-as-usual, "peacetime" activities (usually to train and regain strength) and the energy used for operations (to deploy, sustain and recover the force). Another factor is that the energy used during operations includes the energy required for temporary operational bases and deployed operating bases, while the energy needed for infrastructures in the business-as-usual situation is a separate portfolio owned by the DIO.[7,8]

Unfortunately, there is no widely accepted definition of Operational Energy, and the boundary between Operational and Installation Energy is a bit unclear.

As an example, the U.S. DoD is the largest single energy consumer in America. Together, the DoD's operational and installation energies make up about 80% of the federal government's total energy consumption. An estimated 75% of the DoD's energy use is for operational use and the remaining 25% is used for installation energy. The DoD's operational energy use is dominated by air and sea platforms of the Air Force and Navy; the Air Force uses roughly half of the fuel consumed by the DoD, and the Navy consumes about one-third. In 2019, the U.S. DoD consumed nearly 84 million barrels of fuel to power ships, aircraft, combat vehicles, and contingency bases; the total operational energy expenditure accounted for $11 billion. In 2019, the Air Force spent $5 billion on approximately 2 billion gallons of aviation fuel.[5,6,9]

The demand for energy during military operations has been increasing. To illustrate this point, fuel consumption in the U.S. Army increased from an average of one gallon per soldier per day during World War II to 20 gallons per soldier per day during Operations Enduring Freedom and Iraqi Freedom.[10] One of the reasons is that bases and soldiers are equipped with additional energy-demanding equipment that provides both increased safety and quality of life. The inefficient use of generators in camps, poor insulation of shelters, and a lack of desire or awareness to control energy consumption have contributed to increased demand. It has significantly increased the financial and logistical burden and put soldiers and contractors at risk in convoys, for which additional support requires time and resources from other missions.[11]

Large amounts of diesel fuel and other cargo are often transported to remote and/or dangerous areas, with increased risk to personnel and equipment and significantly added financial cost. A study of the U.S. Army Environmental Policy Institute found that, between 2003 and 2007, more than 3,000 U.S. troops and contractors were dead or injured during attacks on fuel and water convoys in Afghanistan and Iraq, with approximately one casualty for every 24 convoys. [6,12] Unfortunately, the loss of life resulting from it is unacceptably high. Such facts once

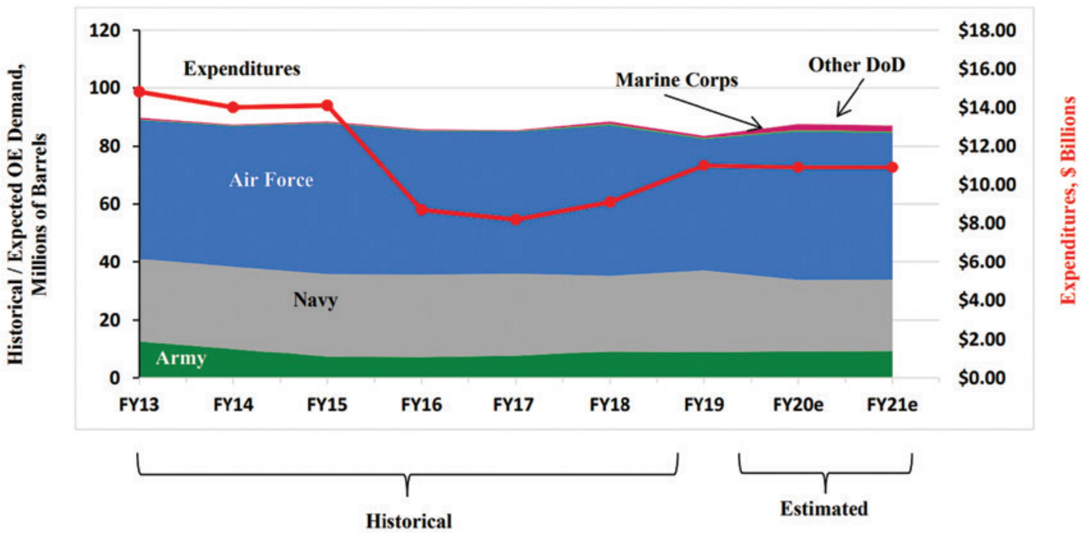


Figure 2: The U.S. military operational energy demand, 2013 - 2021
Source: U.S. DoD [9]

again underline that considering sustainability elements helps to improve the military forces' operational capability and vice versa. Transporting diesel is not only highly dangerous but also highly uneconomical. Data shows that for every gallon of generator fuel used during the Afghan conflict, seven gallons were used for its transportation. Consequently, the accumulated costs of delivering each of these gallons to a forward operating base can add up to hundreds of dollars. [8] The U.S. Navy has estimated the demand at 1000 kWh per day for a company-sized base.[8] This demand is almost entirely covered by generators fueled with diesel, which is delivered via an expensive, inefficient and dangerous supply chain. To best support its forces and reduce the risks of moving fuel, the U.S. DoD purchases fuel close to the point of use; in 2019, the DoD purchased 48% of its fuel outside the U.S.[9]

NATO acknowledges that its military energy consumption has reached unprecedented levels and that military energy requirements continue to rise; current levels of the Allies' military energy consumption are unsustainable in the long run. [13] The level of energy consumption is one of the reasons why NATO's activities, particularly operations and exercises, which involve movement, deployment, sustainment, and redeployment of considerable quantities of equipment and troops, have a significant environmental impact.

The growing energy demand during operations greatly affects the effectiveness of military forces. The supply of energy to end-users requires enormous logistical efforts and costs, and the dependence on energy in combination with the vulnerability of lines of supply creates security risks. It is important that military land, naval, and air operations rely almost exclusively on traditional fuel sources. Along with growing consumption, the volatility of fuel prices is also an essential factor; it complicates the adequate delivery of energy to the military forces. Rapidly rising prices can become a serious problem for countries' budgets. For example, the U.S. DoD estimates that every $1 increase in the price of a gallon of petroleum-based fuel costs the U.S. military billions of dollars in additional fuel costs. [6] That is why to minimize the risks related to fuel transportation and avoid spending extra money, purchasing fuel close to the point of use is one of the right solutions, as in the case of the U.S.. As a positive side-effect, rising fuel costs, the logistical challenge of supplying large quantities of fuel during operations, and the risks to the soldiers protecting fuel convoys became drivers of national and multinational initiatives for the development of alternative energy supply and energy-efficient technologies, with consideration of sustainability components.

For lowering the carbon footprint and, at the same time, increasing the effectiveness of the armed forces, the greening of defence is essential. The optimal way to contribute to climate change mitigation is directing towards a sustainable model of military operations to develop resiliency to the oncoming changes, including an adaptation of new renewable energy and energy-efficient technologies in the sector, the development of natural resource management and adequate infrastructure. The reduction of dependence on traditional fuel could be achieved by developing efficiency in mobile platforms, either land, air or naval, and fossil fuel-based power generation plants; by using renewable energy systems adapted to the military environment, as well as by smart and decentralized energy management systems and by improving infrastructures where energy consumption is concerned.

In many cases, future energy demand is not adequately factored into capability planning stages, and opportunities for efficient consumption are rarely explored. However, there is a common understanding that the reduction of energy usage, along with the enhancement of energy efficiency, are important for reinforcing military operational capabilities, and simultaneously reducing energy budgets as well as resource-spending and GHG emissions. Therefore, for better results, considering the activities for increasing the share of renewable energy sources and improving energy efficiency from the planning stage is very important.

Reduced energy consumption means increased range, endurance and agility as well as increased operational flexibility and resilience of forces, which improves operational capabilities. Saving fuel means that constrained defence budgets can be used to support other ongoing operations and/or invest in future capabilities, which is significant due to the growing complexity of military operations. However, reductions in energy use should not be the sole target, because without considering energy efficiency and alternative energy sources, it could become a reason for decreasing operational capabilities.

2.2. GLOBAL AND NATIONAL ATTENTION TOWARDS "GREENING" DEFENCE

Three main objectives drive the EU's energy policy: securing energy supply to ensure the reliable provision of energy whenever and wherever it is needed; ensuring a competitive environment for energy providers that supports affordable prices for households, businesses, and industries; sustainable energy consumption, through the lowering of GHG emissions, pollution, and fossil fuel dependence. Considering these objectives, the EU has developed the "Climate and Energy Framework 2030", which includes the EU's goals for the period 2021-2030. According to it, the EU plans to reduce GHG emissions by at least 40% compared to 1990, increase the share of renewable energy in the EU's energy consumption to at least 32%; achieve a 14% share of renewable energy in the transport sector and reduce energy consumption through improvements in energy efficiency by 2030 by at least 32.5%, relative to a "business as usual" scenario.[14] By 2050, the EU aims to achieve an 80% to 95% reduction in GHGs compared to 1990 levels; reach a 75% share of renewable energy sources in gross final energy consumption, including a 97% share of renewable energy sources in electricity consumption.[15]

Along with the EU, NATO recognises energy security as part of their common security, a key element of the Alliance's enhanced resilience and for countering hybrid warfare; since for NATO, assuring energy supplies to military operations is very important. Also, the "NATO 2030" document underlines climate change as one of the most significant challenges for NATO, which holds serious implications for the security and economic interests of all thirty members of the Alliance. [16] The Alliance emphasizes the importance of green defence, which is defined as a multifaceted endeavour that consolidates different types of activities, including operational effectiveness, environmental protection, and energy efficiency. It involves several directions, including operations, logistics, engineering and defence planning; it also includes various actors: civilian and military, allies and partners, international organisations and the private sector. Today, different activities related to Green Defence are underway throughout NATO and its nations. There are various projects to share the best practices of "green" solutions that can improve the efficiency of resources and create operational benefits at a reasonable cost via different types of activities. At the international policy level, the Green Defence Framework (adopted in 2014 by NATO Defence Ministers) is one of the main documents that gives direction for the NATO green agenda and forms a basis for cooperation regarding the development and use of green solutions within the military area. Additionally, security concerns related to the environment were acknowledged in the 2010 Strategic Concept. NATO has also developed some standardization documents related to Military Energy, which are part of its efforts to improve energy efficiency: STANAG 2536, Allied Joint Doctrine for Petroleum; STANAG 2406, Land Forces Logistic Doctrine; STANAG 2582, Environmental Protection Best Practices and Standards for Military Camps in NATO-Led Military Operations; and STANAG 2394, Allied Tactical Doctrine for Military Engineering.[7,17]

Various committees, working groups and NATO bodies work on different aspects of Green Defence. The Allied Command Transformation and the relevant COEs, including ENSEC and MILENG COEs play a significant role in these activities. Green Defence related issues continue to be reflected, where appropriate, in NATO training and education curricula as well as exercise planning, relying on existing efforts in this area and highlighting the direct operational value of energy-efficient technologies and practices. The NATO STO works on making groundwork for "greener" future military capabilities and cooperates with NATO Military Authorities. Through various structures, NATO seeks to ensure an effective connection between all of these efforts within the Alliance that could potentially reduce costs, lower the risks to Allied soldiers and help to reduce the environmental footprint. Over the past years, the Allies have been looking for ways to reduce their armed forces' energy consumption. The Petroleum Committee is responsible for revising the vision on future fuels. NATO Military Principles and Policies for Environmental Protection, a range of NATO STANAGs and other joint standardization publications provide a solid conceptual basis for environmental protection during the preparation and execution of military activities. The NATO Army Armaments Group developed a number of projects that have environmental and energy savings elements. The NATO Industrial Advisory Group is looking into dual-use green technologies in support of consequent management operations, and considers the "green" aspects of capabilities whenever possible and appropriate. [7,17]

Like other sectors, the defence sector is also responsible for taking into account unions' and nations' visions and strategies regarding energy and climate change, along with their needs. According to available national and international materials, within NATO and EDA countries, in the case of most MoDs, the Energy Strategy is consolidated with the Environmental Protection or Sustainable Development Strategy into one document. Only in a few cases has a stand-alone Energy Strategy been issued. Also, only a few countries have issued both a Sustainable Defence Strategy (including energy) and a dedicated Energy Performance Strategy. In the majority of the MoDs that do have an Energy Strategy, the Energy Strategy is linked to military operational capabilities. In the other cases, the Energy Strategy deals only with infrastructure and support activities. Only a minority of nations have a separate energy strategy or policy for defence, and Only a few countries have implemented the RES and EE directives in the defence sector. The fulfillment of the goals set up by the strategies is highly dependent on the availability of funds and investments for the MoDs; unfortunately, sometimes actions do not follow plans, but most of the MoDs recognise the necessity of Energy Strategies as the significant enabler to increase energy efficiency and reduce energy consumption within the defence sector. During the development of a military energy strategy document, it is recommended to effectively link the aspects of energy and sustainability to the objectives of the defence sector for better results.

Only a few NATO and PfP countries have developed official national documents reflecting operational energy issues. In this regard, the case of the U.S. is particularly noteworthy. They have developed the Operational Energy Strategy 2016, which identifies a comprehensive set of initiatives to improve future capabilities, reduce risks, and enhance current mission effectiveness. There is a focus on the following tasks: increasing future warfighting capabilities by including energy throughout future force development; identifying and reducing logistical and operational risks from operational energy vulnerabilities; enhancing the current force's mission effectiveness through updated equipment and improvements in training, exercises, and operations.[5]

Only a few nations have approved definitions of "operational energy" and "military energy efficiency". In most cases, these are the nations that are developing or have already approved Defence Energy Strategies. Nationally approved definitions of energy efficiency are often used in both civilian and military contexts.

Despite the many activities of NATO and its Nations for greening defence, the process is still at an early stage and requires the more active involvement of each country.

2.3. THE IMPORTANCE OF CIVIL-MILITARY CO-OPERATION FOR THE "GREENING" OF DEFENCE

As a development tool, innovation plays a significant role in all spheres, especially in the military sector. In order to optimize energy consumption, in addition to increasing the use of renewable sources, energy-efficient measures are also required. However, energy resources have to be used efficiently as long as they do not reduce the combat power of the armed forces. Enhancing the energy efficiency of the military forces means spending less money on fuels and reducing the environmental footprint. At the same time, more energy-efficient equipment means transporting less fuel over long and dangerous supply routes. Reducing the logistics footprint by improving energy efficiency is a key factor for the armed forces, both in permanent national installations and in installations in the area of operations, where missions are undertaken in complex scenarios in which the security of the logistics chain could cause problems. Also, based on experience, the price of fuel could increase significantly; the military forces are vulnerable to sudden changes in the price of energy and disruption of supply. The military forces' over-reliance on petroleum-based fuel causes operational, strategic, and financial risks and endangers critical missions.

First of all, the military forces' timely and adequate adaptation to the new environmental and climatic conditions is important. The armed force's ability to perform tasks is highly dependent on the uninterrupted supply of energy resources, because to operate in the chosen time and place requires more lethal, resilient, adaptable, and innovative capabilities in every domain of warfare. Operational energy, as a vital enabler for critical military missions, must be available in the right quantities and at the right time to support global operations. Therefore, the earlier the forces take into account energy transformation in the planning process, the more they will be able to influence the design and capabilities of future systems. Alternative sources of energy supply have to be identified in the planning of military operations. In addition to reducing energy demand, it is essential that the decision-makers focus on achieving increased warfighter capability during energy planning. By consistently including green elements in the planning process, execution and evaluation of operative deployments, a reduction in logistical needs and energy consumption are enabled. Consequently, this may lead to significant environmental benefits that ultimately could increase efficiency in the mission areas. Additionally, this may also result in lowering the cost of operations.

The military forces' needs to reach this target show that lots of investments in people, equipment, and installations are required. Significant investments in new low-carbon technologies, renewable energy, energy efficiency, storage and grid infrastructure are needed. Technologies such as smart grids to improve bases' energy management, energy production based on non-traditional fuels, insulation against heat and cold, energy-efficient lighting systems, small portable energy storages for soldiers, and others are technologies that together can fundamentally change the way to conduct future military operations. For the development and improvement of suitable innovative technologies, the governments' budget is not enough; the commercial industry also plays a significant role along with governmental and multinational organisations. However, since the military sector is a sphere that mostly depends on the governments' and alliances' decisions, their identified and declared needs are very meaningful for the commercial industry. Declaring countries' national aspirations to move towards "greener" defence, through policies and strategies, helps commercial industries decide to invest money in developing new innovative technologies. It is also very important for research institutions, which support this sphere. Unfortunately, there are no such informative documents in many cases, or materials are restricted for the majority of stakeholders due to secrecy. Another problem is the language of documents; often, they are only in the national language.

Fortunately, many countries spend lots of money on the development of innovative products, especially the U.S., which widely focuses on technology innovation and tries to identify and invest in unique capabilities to maintain the DoD's military superiority in the 21st Century.[18] Over the last years, the U.S. military has invested a significant amount of time and money into renewable energy, energy efficiency, and sustainability.[6] Canada's contribution is also important; they have also invested more than $165 million in green infrastructure projects to green their operations and reduce their environmental footprint.[19] Since 2017, the EDF, which is a component of the EU's CSDP, has been playing a significant role in increasing national investment in defence research and improving interoperability between national armed forces. The fund consists of two components: Research and Development & Acquisition. For the period 2021-2027, the total agreed budget of the EDF is €7.953 billion. According to the plan, from this amount of money, about one-third will finance competitive and collaborative defence research projects, in particular through grants, and two-thirds will complement member states' investments by co-financing the costs for defence capabilities development following the research stage.[20] The EDF also takes into account the issues of sustainable energy and energy efficiency, and the EU countries expect to develop some projects in this area with its support.

In the development process of the military sector's sustainable components, having a platform for sharing the information and experiences regarding best practices and technologies, and also for the demonstration of technologies, is significant. One of such successful platforms is the international conference and industrial exhibition IESMA[2] - the Innovative Energy Solutions for Military Applications, organized by the NATO ENSEC COE; where energy experts from military, academia, industry and government from NATO and NATO partner nations and other countries around the world, discuss advanced energy technologies, material and non-material aspects of smart energy; IESMA offers companies the opportunity to display, explain and present their innovative energy solutions/technologies.

2.4. FUTURE DEVELOPMENT VISIONS, PLANS AND EXPECTATIONS

In the future, the world will need more energy, and its production and usage will be a critical factor for the future global economy, geopolitics, and environment. Based on a business-as-usual scenario, McKinsey's "Energy 2050" estimates that in 2050, coal, oil and gas will continue to account for 74% of primary energy demand, compared with 82% in 2016. The report identifies several possible outcomes, including that:

- Global energy demand will continue to grow, but growth will be slower by an average of about 0.7% per year through 2050;
- Demand for electricity will grow twice, noting that China and India will account for 71% of new capacity. By 2050, electricity will account for a quarter of total energy demand, compared with 18% in 2016, and non-hydro renewables will account for more than a third of global power generation;
- Fossil fuels will dominate energy use through 2050 due to the massive investments that have already been made and because of the superior energy intensity and reliability of fossil fuels;
- By 2036, energy-related GHG emissions will rise by 14% compared to the 2016 level, in direct contrast to the goal of the 2015 Paris climate conference.[21]

Given global energy demand growth, prices will likely continue to be volatile, influencing almost all sectors. A crucial way to reduce related risks is technological development to ensure that the world will get the energy it needs considering environmental harm mitigation, which requires substantial new investments in various sectors. One of such sectors is the military sphere, because energy demand for the provision of military operations will be quite notable. Capabilities will be at the core of new technologies, linking strategic bases and operational headquarters to the deployed armed forces right down to servicepersons, advanced robotics, and tactical equipment types such as sensors. The amount of information being exchanged is likely to increase by orders of magnitude, and the information coordination requirement will increase correspondingly, as the requirement for processing power, whilst remaining secure and able to combat cyberattacks.

The power required to support this integrated technology will be complex with deployed personnel, requiring a light, high endurance, resilient and agile power supply. The challenge for the support network will be in supplying the power and maintaining the associated equipment. The nature and balance of the energy requirement will significantly change.

New defence technology solutions will bring different energy requirements and, when set against global environmental targets, will drive a need for

[2] https://www.iesma.info/

resilient, agile and sustainable alternative power solutions. In particular, there is likely to be a need for rapid charging of vehicles, communication equipment and possibly future weapons. The use of Robotics and Autonomous Systems and Additive Manufacture capabilities, health monitoring and wearables, while possibly reducing overall defence energy requirements, will require discrete energy provision at the point of need, which could be at the forward edge of the battlespace. Thus, energy storage, generation, and distribution, possibly over significant distances, may well need to change significantly from today, at all three levels: strategic, operational, and tactical. Renewable sources, which are less suitable for today's military operations, for example, hydropower plants, might become more important sources for future operations as energy sources for distance control services. Depending on location, remote control platforms are part of installation energy, with the ability to connect to central power grids, but they have a direct impact on military operations that will be much higher in the future operational environment.

To meet future military requirements, according to experts in the field, there are several enabling technologies and innovations which have more potential for development:[8]

- Smaller, lighter, higher energy density batteries to enable longer operation times and support more power-consuming equipment without reducing platform mobility;
- Batteries or fuel cells with greater power density to provide more power without increasing the physical burden on the individual;
- Structural and conformable batteries, solid electrolyte batteries and load-bearing supercapacitors that form part of the hull, wing, fuselage or chassis of a platform, saving internal space and allowing for alternative weight distribution;
- Ultra high-power batteries and flywheels that can deliver huge bursts of energy in a very short time before returning to their full storage capacity within minutes, essential for technologies such as directed energy systems and electromagnetic aircraft launch systems;
- Remote charging stations deployed in the field, which expand the range of electrical platforms;
- Wireless power transfer, either on contact or beamed from a directed energy system, to enable recharging with minimal disruption to operations;
- Energy informed operations microgrids, in which power input, output and storage are monitored, informing decisions on energy generation, storage and conservation;
- Integration of microgrids with external power consumers and providers to offer a system of systems view of total power availability and demand;
- Power management system, which integrates power data from all sources and takes automated steps to increase generation, reduce consumption, or redirect energy from other sources;
- Renewable energy sources to service low-level power requirements, such as wave-powered propulsion for maritime vehicles and solar cells to power self-sufficient smart sensors;
- Easily portable power systems to fuel equipment and recharge on-person power in remote locations – Integrated and ergonomic body-worn power systems that can draw power from multiple sources and supply it to any piece of necessary equipment, based on modular architecture so that the kit can be removed at pace in an emergency;
- Sustainable power sources, such as large, rapidly deployable solar panels, or turbines, driven by wind or water, to supplement diesel-generated power;
- Hybrid field power units – small, lightweight diesel generators combined with fuel cells, batteries and inverter systems to reduce diesel consumption for small command posts by up to 80%;
- Hybrid electric drive systems for land platforms, which create new design options that improve mobility, survivability and lethality;

- Where practical, resupply using unmanned or autonomous systems to further reduce the burden on the soldier;
- Advanced situational awareness tools, such as head-up displays, gunshot localisation, and navigation that works in GPS-denied environments;
- Situational awareness provided by smart remote sensors, such as mounted on unmanned platforms, which process data at the delivery end to reduce the computing power needed at the receiving end;
- Advanced materials that improve the thermal performance of structures, minimising the loss of hot or cold air and reducing the power generation requirement through decreased wastage.

In order to meet future needs of military energy, at first, clear, unified national visions are necessary with a focus on all three components of energy transition: improving capabilities, mitigating climate change and enhancing energy security parameters. To support the energy transition process of the Armed Forces of NATO and its member countries, based on the NATO ACT initiative, NATO ENSEC COE has begun the work for the development of the NATO concept on Operational Energy, which will be submitted to the NATO countries for approval. The first phase (pre-initiation) of the project has already been completed; the Concept Plan and Resource Request (CP&R) document has been submitted to the NATO ACT for approval by the NATO HQ SACT. Based on existing and perspective smart technological and non-technological energy solutions, including energy efficiency and sustainable energy, this concept aims to suggest to NATO, its nations and partner countries guidance for preparing the logistical assets and procedures related to future operational energy.[156]

Currently, as mentioned, in most nations, strategic military energy topics are addressed in either National Defence Strategies, National Energy Strategies, National Environmental Strategies, National Military Environmental Strategies or National Security Strategies. However, in many nations, military energy topics are more generally mentioned and there is no direct guidance provided regarding further developments in the military energy domain.

The majority of nations indicate that the consideration of energy efficiency and sustainable energy components during military procurement, personnel's education and industry development are enablers for greening defence and enhancing military energy efficiency. Countries are taking various steps to develop and improve energy efficiency and sustainable energy in the military sector. Most national efforts towards it are concentrated on the following areas: infrastructure (e.g., lighting, heating, cooling and ventilation); reduction of the use of fossil fuels; mitigation of CO_2 emissions; diversification by the integration of renewable energy sources; and adaptation to climate change. The majority of national efforts are concentrated on improving energy efficiency and increasing the share of sustainable energy in domestic defence infrastructure and activities. Only a few nations are addressing it during deployed operations. Smart energy has become one of the major topics for many governments that are trying to reduce energy dependence to increase the capabilities and security of their military forces. Various national field studies have been conducted and planned to assess opportunities to improve energy efficiency and increase the share of sustainable energy in the military field. Not all NATO and PfP countries' efforts and plans towards improving operational energy parameters are available or noticeable, but some countries can be mentioned.

CANADA

Canada's priorities include the environment and a sustainable economy. In line with this, Canada's defence policy is focused on greening defence and developing next-generation technologies. Canadian Armed Forces are oriented on reducing the energy demand of defence by increasing energy efficiency and saving measures in all aspects of defence activities; moving to lower-emission and more sustainable energy sources such as hydropower, wind turbines and solar photovoltaic panels; reducing GHG emissions and other environmental impacts of the infrastructure portfolio, commercial and operational fleets, and equipment.

To green the defence sector, the Canadian Armed Forces plans to: reduce GHG emissions from federal government facilities and light-duty commercial fleets by 40% (2030) and 80% (2050); then, improve the Army's ability to operate in remote regions by investing in modernized communications, shelters, power generation, advanced water purification systems, and equipment for austere environments.

To reach this, they plan to achieve an energy efficiency of 85% for fossil-fuel electrical generation and distribution utilities in major deployed camps by 2023; to reduce petroleum-generated electrical energy consumption at least by 50% at deployed camps by 2030; to develop and introduce energy-efficient military equipment and to use alternative fuel as much as it is possible in line with operational requirements to reduce overall operating costs and environmental impacts; to have 30% of light-duty vehicle fleet run on hybrid, plug-in hybrid and/or electric technology; also, to reduce energy consumption by increasing awareness through training, simulation and education courses. The DND has also designated energy managers for each base and wing to improve energy efficiency, which will also help reduce GHG emissions. Additionally, the federal government negotiates with utility companies to obtain green electricity as well as to offer opportunities to clean technology companies in order to reduce emissions.[19, 22-26, 59]

DENMARK

The 2016-2020 Environment and Energy Strategy of the Danish MoD focuses on climate, energy, nature and environment. According to it, the defence sector aims for a widespread transition to alternative renewable energy sources and limitations of pollution and emissions, considering the achievement of maximum operative efficiency. To increase operational activity, one of their strategies is the effective utilization of available resources and investments in existing and new capabilities, which reduce operating costs, considering reducing the forces' resupply requirements.

In order to obtain resource savings, financial and logistical benefits, they are going to continue to take into account various environmental aspects (energy systems, fuel, camp support, waste, etc.) during exercises and mission deployments, including the implementation of more effective green technologies and a green behaviour-change campaign.[27]

FINLAND

According to the 2018-2021 Energy and Climate Program of the Finnish Defence Forces, the planned energy-related activities of the Finish Defence mainly focus on improving the energy efficiency of buildings. To improve the energy efficiency of the real estates used by the armed forces, the following targets are set: reduce CO_2 emissions by 75% and energy consumption by 26.5% by 2025 compared to 2010 levels; switch the energy demand for heat production in separate real estates from traditional fuel to renewable energy, and end the use of fossil oil by 2025, taking into account national emergency supply views. In addition, the country's future ambition is to improve the operational energy performance of the armed forces so that the same level could be achieved using less energy.

Climate change is also taken into account in their procurement planning. As Finland is highly dependent on buying equipment from foreign suppliers, it is expected that producers abroad will take the necessary measures. It should also be noted that solar energy plays only a limited role in Finland due to its weather conditions and long dark winters. So, increasing attention is being paid to the use of other non-fossil fuels, such as energy derived from wood. Finland's other efforts include: energy efficiency agreements and audits; the use of energy management systems; increase the use of renewable energy sources (including biofuels), regular maintenance and updating of vehicles, vessels and aircraft; economic driving education system for drivers; improvement of storage conditions and increase the use of alternative energy sources in military applications.[7,26,28]

According to the plan, Finnish Defence Forces'

Energy and Climate Program will be updated in 2021, changing the focus area from buildings to defence functions and also presenting the measures to introduce sustainable acquisitions and increase the use of renewable energy.

FRANCE

The issue of ecological transition is one of the main priorities of the French MoD. In line with the priorities, the French 2019-2023 Defence Energy Performance Strategy sets out three commitments: reducing energy consumption, developing the integration of renewable energies, and finding energy transition opportunities for operational activities. A number of objectives have been set for each commitment, mainly related to installation energy, for the MoD's contribution to the national ecological transition strategy towards sustainability. In order to decrease the energy consumption of defence bases and to achieve the energy transition objectives, France plans to spend about €500 million over the period 2020-2026, which includes: organizing 12 new energy performance contracts for the period 2020-2025; replacing all coal and fuel oil power plants (excluding emergency power plants) and putting in place less polluting and more cost-effective heat production systems, during the period 2020-2031; developing a sustainable mobility plan for each defence base by 2022, with the goal of having a vehicle fleet composed by at least 50% of environmentally-friendly vehicles (excluding operations) in 2030 and dedicating 2,000 hectares of military land to set up photovoltaic solar energy farms by 2022. Additionally, according to the new Defence Energy Strategy (2020), the MoD plans: to reduce the energy consumption of military camps deployed on overseas operations by 40% via the "Eco-Camp 2025 project" by 2030; to provide the French Armed Forces with hybrid armoured vehicles (Griffon/multi-role armoured vehicle and VBCI/armoured infantry fighting vehicle) and to reach the goal of at least 5% of biofuel in the jet fuels consumed by the armed forces by 2030.[157-160]

GERMANY

The main effort of the German MoD towards sustainable defence is energy-efficient buildings, which are mostly part of installation energy, and energy supply optimization in static field accommodations for limiting primary energy in operational infrastructure and camps.

The Federal MoD aims to achieve around 40% of overall GHG reductions over the next ten years. In addition, their ambitious objective is to achieve carbon neutrality by 2023 through their "roadmap" to avoid reducing and then offsetting GHG emissions.

The German Defence Policy is focused on probable future missions. To ensure the adequate capability of future armed forces, energy, including fossil fuels, is a factor of increasing importance in this context. From Bundeswehr's point of view, the issue of energy with all its related aspects, e.g., security of energy supply, reliance on multiple sources of energy, measures to save energy and reduce pollution, use of alternative drive technologies and energy supply systems - is of fundamental importance.[4,7]

GREECE

Based on the National Policy of Environment, Energy and Climate Change of Greece, the prevention of environmental degradation, the efficient use of natural resources, and the simultaneous enhancement of renewable energy sources in the national energy balance are a high priority for the country. In line with it, the Hellenic Armed Forces are focused on responding to climate change and promoting sustainable development. The vision of the Hellenic MoD regarding sustainability in the armed forces is to maintain the ability to perform its mission in the future without the risk of environmental degradation. Their goal for the future is to have energy-efficient armed forces, with a lower environmental footprint through the use of new technologies while efficiently responding to external threats and unpredictable effects of climate change at the operational and social levels. Within the Strategic Planning of the Ministry on Environmental Protection, along with energy efficiency, the utilization of Renewable Energy sources is set as an operational target under the overarching strategic target of the integration of sustainability into the armed forces.[7,29]

ITALY

Improving and making the defence sector more efficient is one of the main objectives of the Italian defence sector, including reducing and rationalising energy consumption through technological innovation. As in most cases, Italian defence energy plans are mainly focused on installation energy, but they also cover some aspects of operational energy. By producing the guidelines for energy-saving, an energy reduction of its buildings and systems and the policy directive on energy-efficiency of military infrastructure, the Italian MoD underlines the importance of this issue for their forces. The Italian defence sector plans to improve the energy efficiency of buildings, replace fossil fuels with renewable energies and gradually reduce GHG emissions. To achieve these goals, the following tools are used: sustainable procurement of goods and services, with a requirement to incorporate environmental information in technical specifications, contract selection based on low environmental impact and the use of life-cycle analysis during the planning of activities, works and supplies to manage their environmental impacts. Regarding operational energy, the Italian MoD promotes clean energy and sustainable mobility for the armed forces. Its interest is the use of renewable gas for the armed forces' vehicles to contribute to sustainable mobility for medium and long distances with a lower environmental impact, allowing a reduction in pollutant emissions for the benefit of air quality in the country.[4,30]

NETHERLANDS

Regarding energy, the Netherlands Armed Forces' strategy is: to enlarge the knowledge base and innovative potential in the field of energy; to reduce energy consumption; to increase the share of sustainable energy used during operations; to improve energy-conscious behaviour.

The Netherlands Armed Forces' ambition is to operate largely independently from fossil fuels and conduct prolonged operations without the need for external energy supply by 2050. In concrete terms: by 2030, to achieve a reduction of reliance on fossil fuels by at least 20% compared to 2010 and by 2050 - by at least 70%; by 2030, to reach 50% share of sustainable energy in the energy consumption of military compounds; by 2050, to make military compounds fully self-sufficient in terms of energy. Replacing old generators with more energy-efficient new generators and developing projects on waste-energy re-use is also important. The country also plans to use sustainable biofuels in all its operational vehicles, vessels and aircraft, where possible.[7,31]

SPAIN

To adapt to Operating Environment 2035, the Spanish Armed Forces are oriented to reduce the logistical footprint, improve supply chains, and optimize fuel consumption by investing in developing certain emerging technologies. To protect the environment and reduce GHG emissions, they work towards energy transition in national installations and deployable infrastructures.

For the electrification of platforms and soldier systems and the development of new systems with high electric power demand, such as laser weapons, the Spanish Armed Forces are working to increase energy storages. They plan to reach progress in the energetic autonomy of the bases through the use of renewable energies and improved energy efficiency; also, they plan to decrease CO_2 emissions into the atmosphere by about 1.36 billion tonnes a year.

The main effort is concentrated on the HVAC (heating, ventilation, and air conditioning) technologies of indoor environmental comfort using geothermal, cogeneration, trigeneration and thermoelectric materials. They are planning some modifications on power generators during international operations.[7, 32-34]

SWEDEN

The Swedish Armed Forces follow the national goal of achieving climate neutrality by 2045. According to the Swedish Armed Forces Environmental Policy, the defence sector is working towards sustainable development where the environmental aspects are integrated into all activities, nationally as well as internationally. To reduce environmental impact, the armed forces are focused on the following three objectives:

energy, waste and exercises. In line with them, one of their joint environmental works and efforts is to reduce the ecological footprint and GHG emissions as much as possible, including through energy optimization, by using energy more efficiently and reducing the need for fossil fuels by increasing the use of renewable sources. In line with security policy, they work to identify opportunities, risks and methods to continue reducing the defence sector's dependence on fossil fuels and reach fossil-free armed forces by 2045. Furthermore, work is also underway on more efficient use of infrastructure-related energy (barracks, buildings, etc.); which accounts for about one-third of the Swedish Armed Forces' total energy use, which is another target area. For now, the effect is that the Swedish Armed Forces benefit from more effective energy use than before and that energy supplies last longer.[26,35]

UNITED KINGDOM

The UK's Sustainable Development Strategy sets out the MoD's objectives in five priority areas: sustainable consumption and production; climate change and energy; natural resource protection and environmental enhancement; creating sustainable communities and a fairer world and delivery. Also, the UK National Security Strategy and the UK Strategic Defence and Security Review note that new and emerging threats to global stability and national security include increasing costs and access to natural resources and the risk of a multiplying effect of climate change. To address these issues, the MoD places increasing importance on managing these risks in its capability requirements, with outputs expected to reduce costs and supply chain risks while enhancing operational endurance and resilience. The MoD places importance on sustainable elements during procurements. A separate target aims to reduce reliance on fossil fuels for operational energy by 18% by 2020-2021 (from a 2009-2010 baseline).

In addition, science and technology play a central role in UK defence and security, driving the efficiency of national security and the armed forces' capabilities. The country develops disruptive and affordable winning edge technologies and identifies alternative solutions to address the strategic challenges of defence, which have a central role in growing and sustaining defence's enablers, systems and capabilities. To make the armed forces more effective, the UK plans to continue working on it through collaboration with industry and academia and through targeted technology development and demonstration.[7,36]

UNITED STATES

The U.S.'s Military Operational Energy Policy directs to enhance military capability, improve energy security, and mitigate consumption costs. The U.S. Army's Energy Security and Sustainability Strategy is oriented on using energy sources rationally, optimizing demand, accessing to energy, increasing resilience, and driving innovation. The Operational Energy Strategy of the U.S.'s defence aims to increase future warfighting capability by implementing rational and innovative energy solutions.

To improve future combat effectiveness and capability, enhance the ability to operate in diverse environments, and reduce energy logistics requirements, the U.S. Armed Forces plan the following: improve the energy performance of weapons systems, platforms, equipment, and products, and their modifications, also installations, including both enduring and non-enduring locations and military forces; diversify and expand energy supplies and sources, including renewable energy sources and alternative fuels; develop and acquire technologies that meet defence energy needs and manage risks; educate and train personnel in valuing energy as a mission-essential resource; provide more effective and efficient force readiness for operations' support; continue to invest in research and development of energy innovation, that may include improved propulsion, lightweight and stronger materials, new designs, enhanced payloads and sub-systems, and even directed energy weapons. It should be noted that the Operational Energy Strategy of the U.S. DoD does not include specific energy reduction targets.

In order to enhance the mission effectiveness of the current armed force and diversify energy supplies, the armed forces have the following priorities: continue to integrate alternative energy sources, primarily solar, into contingency bases and individual warfighter equipment to minimize the burden of supplying liquid fuel to deployed forces; develop and test technologies and practices that "harvest" energy from the surrounding environment, decrease the logistical footprint and increase the overall combat capability of the deployed armed forces. This includes solar or kinetic-powered devices for the individual warfighter, solar-powered UAVs, waste-to-energy and other technologies that enable the utilization of locally available energy; as well as testing and using various alternative fuels in air, sea, and ground platforms; improving current types of equipment that consume significant amounts of energy; improving decision-support tools, dashboards, and routing and planning tools; and filling gaps in understanding energy use and the overall supply chain, through training.

With the goal of increasing operational capability and resilience by decreasing the reliance on petroleum and increasing the use of alternative energy in operations and facilities, the Navy Energy Strategy encompasses robust investments across the Aviation, Expeditionary, Maritime, and Shore enterprises. To increase combat readiness and mission success, the Navy is expecting significant short-term gains by adjusting policies to enable more energy-efficient operations, encouraging awareness and energy-conscious behavior, optimizing existing technologies to reduce energy consumption, and accelerating the implementation of new technologies.

As the DoD's largest operational energy consumer, the Air Force is oriented to identify operational inefficiencies and outdated technologies to optimize operational energy usage and maximize combat capability. The Air Force Energy Strategic Plan identifies four priorities: improve resiliency - identify vulnerabilities to energy and water supplies, such as physical and cyberattacks or natural disasters; mitigate impacts from disruptions in energy supplies to critical assets, installations, and priority missions; reduce demand - increase energy efficiency and operational efficiency for the Air Force systems and processes without losing mission capabilities; assure supply - integrate platform-compatible alternative sources of energy, diversify drop-in sources of energy and increase access to reliable and uninterrupted energy supplies; foster an energy awareness culture - integrate communication efforts using training and education opportunities to increase awareness of energy impacts on missions.

To improve soldiers' capability to operate for longer periods, over greater distances, and at a high operational tempo, the Army efforts to reduce the energy demand characteristics of the force and provide operational energy more effectively. To achieve this, the Army plans to use energy more effectively, including by increasing the energy efficiency of its platforms, devices, and equipment; plus, it plans to use energy management plans at all levels, while also integrating energy control and accountability systems with mission command systems; also, to increase the use of renewable energy, develop operationally viable alternative energy sources, expand flexibility in system energy use and integrate energy networking capabilities.[5,7, 37-39]

2.5. CONSIDERABLE FUTURE PERSPECTIVES

In recent decades, access to cheap and reliable energy has become increasingly important to improve the economy, quality of life, and national security. The world is changing rapidly, and the operating environment is becoming more contested, more lethal, and more complex. In the future, a high-powered, platform-mounted directed energy system will likely require more electrical energy than it is currently available on a typical platform. Firing the weapon requires repeated, rapid delivery of power, which must come either from large storage cells or from a generator able to replenish the energy stores very quickly.[8]

The capability of national defence depends on energy. Energy fuels the fleets of the Navy, Army and Air Force. It increases the resilience of soldiers and military camps, some of which are located in difficult or extreme environments. Having access to adequate, reliable, affordable energy, when and where it is needed supports the operational readiness and sustainability of the armed forces. The world's security environment is affected by rapid technological progress and the changing character of war. Each nation's long-term security depends on the armed forces' readiness for today's crises and preparedness for tomorrow's threats.

Year by year, innovative technologies are changing the shape of warfare. In the future, experts are expecting that battlefields will be much more complicated than the current ones with more intensive fire exchanges. In the perspective of 2032 and beyond, it is expected that conventional military equipment – such as tanks, armored vehicles, and manned multirole aircraft – will still play key roles on the battlefield, but remotely controlled platforms will operate to a much greater extent, executing autonomous tasks using dedicated algorithms; modern new reconnaissance (including satellites), camouflage and assault systems will be cheaper to develop and easier to implement; also, the importance of automated systems will increase.[40]

It is also expected that competition in technology development will increase, especially among the main global economic powers. The focus will be on electronic warfare technologies. According to the "Tech Trends Report 2017" prepared by the "NATO Science and Technology Organization", several major military technology trends are expected, which will also influence the use of energy in military operations in the upcoming years.:[41]

Trends for Short Term <6 years: the creation of 3D solid objects, that can be used for rapid prototyping, on-site production and repair of deployed military equipment, precision, custom and unique parts production; Computing anytime and anywhere, that has the potential to provide real-time decision support to the soldiers at all places; Unmanned Air Vehicles, that may be remotely controlled, that includes cheaper, automated logistics deliveries.

Trends for Term 6-20 years: Sensors Everywhere to detect and track any object or phenomenon from a distance by processing data acquired from high tech, low tech, active and passive sensors as well as background sensors; essentially, everything could be a sensor.

Trends for Long Term >20 years: Artificial Intelligence, that has the ability to become close to humans in terms of learning, reasoning, planning and acting in complex cyber-physical environments and has the potential to replace human decision-makers. Electromagnetic Dominance - that is the ability to use more spectrum, share spectrum more efficiently, protect the use of spectrum by the armed forces, and deny its use by the enemy.

All the above-mentioned technologies once more underline that the defence system is moving towards integrating more electric-based technologies and that the balance of future forces will depend on readiness for this.

Such types of technologies require more energy, and in order to meet the energy demand of the future shape of warfare and at the same time mitigate future environmental impacts, energy usage optimization is necessary. It can be achieved through the utilization of green energy sources and energy-efficient innovative technologies. Along with technologies, improvements of energy-conscious behaviours and environmental awareness during each activity, including in the decision-making process, are essential. To close the gaps between customers' needs and the technological potentials, the improvement of the connection between science and the military sectors is also very significant. It is also noteworthy that such type of warfighting environment will rise up additional cybersecurity issues.

Finding innovative and sustainable solutions to improve the energy performance of military equipment can contribute to enhancing military capability while managing different risks. For instance, by increasing the energy/fuel efficiency of military equipment, by integrating renewable and alternative energy/fuel systems into power source mixes, and by monitoring and managing energy requirements, the defence sector can reduce through-life cost risks. Therefore, there is a need for the defence sector to become more efficient with the energy resources it consumes and reduce its dependence on fossil fuels, through the implementation of energy efficiency and renewable energy production technologies, policy and behavioural interventions.

Future Energy demand can be managed through the use of smart technologies and load and demand management, such as:[8]

- Conservation - optimal driving and routing, more efficient sub-systems, behavior change;
- Generation - use of platform-based, wearable and other agile power creation capabilities;
- Renewables - energy from a source that is not depleted when used, such as hydro, wind, solar, power;
- Storage - the use of advanced battery/storage technologies that store off-peak energy production to mitigate short notice peak loads by storing energy;
- Recycling - reuse of all types of waste to create energy;
- Alternatives - biofuels, geothermal, deployable nuclear, LNG, LPG, ammonia, etc.;
- Energy harvesting - capturing or sharing energy from external sources (e.g., solar power, thermal energy, wind energy, etc.) and storing it for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks and/or reusing CO_2 emissions combined with renewable energy sources for production tasks.

In order for the defence to be able to assure the achievement of future defence tasks, it must be highlighted that there are some natural constraints in moving to these new sources of energy that must be analyzed in each countries' case. But it is expected that producers worldwide will take the necessary measures, as many countries are interested in integrating "greener" equipment.

The characteristics of sustainable energy facilities that make them particularly valuable from a national security perspective include the following:

- Renewable energy sources are not dependent on global marketplaces that can be vulnerable to volatile price spikes or unexpected changes to fuel availability. Unlike conventional methods of producing electricity, renewable energy generators do not rely on fuel supply chains that can be disrupted intentionally or by natural events;
- Renewable electricity relies on naturally occurring, free and self-replenishing sources of fuel such as sunlight, wind, the earth's heat or the kinetic energy of a flowing river. While some of these fuel sources can vary temporally, they are steady over annual periods, and advanced modeling can accurately predict their availability. Also, renewable energy can be economically deployed in small units;
- A bountiful resource available at the point of use - lots of countries are blessed with particularly abundant renewable energy resources, though almost every region of the world has the potential to harvest substantial wind and solar energy;
- Renewable energy can be built and deployed far more quickly than traditional fossil or nuclear generation;
- The ability to deploy renewable energy close to load centers and in smaller capacity units is an important physical security advantage that bolsters grid resilience. Furthermore, as the cost of renewable energy continues to decline, it is quickly becoming the cheapest available source of electricity, which can free significant defence spending for other essential mission expenses;
- Unlike combustible fuels, renewable energy does not pose a risk of dangerous leaks or explosions that threaten human health and public safety; they are also less vulnerable to acts of terrorism;
- These convoys are easy to attack and mobile solar-power units are silent, allowing soldiers to move unnoticed through enemy territory.

In order to support the achievement of sustainable energy security in the defence sector, nationally and globally, through raising awareness on this issue, for preparing the future defence environment and at the same time transforming the existing operational environment towards more sustainability, the following chapters provide an overview of the best examples of smart energy technological and non-technological solutions in the field of military operations within NATO and several selected PfP countries.

3. *THE BEST EXAMPLES OF MILITARY ENERGY MANAGEMENT

Potential threats, aimed at interrupting regular energy supply, represent one of the main factors which affect energy security condition, including during military operations: according to the IEA, energy security is defined as "the uninterrupted availability of energy sources at an affordable price".[42] In the military field, energy security has progressively become a key priority of NATO and nations' operations: the goal of ensuring uninterrupted access to energy by military units across a wide theater of operations (namely, preserving operational energy security) has become a critical and strategic logistic function. To achieve this aim, the adoption of innovative and sustainable solutions to improve the energy performance of military equipment can contribute to enhancing military capability while helping to manage through-life cost and other risks; including through the introduction of energy efficiency (e.g., monitoring and managing energy demand) and the integration of renewable energy sources (using alternative energy to diversify the energy mix reducing the reliance on fossil fuels). Furthermore, the adoption of an energy management system represents a significant and relevant tool for achieving energy efficiency in the military field, as well as to promote an increasing "green" approach in the defence sector, in an environmentally responsible and sustainable fashion. The implementation of best practices in energy management can improve the sustainability of military operations, with net-zero economic impact. However, in order to achieve concrete results, the implementation of legal and technical regulation is a key priority, which allows to ensure the standardisation of EnMS initiatives aimed at increasing interoperability, as well as to provide a comprehensive regulatory framework within which the different military branches and departments can coordinate their efforts in compliance with national and international law and requirements. The definition and the application of a regulation system can contribute to preserving military operational energy providing technical and legal requirements to the military personnel deployed in an operative scenario. The paper provides an overview of the energy efficiency and renewable energy regulations adopted by NATO member countries as well as by the EDA and the EU; also, a thorough analysis of the current status is carried out on:

a) Energy Strategies including the definitions of energy security, operational energy and operational infrastructure in order to better understand the impact of regulation in the military energy dimension;

b) Energy Management Systems, in particular, the development and implementation of Energy Management Systems according to four categories:

- Energy data and billing;
- The human factors that affect energy in the defence context;
- Procurement elements;
- Contract elements (Energy Performance Contracting).

3.1. THE BEST EXAMPLES OF LEGAL REGULATIONS

A general definition of the concepts of energy efficiency and renewable energy sources can be useful to better focus on the sensitive issue of this paragraph, pointing out their rising relevance in the military field, and how the implementation of legal and technical regulations can support the attempts to reduce energy polluting consumption through a policy of optimization and an increase in the use of clean energy, produced by renewable sources like solar, wind and others.

One of the most comprehensive definitions of energy efficiency is provided by the Environmental and Energy Study Institute: "Energy efficiency simply means using less energy to perform the same task - that is, eliminating energy waste. Energy efficiency brings a variety of benefits: reducing GHG emissions, reducing demand for energy imports, and lowering our costs on a household and economy-wide level. While renewable energy technologies also help accomplish these objectives, improving energy efficiency is the cheapest – and often the most immediate – way to reduce the use of fossil fuels".[44] According to the IEA, renewable energy is "energy derived from natural processes (e.g., sunlight and wind) that are replenished at a faster rate than they are consumed. Solar, wind geothermal, hydro, and some forms of biomass are common sources of renewable energy".[45]

3.1.1 LEGAL REGULATIONS AT THE INTERNATIONAL LEVEL

From a military perspective, for NATO, its Allies and several PfP countries, energy efficiency and renewable energy sources play a significant role in strengthening energy security during military operations, which can also be affected by environmental pressures: the deployment of armed forces in hostile environments with potential energy shortage could increase energy demand, so it will be necessary to ensure availability of resources and to protect and manage supply chains avoiding disruptions.[7,17,43] In order to reduce the condition of dependence and vulnerability and to enhance efficiency (mainly during military operations), NATO essentially focuses its initiative to achieve three main tasks: 1) raising strategic awareness of energy developments with security implications, 2) contributing to the protection of critical energy infrastructure, and 3) enhancing energy efficiency in the military sector, reducing dependencies on energy resources outside of the Alliance by enhancing energy efficiency through applied technical solutions, focusing on operational energy (OE).[46] Within a regulatory framework, NATO has promoted its strategy by addressing recommendations towards its Member States, with the purpose to work together and in a coordinated way (through consultations on energy security issues, sharing best practices) in order to progressively adopt energy efficiency measures and to use renewable energy sources. The decision of the Allies to "integrate energy security considerations in NATO's policies and activities" (2010 Lisbon Summit Declaration) has been implemented by focusing the efforts on the training and education dimension (courses) as well as by organizing joint exercises which include energy-related developments.[47]

The adoption of the NATO's "Green Defence" framework in February 2014 has represented the most significant action to regulate NATO members' initiatives in the energy efficiency sphere, even if the document merely "invites" and "encourages" Allies to continue implementing the agreed policies and standards related to Green Defence.[17] NATO's official engagement to promote energy efficiency was expressed in 2012 during the Chicago summit, when the Allied Heads of State and Government agreed that NATO should work "towards significantly improving the energy efficiency of our military forces".[48] Following the Chicago Summit Declaration, in October 2012, the SENT was established. One of the main SENT's tasks was to analyze how reducing the energy requirement could shrink the logistical footprint, thus improving operational capabilities, minimizing the potential environmental consequences of NATO military activities and reducing force protection requirements.[7] Two years later, NATO countries confirmed their engagement to improve the energy efficiency of the armed forces during the Wales summit: in the final document, there was also an explicit reference to the Green Defence Framework.[49]

NATO members have become progressively aware that reducing fossil fuel consumption in deployed force infrastructure (i.e., camps) will lead to more autonomy, a lesser logistical burden and a smaller environmental footprint. The Green Defence Framework is based on three pillars: operational effectiveness, environmental protection and energy efficiency and aims to face logistical challenges and to reduce NATO's environmental footprint, working together in order to move towards a "greener NATO".[17] In order to implement a more comprehensive approach towards energy security, the Green Defence Framework expressly mentioned training, education and exercises based on energy-related developments to increase awareness: several training courses have been stood up, both nationally and at the NATO School in Oberammergau, Germany,[47] while the initiatives of relevant COEs - especially the NATO ENSEC COE established in Vilnius (Lithuania) - show how the cooperation between national armed forces and these high-level institutions will have a positive impact on the promotion of energy efficiency in the defence sector of NATO members and several PfP countries. In parallel with NATO's actions to promote the more efficient use of energy, also the EDA works together with the Member States in order to support decision-making and to enhance European cooperation on research and development in the fields of energy efficiency, renewable energy sources and procurement. Even if this military cooperation is not regulated on a mandatory basis, the EDA has been able to implement a wider partnership involving the armed forces of several countries to develop innovative "green" projects. Since 2016, the EDA has started to collect defence-related energy data (provided by the Member States), concerning energy consumption, types and volumes of energy resources used by the armed forces on an annual basis. The EDA's analysis aims at identifying potential dependencies of Member States' Armed Forces and, consequently, promoting energy efficiency measures.[3] The legislation framework within which the European Defence Agency acts are:[50-53]

- The amended EU Directive on Energy Efficiency (2018), which establishes a common framework of measures to promote energy efficiency within the Union in order to achieve the planned targets on energy efficiency of 32.5% by 2030.
- The recast Renewable Energy Directive 2018/2001/EU, which aims to promote energy usage from renewable sources. It sets a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible upwards revision by 2023, and comprises measures for the different sectors to achieve this target.
- The revised EU Directive on Energy Performance of Buildings (2018), which is the main EU legislative instrument to leverage the potential contribution of the building sector to the EU's long-term energy and climate objectives.

Since 2015, the EDA manages the CF SEDSS, conceived to assist the EU Ministries of Defence to move towards green, resilient, and efficient energy models, by sharing good practice and expertise on improving the capabilities of the defence sector.[54] The EU Military Concept on Environmental Protection and Energy Efficiency for EU-led military operations represents the attempts of the EU to address relevant energy-related aspects, such as energy efficiency and the use of renewable energies during military operations. The aim is to establish principles and responsibilities to meet the requirements of EP during EU-led military operations in support of the Common Security Defence Policy, and to promote a common understanding of EP during EU-led operations, in order to enhance interoperability among the EU Member States and strategic partners. The EU highlights the need to adopt a more efficient approach to sustainable energy supply in EU-led military operations in order to become less vulnerable and more flexible. This could be achieved both by reducing energy consumption and by improving energy efficiency, which requires not only organizational and technological enhancements but also a new and conscious behavioral approach.[55] Before describing some of the most relevant examples of national regulations within NATO member countries, it is necessary to introduce the distinction between operational infrastructures and fixed installations and between operational and installation energy.

According to the definition of the UK MoD, operational infrastructure is defined as the basic physical structures (e.g., buildings, roads, power supplies) within the area of joint operations upon which the UK Armed Forces rely on for the prosecution of its mission through the sustainment and exercise of deployed military capability.[56] So, operational infrastructure supports and maintains the deployed forces in the operational environment, while fixed installations concern military infrastructures outside the operational environment. Operational Energy is defined by the U.S. DoD as the "energy required for training, moving, and sustaining military forces and weapons platforms for military operations", while installation energy refers to energy for fixed installations and non-tactical vehicles.[57]

3.1.2 LEGAL REGULATIONS AT THE NATIONAL LEVEL

Canada - The Canadian DND has adopted several policies to enhance energy efficiency and to promote the rising use of renewable sources in the military field.

The main legal priority of DND is to adopt initiatives in keeping with the purposes of the Federal Sustainable Development Act, in order to make environmental decision-making more transparent and accountable to the Parliament: the implementation of the Federal Sustainable Development Strategy and the DEES are the two main pillars.[58] The Government of Canada accepts the basic principle that sustainable development is based on the ecologically efficient use of natural, social and economic resources and acknowledges the need to integrate environmental, economic and social factors in the government decision-making process. The CAF have recently adopted an updated version of DEES, which aims to reduce the energy demand for defence by increasing energy efficiency and conservation measures, as well as to reduce environmental footprint by cutting GHG emissions and other environmental impacts from the operational fleets and equipment, and by adopting measures on operational energy.[59] The DEES builds on Canadian defence policy, Strong, Secure, Engaged and reaffirms the strategy's commitment of greening DND's operations. Moreover, DND and CAF are committed to applying the principles of the Green Procurement Directive, by integrating environmental considerations into decision-making processes and practices, in line with operational requirements: according to the directive, they have to include green criteria in contracts for equipment and in the construction industry, supporting the enhancement of the green economy, by favoring low-carbon materials and green technologies.[60] The existence of mandatory targets to achieve the reduction of GHG emissions and to implement the Green Procurement Directive have contributed to increase the DND's conscious commitment to promote energy efficiency within military forces. The Canadian case represents one of the most comprehensive models characterized by a detailed legal regulation and the concrete implementation undertaken by the CAF.

France - The French MoD has adopted the Sustainable Development Strategy (S3D), within which the key goals to achieve are improving energy efficiency and consumption management; and raising awareness among the personnel of the ministry in sustainable development.[61] Moreover, the plan to adopt less consuming and less polluting means of transportation in military operations will help to bolster energy efficiency. In the National Navy, the proposal to grant "Green passports" for the warships appears another positive measure. The recent Defence Energy Strategy (2020) underlines the importance of providing energy security for military operations, avoiding dangerous disruptions: moreover, the document also reaffirms that energy efficiency directly contributes to the operational efficiency of armed forces.[158] Between 2010 and 2018, the MoD was able to reduce energy consumption by 15%, thanks to the combination of the previous Energy Performance Strategy of 2012 together with the effects of the Military Planning Law 2013-1168 (which envisaged a program for the period 2014-2018), which imposed a reduction of the military personnel and of the defence's property assets, as a way to obtain energy savings.[63] The MoD also contributes to implementing the "Solar Place" governmental plan, conceived to increase the production of electricity from solar energy sources: until 2022, the French MoD has made available 2,000 hectares of land in order to develop a photovoltaic project aimed at producing clean electricity, such as in the Creil airbase, Saint-Christol infrastructures and La Valbonne camp.[64] In France, environmental laws set up the frame of reference for the MoD's initiatives aimed at reducing energy consumption and improving energy efficiency through tailored policies focused on increasing energy savings. As a matter of fact, the engagement to meet the main targets of these environmental laws has pushed the French MoD to adopt successful tools (such as the Energy Performance Contracts for upgrading the energy efficiency of several military bases) to strengthen its environmental-greener footprint.

Germany - In 2017, Germany adopted the "Concept - Increasing the Security of Supply by Optimizing the Energy and Utility Supply in Static Field Accommodations" intended to describe and limit energy and utility consumption along the entire supply chain. The guidelines included in the above-mentioned concept are best practices to follow: the measurement and monitoring of energy consumption allow to limit (and to optimize) energy demand in the Operational Infrastructure through the adoption of technical, organizational and logistic measures.[65] In the last years, the German MoD has increased its attention on the impact of climate change to the Bundeswehr in terms of operational impact, in particular on personnel and equipment. The German Climate Action Plan 2050 represents the main regulatory framework, within which targets are defined for specific sectors: the overall GHG emission reduction targets are -55% (2030), -70% (2040) and 80-95% (2050) – compared to the 1990 level.[26] Even if defence is not expressly mentioned in the document, the German MoD is committed to taking these targets into its infrastructure planning in order to improve a greener approach and to enhance its energy efficiency. According to the MoD, the Bundeswehr achieved a significant GHG emissions reduction in the past years. The military sector's total CO_2 emissions dropped by 20%, from 1.78 tonnes to 1.45 million tonnes between 2015 and 2019.[66]

Italy - In the last five years, the Italian MoD has undertaken several initiatives aiming to ensure more efficient management of energy resources.[67] In 2019, Italy adopted the Defence Energy Strategy Plan to provide energy security, which can be achieved through 3 actions: cognitive development, energy management and protection of critical energy infrastructures. This document highlights the role of military forces, not only to enhance operational energy but also to achieve the aims of national energy security, namely reducing consumption and promoting energy efficiency in order to reduce dependence from abroad and increase the resilience of infrastructures. Furthermore, the Italian MoD also implements the Green Public Procurement normative, which introduces the energy and environmental sustainability criteria in order to regulate the procedure for buying equipment and consumption in the public administration.[68] According to the normative elaborated by the Ministry of Economic Development in December 2014, it is mandatory for the Italian Armed Forces to nominate an Energy Manager (a figure expressly mentioned by DES), who has the task to identify actions in order to promote best practices of energy efficiency and savings, monitoring consumption and prioritizing the production of electricity by renewable sources.[69] In the period between 2014 and 2016, the Italian Navy adopted a directive in order to promote the "Green Fleet" initiative - in accordance with the goals of the EU Directive 2009/29/EC (Horizon 2020) - aimed at enhancing the process of national Navy's decarbonization. This project initiative was developed together with the U.S. Navy: during that period, Navy ships and submarines started to use green diesel for their refueling. Flotta Verde Initiative allowed a 26% reduction of polluting emissions deriving from the activities of the Italian Navy, also contributing to meet national and EU targets about the containment of GHG emissions.[70]

Netherlands - Following the implementation of the Energy Efficiency Directive (EED) (2012/27/EU), the Dutch MoD has been obliged to undertake initiatives to renovate military buildings (barracks and other infrastructures) and defence properties, in order to achieve the required shares of energy savings.

In 2014, the Dutch MoD published its first Operational Energy Strategy (OES), which took into account concerns that growing energy demand during operations greatly affects the effectiveness of the deployment of military means. The goal of the OES is to "increase the operational independence of the armed forces, on the one hand, by managing energy consumption and, on the other hand, by transitioning to other types of energy supply".[31] The defence organization aims to reduce energy dependence during operations and their preparation and thus to increase the armed forces' effectiveness, efficiency and resilience. This will simultaneously reduce the environmental impact. In 2020, the Dutch authorities released the Defence Energy and Environment Strategy 2019-2022, combining the

Operational Energy Strategy and the Defence Energy and Environment Policy Agenda, which revised environmental and energy targets.

United Kingdom - Energy efficiency and sustainability remain key drivers for the UK MoD (the Department), because environmental issues and climate change can negatively influence defence capabilities and military operations.[71] The Department developed a comprehensive sustainable development approach in 2011, which was further implemented with updated periodical integrations. Following the UK's implementation of the EU Energy Efficiency Directive and the adoption of the National Renewable Energy Action Plan - in accordance with article 4 of the EU Renewable Energy Directive on the promotion of the use of energy from renewable sources - the Department has undertaken initiatives to improve its green footprint in both installation and operational energy. The Department has included the GGC (2016-2020) in the annual Defence Plan (which sets priorities and targets for the coming year), in order to coordinate its efforts with the other government departments and agencies to reduce the impact on the environment, also considering that in 2017-2018, the Department was responsible for half of the GHG emissions reported by the central government. The Department has already achieved its GGC target to reduce GHG emissions by 39.9% from 2010 levels. However, a significant portion of the Department's energy usage is outside the GGC targets, mainly operational energy: military activities, such as the operation of defence equipment (including for land vehicles, aircraft and navy vessels) by the armed forces, are not included in the GGCs, and these are not subject to formal targets. In June 2019, the UK government committed itself to cut GHG emissions to "net-zero" by 2050, which raises the ambition of the UK's legislative target, first established by the Climate Change Act over a decade earlier with an 80% reduction from 1990 levels.[72] In spite of the UK's policy to introduce several directives and regulations to deal with the challenge of energy efficiency, UK military forces have not completely developed a comprehensive strategy on these issues, mainly because these are exempted from some relevant legal dispositions. As a matter of fact, operational energy is not subject to a formal target of the GGC and the same approach would also be preserved for the new Climate Change Act, so limiting MoD's contribution to the achievement of the "net-zero" target.

United States - Considering that the U.S. DoD consumes more energy than any other federal agency (approximately 80% of the entire federal government's energy consumption), energy efficiency and energy security represent very sensitive issues to preserve, within a detailed and comprehensive regulatory framework.

Since the 1970s, the U.S. Congress has mandated energy requirements for federal agencies. The legislation required reductions in fossil fuel consumption and increases in renewable energy use and efficiency targets for government fleets and buildings. The main federal regulations are the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007 (which amended previous Acts), as well as the President's executive orders. However, there is an important distinction to highlight: as a matter of fact, if DoD's installation energy (i.e., energy for fixed installations and non-tactical vehicles) is subject to federal energy management requirements, DoD's operational energy is not subject to federal requirements, but it is mandated by 10 U.S.C. 2926. The DoD issues directives, memorandums, manuals, and guidance instructions to military departments and agencies on complying with statutes and executive orders. Furthermore, 10 U.S.C. 2925 mandates DoD to submit to Congress two annual reports on the progress made on meeting federal and executive energy targets.[73] 10 U.S.C. 2926 Operational Energy Activities act provides DoD with an operational energy policy, which allows the Department, or each military branch, the power to determine and decide operational energy efficiency goals.[57] As part of the operational energy policy, the DoD establishes a strategy including plans and performance metrics. Additionally, the DoD is mandated to submit to Congress a report on the strategy's implementation. The Operational Energy Strategy's purpose is to ensure the consistent delivery of energy to the Warfighter through the achievement of three objectives: increase future capability; identify and reduce risks; enhance current mission effectiveness. The strategy contributes to that purpose with defined and measurable targets for completion.

Consequently, all military branches are committed to optimize operational energy in order to enhance combat capability and readiness, also ensuring energy savings.

The U.S. Air Force's support for energy optimization efforts to reform cost, supportability, and efficiency - both materiel and process-oriented - results in increased aircraft lifespan, lower aircraft maintenance costs, and more training opportunities.[9] In 2009, U.S. Navy military authorities elaborated five operational energy's efficiency goals (among them, alternative energy sources to reach 50% of total consumption by 2020; 50% of Navy and Marine Corps installations net-zero by 2020; the deployment of a Green Fleet which uses alternative fuel blends; energy as a mandatory evaluation factor when awarding contracts for systems and buildings) and then issued a number of strategic planning documents for implementing energy management goals into mission operations (such as the Department of the Navy Strategy for Renewable Energy.).[74]

If the U.S. DoD aims to improve operational effectiveness through energy efficiency - while maintaining the same military expenditure - the other departments of defence in the world focus on reducing GHG emissions and cutting down energy costs through energy efficiency measures, while keeping the same operational capability.

3.2. THE BEST EXAMPLES OF ENERGY MANAGEMENT SYSTEM

NATO and PfP member countries are engaged - at different levels - to promote and implement EnMS in military operations. EnMS can be defined as one of the tools for achieving energy efficiency, as well as an instrument that can be implemented with low economic impact, and which can be standardized for interoperability.

The application of an internationally recognized Energy Management System can provide quantitative energy savings, promoting the more efficient and effective use of energy.

For this purpose, the NATO ENSEC COE is working - in close cooperation with the NATO MILENG COE, Canada, and the United Kingdom - on an Energy Management handbook to assist energy management personnel during missions or operations.[75] The draft document is already ready, which will be submitted to the NATO Standardization Office in the nearest future for the development of a new energy efficiency standard for deployed military units. The guide will be a "militarized" version of the ISO 50001 Energy Management System handbook - ISO 50001[76] is a worldwide standard, making it the most widely accepted system to manage energy -, and it will allow to promote the efficient use of energy through improvements in three key areas:

- Organizational management (Command and Control – C2): this requires assigning responsibility for energy management to appropriate staff, providing time and resources for energy to be monitored and managed, reviewing energy use through periodical assessments, and taking action when needed;
- Technological Applications: in the context of energy management, technological applications do not refer to technology for producing or storing energy, but to metering and monitoring how much energy is used;
- Behavior Change: through applying behavior change processes, people can become more aware of how their individual actions contribute to energy efficiency and energy security.[77]

The use of a standardized approach based on EnMS during military operations is expected to produce several benefits, such as an increase in energy efficiency, a reduction in energy resource consumption, improvements in safety for military personnel, reductions in logistical burdens related to the supply of energy, financial savings, and improvements in environmental protection.[78] Energy efficiency represents another strategic target that NATO forces aim to achieve in order to enhance energy security conditions during military operations, through the reduction of their dependence on fossil fuels. In addition to energy efficiency material tools (equipment and modern technologies based on renewable sources), also non-material initiatives – such as energy management techniques and the promotion of behavioral change among NATO military personnel in their use of energy - represent an excellent opportunity to achieve and realize a low-cost solution, in terms of reducing energy usage, costs as well as force protection requirements, and loss of lives from enemy attacks on fuel distribution networks.[79] The description of the best examples of the energy management system undertaken by some NATO member countries - as well as by some PfP countries - also during military operations, allows to better understand the efforts within the Atlantic Alliance to change the approach towards energy issues. The purpose of this section is to highlight the best EnMS solutions according to identified categories: billing and energy data, human factors, procurement and contract elements.

3.2.1 BILLING AND ENERGY DATA

The growing use of smart energy meters and monitoring stations (utility meters) to collect information about energy consumption, represents one of the main and largely-used solutions (practices) adopted by NATO member countries: indeed, monitoring consumption allows national MoDs to understand the real energy needs of deployed camps (as well as of military buildings and facilities), as a first step and necessary precondition to successfully plan and implement tailored initiatives to reduce consumption or to avoid potential energy wastes, increasing the environmental footprint during military operations.

After monitoring and collecting data, the development of a related energy management plan to elaborate and study them, allows developing an efficient methodological approach aimed to provide a description of who, what, where, when and how much energy is used in military camps, and in which ways it can affect energy dependence and efficiency.

In order to collect and understand the energy needs of deployed camps, the CJOC has installed monitoring at several deployed camps, including the Ali Al Salem Air Base in Kuwait, Ādaži, Latvia, and Ouallam, Niger. After data collection, CJOC can identify the real energy requirements of the deployed camps (also improving the camp design), updating current fields manuals whose current specified energy requirements of 3.0kW/hour/person are suspected to be too high: this could avoid the over design of generators and needless consumption of diesel fuel, so leading to a more profitable money-saving and protecting the environment.[80]

Concerning military bases on Canadian soil, the Department of National Defence has decided to install “smart” energy meters to monitor consumption in nine buildings of the CFB Halifax (Canada’s East Coast naval base). The introduction of smart energy meters is one of the measures contained in Canada’s National Defence Strategy, which includes spending about $225 million on energy efficiency and bringing DND’s GHG emissions down to 40% below 2005 baseline levels by 2030. According to the National Research Council, the application of smart meters can help save between 10 to 15% on energy costs, namely between $17 million and $25.5-million on its annual $170-million utilities bill.[81]

Consequently, the investment of Canadian DND to introduce smart energy meters will be paid off by 10 years, producing long-term results in terms of lower bill costs, high energy savings and developing an updated database which collects useful information about energy consumption.

Similarly, Danish MoD has decided to collect energy consumption data in operational military camps, as well as to implement energy savings initiatives in order to reduce heat/cooling losses in camp facilities.[27] The introduction of energy meters is part of a wider strategy aimed at creating an energy management system which could map and register resource consumption and environmental impacts in order to later outline improvement plans and reduction targets. In support of collecting operations, the Danish MoD also envisages the use of energy dashboards programs, which are considered useful tools to enhance energy efficiency and to implement energy optimization initiatives, including operations of the Danish Royal Navy and aircraft. In terms of monitoring energy consumption, the Green Camp project has represented a successful experience for the Danish Army. The core of the Green Camp concept is the compilation of a knowledge base around the consumption patterns in the camps by different climatic conditions, as well as the characteristics of the different elements/ units forming part of a camp - both through the use of traditional, as well as environment-friendly technologies.[74]

An Armed Forces Energy Management Map has been developed by Greece, which needs to measure the environmental footprint of military forces during operations, in order to support the efforts of national armed forces to progressively become energy efficient. Through the registration of the major Commands overall energy consumption as well as of their spatial distribution using a GIS, these data will successively be used for the application of renewable energy sources in armed forces units, aiming at a reduction in the environmental footprint and at the better energy management of the units.[29] One of the best practices introduced by the Greek MoD is recognizing certification for military camps that develop EnMS, even if it relates to military camps and bases within the national territory.[83] In 2018, the Hellenic Army General Staff developed the EnMS at the "Kandilaptis" Camp in Alexandroupolis, which received an ISO 50001:2011 certification, and improved the Army's environmental performance. A similar certification was also granted to the "Triantafyllidis" Camp (25 Armoured Brigade) in Xanthi, which already utilizes the EDA's EnMS. These initiatives are in line with the MECM project, which aimed to develop and implement an EnMS in three Military Camps of the armed forces (Xanthi, Souda naval base and Larissa airbase) according to the international standard EN ISO 50001:2011.[84] An EnMS and an Energy Management Action Plan were implemented in these three military camps, and meter devices were introduced to measure electricity consumption. In 2016, the energy used by the "Triantafyllidi" Army was 46% lower than the baseline year (2011). The related MECM final report showed that great energy reduction and cost savings had been achieved by implementing efficient energy usage practices. Overall, this results in potential energy reduction and cost savings of up to 50%. In Souda Naval Base, energy savings reached 2-3% of annual reduction, while, in 2016, energy consumption in Larissa Air Base - in relation to the reference year 2011 - decreased by 27%.[85]

SINFRADEF (Computer System of Defence Infrastructures) is the name of the energy management system developed by the Spanish MoD – even if it is mainly related to installation energy - which contains information on the consumption and energy efficiency of all its buildings, as a possible tool for the analysis and management of GHG emissions.[86] About the need to metering military energy consumption to implement EnMS appropriated policies, the "Energy Management Plan for Military Camps" (the result of a cooperation agreement between the Spanish Army and the University of Granada) has allowed developing a methodological approach aimed to provide a description of who, what, where, when and how much energy is used in military camps, and in which ways these can affect energy dependence and efficiency. It also includes a calculation sheet that allows counting the amount of energy used in camps: after its development and testing, a series of conclusions and recommendations for better energy use have been written.[87]

The U.S. DoD has long been engaged in implementing energy management system approaches that comprehensively involve all military departments (Army, Navy, Air Force) with practical applications. Furthermore, the U.S. statutory requirements require the DoD to track and report on energy resilience metrics and efforts to work towards minimizing installation energy disruptions and, consequently, maintain mission readiness. According to the 10 U.S.C. 2925, the DoD is required to submit each year an AEMRR to the U.S. Congress to show the progress of the different military departments in meeting federal and executive energy targets. In spite of the U.S. DoD's long-term experience and concrete progress in collecting fuel consumption data, significant gaps remain in the ability to track ground component equipment in the Army and Marine

Corps.[9] In terms of metering and monitoring data, the U.S. Navy has achieved the most relevant results, mainly measuring fuel consumption by type of equipment. Among several initiatives and projects promoted by the U.S. DoD, it is important to mention GENESYS, a project developed by the Navy that collects and consolidates existing and automated energy data into a comprehensive picture of how and why energy is used, by integrating and consolidating three existing systems: SEAS, Electronic log book and Fleet energy conservation dashboard. GENESYS allows to provide a real-time assessment of energy usage and recommended actions to reduce fuel and electrical power consumption: this information is directly available to the commanding officer and the ship drivers, rather than having analyses which could delay the process.[74] The Air Force - which represents the DoD's largest consumer of operational energy, with $1.2 billion spent on Air Force aviation fuel in FY 2018 - is working to collect fuel consumption data from all platforms, but not all Air Force platforms currently collect and report data, and some lack the equipment to do so.

The adoption of energy meters and energy consumption monitoring has been recognized as an efficient and successful solution to rationalize energy use and to reduce polluting emissions also by the PfP countries. Among them, the Finnish MoD is developing an environmental system based on the ISO14001 standard, which covers the entire Finnish Defence Forces.[88] Sweden Armed Forces used the digital map tool Collector to collect and publish information about any environmental damage and complaints linked to the Aurora exercise held in 2017: these collected data were useful for all involved personnel also for establishing a direct interlink among them.[35] The use of this digital map tool Collector reflects the Swedish Armed Forces' approach to lead a preventive work and to create conditions to minimize the environmental impact of military operations and exercises. The large adoption of energy meters by a growing number of MoD shows the concrete effectiveness and the positive impact of energy consumption monitoring. This solution has several strengths: it is easy to deploy, with moderated economic costs, and it is able to produce long-term results through the implementation of an updated database which collects all data concerning energy consumption. Moreover, the monitoring of effective energy requirements in military camps allows achieving a successful strategy of energy optimization, avoiding energy wastes in an operational scenario, because of the frequent problems of a regular energy supply.

We can observe significant progress and very positive results linked to this solution: for instance, the approach of the Greek MoD to associate the development of an Energy Management System with the award of an ISO 50001:2011 certification appears as one of the main best practice to underline, and its adoption is highly recommended in order to achieve concrete results in terms of energy optimization.

Likewise, the cooperation between MoD and universities/research centers appears profitable in order to develop a useful methodological approach to better analyze energy data, as well as to find more suitable solutions and practices in terms of energy management.

The main challenging task for NATO countries will be to develop a comprehensive approach which allows them to collect energy consumption data from all military branches in order to elaborate a single-coordinated EnMS plan and to evaluate the impact of energy reduction in the military field.

3.2.2. HUMAN FACTORS

Initiatives and actions aimed to increase and improve energy awareness among military staff and personnel are another significant tool to implement Energy Management System: these actions will contribute to promoting the adoption of a greener behavior among military personnel, focused on more efficient use of energy in order to avoid wastes mainly during military operations, due to the frequent problems of a regular energy supply.

Several studies show the positive benefits and concrete results linked to the adoption of correct

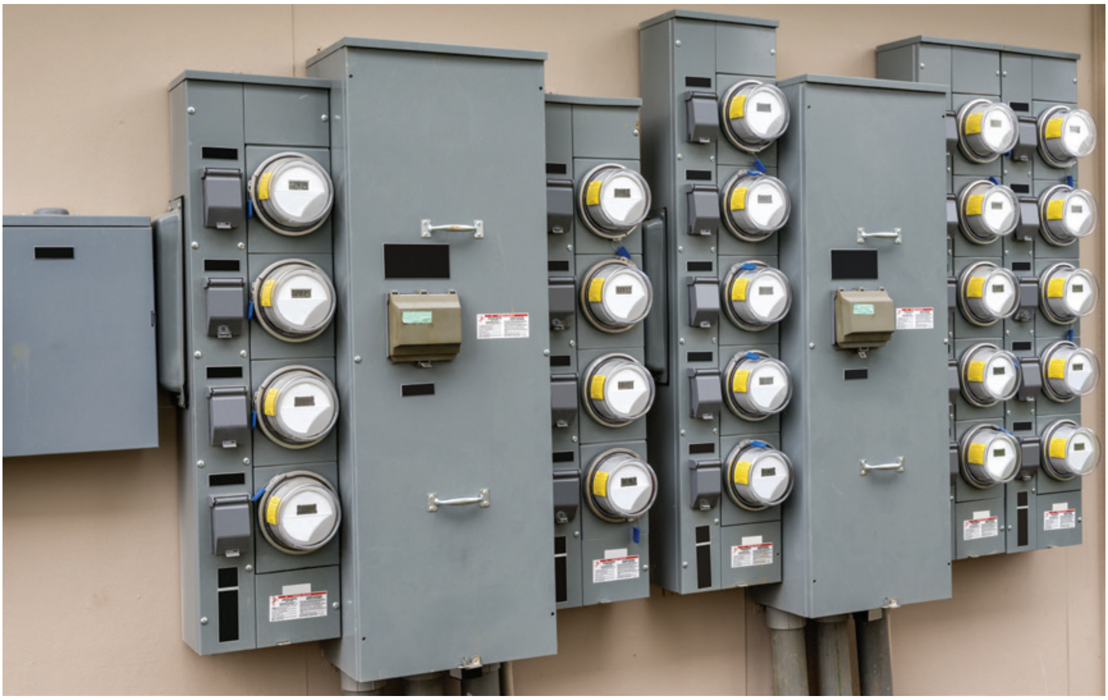


Figure 3: Advanced Metering Infrastructure, Indiana Military Bases, USA

energy behavior: among them, the NATO ENSEC COE study project "Energy Efficiency: Cultural Change" has identified several positive consequences linked to how behavioral change can positively contribute to energy efficiency in the military field:

- Improved effectiveness and mobility of forces;
- Self-sufficiency reduces deployment time, and increases the flexibility of forces;
- Morale increased with lighter loads for infantry;
- Reduced risk to/need for CLPs, and their need for FP
- Reduction of the logistic footprint;
- Increase in the operational capabilities of the troops (e.g., by reducing the need for fuel and water convoys, consequently decreasing escorts and casualties);
- Increase in the level of energy security of the operation (e.g., by reducing the risk related to reliance on fuel delivery);
- Reduction in the cost of the energy supply chain;
- Limiting the carbon footprint of armed forces.[79]

NATO and PfP countries have adopted some initiatives and solutions to promote greener behaviors among military staff and personnel; the most relevant ones appear to be the 7SEBC process and the Green Fleet Initiative.

7 STEPS TO ENERGY BEHAVIOR CHANGE (7SEBC) PROCESS

Concerning the behavior change aspect, the UK MoD has developed a specific tool, the 7SEBC process, which includes the COM-B model of behavior ("Capability + Opportunity + Motivation = Behavior"). The application of the 7SEBC process ensures significant energy savings (from 5-20%). The 7SEBC process has been considered as a model and it is currently being used by several countries to promote energy management in their national defence sector.

The COM-B model proposes that for an individual or a group to engage in a behavior, they require the relevant capability (such as skills or knowledge), opportunity (such as time or resources), and motivation (such as values or beliefs).[77] The UK MoD envisages tailoring training and policy planning in order to increase awareness and to adapt military staff's behavior on sustainable development and energy savings. As part of the Energy Management System, the 7SEBC process was successfully tested in the NATO ENSEC COE-led research project - "Energy Management in a Military Expeditionary Environment", during 2017-2019, in 3 locations: French military base in Niger, German military base in Lithuania and Canadian military base in Latvia.[77]

THE GREEN FLEET INITIATIVE

The Green Fleet initiatives aim at increasing energy efficiency and environmental footprint in military operations, also reducing fossil fuel consumption.

The Italian MoD undertook the "Flotta Verde" (Green Fleet) initiative in the period 2014-2016 (in 2017, Italian MoD temporarily froze this initiative), within which the Italian Navy committed itself to reduce the dependence on imported oil up to 50% by 2030 using alternative fuels such as biofuels and LNG. Furthermore, this initiative intended to promote a global reduction in the energy consumption of ships, through the adoption of energy-saving operating procedures (electric propulsion, energy dashboard).[70] Flotta Verde Initiative allowed a 26% reduction of polluting emissions deriving from the activities of the Italian Navy, also contributing to meet national and EU targets about the containment of GHG emissions.[70] Moreover, for the full implementation of the Green Fleet initiative, the Italian Navy has undertaken a tailored awareness-raising campaign focused on the involved military staff showing the positive benefits (in economic and environmental terms, without affecting operativity) of the energy consumption optimization. The U.S. Navy has also promoted the GGF initiative, aimed at reducing traditional petroleum consumption, both using alternative fuels but also implementing ECMs during the course of normal operations. Throughout 2016, other Departments of Navy platforms participated in the GGF initiative by using energy-efficient systems, operational procedures, and/or alternative fuel during the course of worldwide planned mission functions. Figures on the energy savings achieved by the ships in operations could not be found through open sources. This information may be sensitive, as it is directly related to the decisions made by captains and procedures taken during missions. However, according to some estimates, the combination between energy efficiency measures and the use of alternative fuels allowed the U.S Makin Island ship (one of the GGF's ships) to save $248 million in energy costs over its lifetime, reducing petroleum fuels consumption by 50% in 2020. Since the introduction of energy efficiency measures has a limited influence in terms of additional economic costs, the GGF will become a cost/effective initiative if the price of advanced biofuels remains economically competitive compared to fossil fuels, which are generally used. Indeed, the U.S. Navy is especially sensitive to oil price fluctuations: considering that it consumes ¼ of the DoD's total oil consumption, every price increase in a barrel of oil costs the U.S. Navy $30 million dollars per year.[89]

3.2.3. ENERGY MANAGERS

The presence and the employment of energy managers' figures during military operations and in defence installations is strongly useful to identify, implement and maintain efficient measures aimed at reducing energy consumption. Energy managers' task is to promote energy efficiency without jeopardizing mission capabilities or reducing the quality of life of personnel.

Planning is an important dimension within the energy management program: energy managers have to perform an energy audit in order to identify how energy is currently being used in the facility, setting clear and measurable goals, then developing an action plan to implement those goals. One of the main tasks of the energy manager is to set goals and performance metrics which track progress towards those goals, allowing him to estimate the installation's reasonable potential for energy savings and set goals consistent with that potential. Canadian Armed Forces recognize a key role to the energy managers, defining them as the "energy champions", by expressly mentioning them in several documents concerning energy management system in the military operational field, with the role to identify efficiencies measures to reduce GHG emissions. Energy managers also play a training role in order to strengthen energy-conscious behaviours and energy awareness among all defence personnel.[59] Among NATO countries, Canada has successfully achieved its DEES' goal to designate energy managers in all bases and wings by 2019. At the high level of the chain of command, the British MoD envisages that the MOD Chief Operating Officer and the Deputy Chief of Defence Staff for Military Capability are the Department's sustainability champions, responsible for setting the direction for MoD's sustainability agenda and priorities as well as monitoring progresses.[71] As a forerunner compared to other states, in 2005, the U.S. DoD already released its Energy Manager's Handbook designed to act as a useful tool and guide in assisting DoD installation and facility energy managers to effectively perform tasks associated with their jobs.[90] Besides, Italy's Defence Energy Strategy Plan expressly mentions the role of the energy managers, highlighting their crucial role in promoting coherent energy management in the military field. Among the tasks, they must carry out an energy audit - conceived as a key tool to develop an energy management system - through which energy consumption of the armed forces will be accurately metered and monitored, allowing to determine potential energy savings and to plan measures to improve and achieve energy efficiency and security. United Kingdom's Armed Forces undertook an interesting case study called "Army Energy Review" with the aim to improve energy management initiatives: 29Reg RLC formed an Energy Management Team and established an Energy Management Action Plan. Members of staff were empowered by their managers with the responsibility to take control of their own workplace areas, also pointing out the importance of education with the online Defence Learning Environment environmental awareness course.[71] Italy's Defence Energy Strategy Plan envisages the creation of a governance structure to implement an energy strategy in the defence field, with leadership responsibility for supervising and monitoring energy issues at a central level, and decentralized authorities aimed at controlling the intermediate chain of command.[68] The economic investments of the national MoDs to promote the employment of energy managers in military operations will produce concrete outputs in the medium-long term: after the development of a growing awareness on energy issues among military staff, the shares of energy savings and reduction of GHG emissions will necessarily raise. We can observe that the MoDs, which have introduced these figures, have strongly improved their performances in terms of energy efficiency, developing a coherent and coordinated approach in identifying weakness and distortions about energy consumption, by planning specific measures

Figure 4: The Italian Destroyer Andrea Doria, one of the ships involved in the Green Fleet Initiative

Figure 5: Canadian Armed Forces Base 5 Wing - Goose Bay, Canada

to increase greener energy footprint in military operations.

3.2.4. EDUCATION AND TRAINING

Education and training dimensions represent a key component of the EnMS because these are effective tools aimed to increase awareness of military personnel about how energy affects missions and capabilities, focusing the attention and the attempts on the dimension of behavior change. As a matter of fact, the promotion of greener energy behaviors and green practices among military staff and personnel engaged in military operations consequently leads to a reduction in logistical needs and energy consumption, also lowering operational risks, in addition to significant environmental benefits. In its Energy Performance Strategy, the French MoD underlines the relevance of education and training activities to promote awareness on the impact of energy consumption and carbon footprint among defence staff. The enhancement of energy efficiency directly contributes to the operational efficiency of the armed forces.[62] The improvement of energy behavior represents one of the main targets to achieve the specific goal of "Enhance Current Mission Effectiveness" within the U.S. DoD Operational Energy Strategy. The U.S. DoD was able to successfully include OE principles in required Professional Military Education (PME) courses on strategy, logistics, and campaigning, as well as in general military training, while the target to measure OE consumption by type of equipment has been partially completed. Service schools have incorporated operational energy principles into training at multiple levels. The U.S. Army has Operational Energy PME developed for all levels, up to and including War College. Eisenhower School for National Security and Resource Strategy-National Defence University (NDU), West Point Military Academy and the USMA core curricula include OE concepts. The Navy's Operational Energy Training and Education Plan integrates operational energy concepts into tasks, doctrine, policy, and throughout the Navy's Training and Education continuum. Based on the Air Force's Energy Strategic Plan to increase supply, reduce demand and change culture, the U.S. Air Force Academy in Colorado developed nine key actions to decrease energy consumption, by applying education and awareness plans and reducing fuel costs. At the Tinker Air Force Base, located in Oklahoma City, the personnel attend an energy awareness course; along with the training course, the energy awareness culture also includes soliciting and tracking employee suggestions for additional improvements, and establishing employee teams to analyze energy use in their own areas.[9,74] In terms of education and training, Greece's MoD requires that military staff constantly organizes tailored courses (which incorporate sustainable development principles) to increase the environmental awareness of the staff of the armed forces. Furthermore, Greek military staff regularly attend the DEMC yearly organized by the European Defence Agency since 2017. The course is aimed at increasing energy efficiency and reducing energy consumption in the military domain through the application of defence-specific EnMSs based on the ISO 50001 standard.[91] Furthermore, initiatives aimed at deepening cooperation between MoD and universities to promote training and education of armed forces and staff - in order to increase energy awareness and its implications during military operations - appear to produce positive and significant results. Since 2015, Italy's defence staff (military officers and engineers) have attended University Master and academic courses on energy management, energy efficiency and renewable energy sources (in cooperation with Italian Universities and the Defence Energy Manager Course organized by EDA). This energy-educated staff has the main task to progressively change the approach of Italian military departments concerning energy savings and environmental impact in order to strengthen a green footprint in military operations and activities. The Italian MoD expressly refers to the promotion of a so-called "energy efficiency culture", aimed to increase awareness concerning energy savings and to spread best practices: according to the Italian MoD, following a virtuous behavior concerning energy consumption, it is possible to achieve 10% of energy savings. This process will be based on the combination between a top-down approach – so, adapting the governance system which will promote energy and environmental awareness to the defence decision-makers, enabling them to develop energy policies to create a modern, efficient and powerful military apparatus – and a bottom-up approach, in order to monitor and to spread initiatives aimed at promoting energy-saving behaviors and efficient energy consumption.[69] The cooperation agreement between the Spanish Army and the University of Granada (within the framework called Spanish Army+University = Project I + D) has led to the joint implementation of the Military Energy Management Plan: the series of conclusions and recommendations for better energy use which emerged, have been included (as objectives and contents) in the Military Energy Coordination blended learning training course.[87] Training programs are considered important to increase awareness and preparation of the armed forces, which will become able to reduce their carbon footprint impact on the environment in order to achieve the objective of "Armed Forces, Carbon 0.0". With the aim to raise awareness and spread information concerning the MoD's engagement to promote energy efficiency, the "Zero Carbon" platform has been created on the Ministry's website, containing news, information, training and management on the work of the program to combat climate change, for both internal and external staff. Following a pilot project which took place at Karlberg Military Academy (which was under the EDA's framework initiative), all units, schools and centers of the Swedish Armed Forces now have tools to make energy use more efficient and these have been included in their planned activities. The project was specifically about inducing personnel to change their behavior and optimize the energy used by equipment in buildings. In summary, it involves compiling a basic energy inventory to get an understanding of how energy is being used. The standardization of tools and methods allows the different organizations to compare their energy efficiency with others.[35]

Figure 6: West Point Military Academy, USA

3.2.5. PROCUREMENT ELEMENTS

Considering the strategic relevance of procurement elements within the armed forces (in terms of operational needs and budget issues), the task to develop a Sustainable and Green Procurement in the acquisition of military equipment, services and systems has progressively become a key driver for NATO and PfP member states, allowing them to achieve greater efficiency, resilience and adaptability.

As a matter of fact, the goal to introduce environmental and energy implications in the purchasing decisions of products and services (but at the same time meeting operational needs) represents a great opportunity for the Ministries of Defence to influence the transition to a low-carbon economy by including criteria to address carbon reduction as well as to increase environmental benefits.

Green procurement is defined as "the integration of environmental considerations in the materiel acquisition and support process, including requirement identification and definition, planning, procurement, operation and maintenance, disposal of goods and realty infrastructure, and closure activities in respect of acquired services and facilities". Canadian DND and CAF are committed to applying the principles of the Green Procurement Directive, by integrating environmental considerations into decision-making processes and practices, in line with operational requirements: according to the Directive, CAF's purchases are made through green standing offer agreements and have to include green criteria in contracts for equipment and in the construction industry, in this way supporting the enhancement of the green economy by favoring low-carbon materials and green technologies. Equipment specifics to DND and CAF are dealt with differently than standard goods and services. For this equipment, environmental considerations can be identified and taken into account by using available internal resources, including: assessment of environmental considerations, life cycle analysis, environmental officers, and various tools and websites. Canadian DND applies a life-cycle approach to military equipment procurement, focusing on early integration of design specification that emphasizes energy performance and includes environmental considerations. Moreover, CAF is currently working to promote sustainable packaging for all Canadian Armed forces which could meet environmental and sustainability requirements. Furthermore, Canadian Defence has successfully implemented a clean energy procurement policy, through its commitment to purchase clean power from regional grids, as a very cost-effective way to reduce GHG emissions from military buildings. In 2019-2020, 74% of all the electricity used to power national bases and wings in provinces with carbon-intensive electrical grids came from clean sources. Defence national target is to use 100% clean electricity by 2022, where available, and by 2025 at the latest by producing or purchasing renewable electricity.[59,60]

A Green Public Procurement normative is also implemented by the Italian MoD, a document which introduces the energy and environmental sustainability criteria in order to regulate the procedure for buying equipment and consumption in the public administration. In addition to the evaluation about the energy performance of specific equipment - which must primarily be in line with operational requirements – the Italian MoD also requires to carefully balance between the purchase of modern technology and costs, highlighting that often the best solutions in terms of energy-saving could not necessarily correspond to the most recent technological innovation, usually more expensive than the least recent one. [68] The POEMS is a tool elaborated by the British MoD (the Department) within the sustainable procurement policy: POEMS (which is based on ISO 14001) is tailored to the defence acquisition process, and it is mandated for all equipment acquisition projects to ensure they are compliant with MoD and Government policy. In the UK, the Department's sustainable procurement policy requires staff to consider sustainability from the start of the procurement process, looking across the whole life of what is being procured. DE&S - an arm's-length body of the Department - has the task to deliver the equipment and logistics needed to support the objectives of the UK's Armed Forces. DE&S also has a mandatory process for managing the environmental impacts of equipment projects. DE&S produces guidance for its staff working on procurement projects and provides support and advice to the Commands on how to deliver environmental improvements during training and operations. DE&S requires all acquisition projects to use specific guidance, plans and processes to manage environmental risks at all stages of the project, using the POEMS. According to the DE&S Executive Committee, in 2019, 89% of the equipment projects complied with the required controls to manage residual environmental impacts identified in the DE&S assessment, varying by project type between 98% for land projects to 33% for air projects (since the Department's internal regulators do not set specific requirements for air projects). [72] Where defence procurements are exempted from environmental procurement standards, the Department's policy is to "maintain departmental arrangements that are, so far as reasonably practicable, at least as good as those required by UK legislation". Since 2004, the U.S. DoD has adopted a Sustainable Procurement (Green Procurement) policy aimed at promoting the use of sustainable environmental practices, including - but not limited to - the acquisition of energy-efficient products. The main goal is to achieve 100% compliance with mandatory federal sustainable procurement programs in all acquisition transactions. This applies to all acquisitions, from major systems programs to individual unit supply and service requisitions.

DoD's SPP reduces both life-cycle costs and the impact of DoD activities on the environment, such as reducing GHG emissions and increasing the use of renewable energy sources.

The characteristic feature contained in the SPP is that the main focus is on the roles and responsibilities of each member of the Department (recognizing that every person has a role to play) and not only on procurement function in the strict sense.

The related military staff must support the implementation of the DoD SPP through initiatives such as procurement, contracting, environmental management, energy management, pollution prevention.[92] In order to develop an effective Green Procurement Management, the U.S. DoD requires to implement the following steps: policy, planning, implementation, checking and corrective action, management review.[93] Moreover, in the implementation of its Operational Energy Strategy, the U.S. DoD has already achieved the first objective (increasing capabilities) and its main identified goals: the institutionalization of ESAs in capability development - aimed at ensuring that ESAs are used in all acquisition programs that use operational energy and were established from 2016 onwards - and the improvement of combat effectiveness and supportability - with the purpose to increase energy supportability, as measured against current capabilities, in 100% of all new acquisition programs.[94] The Danish MoD has developed a comprehensive policy on sustainable procurement. One of the main envisaged goals is to integrate environment and climate considerations within the framework of operational needs and into the procedures for the procurement of ammunition and contracts for ship maintenance by 2020.[27] Figures on the achievement of the scheduled targets could not be found through open sources. French authorities also point out other challenges, such as sustainable production and consumption of energy. The Sustainable Development Strategy has identified some best practices to adopt, such as limiting the environmental impacts of the equipment (in-service and post-service), conceive eco-design of the equipment of tomorrow throughout its life cycle.[61] The promotion of sustainable and green procurement policies in the acquisition of military equipment, services and systems represents a positive solution in order to progressively increase the awareness of military staff about the relevance of energy savings and reduction of polluting emissions. For all mentioned countries, one of the main challenges is the ambitious purpose to sensitize the chain of command on the need to adhere to environmental considerations in purchasing decisions. Furthermore, it appears necessary a coordinated effort between Defence Departments and national governments in order to enhance the mandatory dimension of the green procurement policies. As a matter of fact, in the case of the UK, the British government has not required MoD (as well as the other departments) to report compliance data for the government's sustainable procurement buying standards. This is a distortion to address in order to improve the effective impact of sustainable procurement. Finally, the lack of updated figures on concrete results (provided by MoDs) following the implementation of green procurement represents one of the main hindrances to lead a comprehensive and comparative evaluation of national efforts.

3.2.6. CONTRACT ELEMENTS

The possibility to develop new partnerships with non-military actors (such as energy companies) in order to increase energy savings and to rationalize energy consumption is a great opportunity for the DoD, which could benefit from the technical support of energy service companies to achieve their energy efficiency goals.

The implementation of EPCs is one of the most adopted solutions by the different MoD of NATO member states in order to upgrade the energy efficiency of military bases and buildings through energy performances guaranteed by the private sector.

EPC is a contractual arrangement between the MoD and an ESCO, which has the task of carrying out energy efficiency improvement measures at military bases or wings. The measure is verified and monitored during the whole term of the contract, where investments (work, supply or service) are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings. Essentially, the ESCO will not receive its payment unless the project delivers energy performance/savings as guaranteed. The money saved in energy costs is then used to pay the company back over a five to 15-year period.[95] Canadian Armed Forces widely use EPC option: as of March 2020, the DoD has implemented 11 EPCs on bases (Petawawa, Bagotville, Greenwood, Valcartier and Esquimalt) and wings across Canada and more are planned. According to Canadian Defence, the adoption of EPC has allowed to reduce annual GHG emissions by 22,209 tonnes of CO_2 equivalent, and save about $5.7 million in annual energy costs. CAF target included in national DEES is to assess 75% of eligible bases or wings for an EPC and move 50% to the implementation phase by 2023.[59]

Similarly, the French MoD largely uses EPC solutions to upgrade the energy efficiency of its military bases and buildings. There are significant examples and concrete results following the implementation of EPC at La Valbonne and Roc Noir military camps, St Christol and Lann-Bihoué air-navy military base. Roc Noir is defined as the first sustainable military camp in France. Through the refurbishment of 30 military buildings, Roc Noir achieved the following relevant results: 45% of energy saved, 50% of GHG emission reduction and an energy bill reduced by 36%.[96] The case of La Valbonne military camp represents a successful model concerning the achievements of energy efficiency goals in the military field. Following the adoption of EPC, this military camp achieved -50% of GHG emissions, -50% of primary energy consumption, -30% reduction of the energy bill.[64] Moreover, in 2015, La Valbonne received ISO 50001 certification that awards the existing energy management system: in addition to upgrading the energy efficiency of buildings, the adoption of energy saving-oriented behaviors by the military personnel represents the driving factor which has led to the reduction of energy consumption and GHG emissions.[97] At Saint Christol, where the 2e REG is located, the use of renewable energy sources and energy efficiency measures led to -90% of GHG emissions and -45% of energy consumption. In 2017, the French MoD signed another relevant EPC to improve the energy efficiency of Lann-Bihoué air-navy military base in Bretagne, which aims to achieve 41% of energy savings and -67% of GHG emissions.[98]

EPC represents a profitable option to adopt for the French MoD, which allows achieving relevant energy savings in military bases and reduction of the energy bills (-30%), profiting of the financial investments of the Energy Service Companies: MoD has the opportunity to gradually repay these investments in a reasonable period, but permanently benefiting of energy efficiency measures and the upgrading of buildings.

In addition to EPC, an additional solution implemented by French MoD are the energy-saving certificates or "White Certificates": through the development of partnership aimed at promoting the efficient management of energy consumption, the energy providers are obliged to actively promote energy efficiency actions. ESPC is the specific tool developed by the U.S. DoD to improve energy management system in the different military branches. ESPCs enable the Department to cost-effectively pursue energy resilience solutions in a holistic and integrated fashion through the use of third-party financing. In 2018, the Department issued the "Policy on Energy Savings Performance Contracts and Utility Energy Service Contracts" to provide updated guidance on the use of ESPCs and UESCs to enhance energy resilience and cybersecurity at DoD installations in support of the National Defence Strategy. Among several examples of ESPC, the U.S. Navy awarded its largest ever ESPC to Naval Station Guantanamo

Figure 7: U.S. Naval Station Guantanamo Bay, Cuba

Bay, Cuba, to build a new power plant, improve resiliency and reliability, increase efficiency, and add renewable generation to this self-sufficient critical installation.

Annual savings for this ESPC are expected to reach nearly four million BTU and 1 million gallons of water. Additionally, approximately 17% of the power produced by this plant will be from renewable energy sources.[99] In 2018, Hill Airforce Base in Utah awarded a $42 million ESPC for the modernization of 255 buildings in order to increase energy resilience and efficiency. Through the implementation of ESPC, energy consumption at Hill AFB will be reduced by over 217 billion British thermal units per year and save the base approximately $3.2 million annually, which will, in turn, be used to pay for the total cost of the project over the 22-year term of the contract. The projected reduction in the base's utility spending represents an annual saving of 16.7%.[100]

At the basis of the growing use of Energy (Saving) Performance Contracting solution, there is the possibility for the involved parties to have concrete gains and medium-term results: in the current economic scenario, where national states are reluctant to increase the share of the national budget to allocate for Defence Departments, the partnership with the Energy Service Company allows to overcome the existent restrictions, also upgrading the energy efficiency of the defence real estate assets.

3.3. RECOMMENDATIONS BASED ON MILITARY ENERGY MANAGEMENT BEST PRACTICES

The analysis and the evaluation of the different approaches of NATO and PfP member states toward legal and technical regulation of EnMS has clearly shown that introducing regulations on EnMS and advancing mandatory rules allow the achievement of concrete results.

The elaboration of annual reports of energy consumption in the different military departments, the introduction of the figure of an energy manager, the establishment of energy management manuals for major energy-consuming equipment are all relevant tools to promote and improve EnMS, but they can fully deploy their huge potential at the best conditions only within a clear and shared regulatory framework.

After analyzing the different solutions adopted by NATO and PfP member states, a common issue which has emerged among them is the special attention of the Ministries of Defence on the increase of environmental awareness through the promotion of green behavior, and on the role of education and training: these initiatives are conceived as good practice to implement in order to boost energy efficiency and reduce the environmental impact.

In spite of the lack of an adequate range of available data and information concerning military operational energy, it can strongly benefit from the implementation of legal and technical regulations: the key priority to provide energy security and to preserve energy efficiency in the operational theater has to push NATO, its Allies, and PfP countries to adopt a new EnMS-oriented approach.

The engagement of some NATO countries (supported by the NATO ENSEC COE) to realize an Energy Management handbook to assist energy management personnel during missions or operations is a wise step in the right direction, showing the will of NATO countries to deal with new challenges and vulnerabilities which affect operational energy.

This new approach could enforce NATO attempts to promote energy efficiency measures in the post-Afghanistan military operations, aimed at producing positive effects in terms of energy security implementation, by reducing the logistic footprint, by increasing the operational capabilities of troops (e.g., fewer logistic convoys, fewer escorts and fewer casualties), and by increasing the overall energy security of operations (e.g., decreasing the need of energy will limit the risk of disruption).

All the elements which characterize Energy Management System are necessary to implement a successful strategy aimed at improving operational energy and the achievement of concrete results: energy data, human factor, procurement and contract elements are profoundly interlinked with each other and an appropriate combination of these factors appears the most suitable solution for the MoDs.

The promotion of energy awareness among military staff is the most ambitious goal as well as the most difficult to achieve: a potential success in this field could really pave the way for a real change in the approach of the armed forces toward sustainability issues, energy management, energy savings, with the highest ratio in terms of cost-effectiveness analysis.

Among promising initiatives, the 7SEBC process elaborated by the UK MoD appears to be a very comprehensive tool which is able to produce significant energy savings. Considering its potential, 7SEBC could be a reference model for other MoD, supporting their attempts to promote energy management in their national defence sector. However, the adoption of this tool requires a convergence of shared interests among MoD, Government and Universities in order to improve this approach and tailor this to the specific features of the different national armed forces.

4. **THE BEST EXAMPLES OF EXISTING AND PROMISING SMART ENERGY TECHNOLOGIES IN THE FIELD OF MILITARY OPERATIONS

Nowadays, in the military field, RE and EE are as important as high precision-guided weapon systems. According to the trend of the last 10-15 years, energy needs are changing as well as growing. Moreover, the dramatic increase in electrical systems onboard military platforms is driving the electrification of the battlefield. Also, with the lessons identified and learned during NATO's 11 years in command of the ISAF in Afghanistan, access to energy by military units across a wide theatre of operations became a critical logistic function. That factor and the need to reduce the logistics footprint are creating requirements for distributed and portable power generation, smart energy networks, improved energy storage and wireless power transmission.

The paper analyses the main RE and EE projects and initiatives undertaken by NATO and PfP countries (including NATO ENSEC COE members) and their national military/defence companies in recent years. It focuses on fast-developed RE and EE technology solutions used by national military entities in the operational environment, as well as on those which have been recently tested in exercises, demonstrations and combat actions or are at the development stage.

Growing different kind of fuel volumes at home instead of importing them from abroad protects against price spikes in oil markets. Harnessing solar and wind energy to power military bases helps ensure bases do not go dark if a fragile electric grid is damaged. Solar panels on remote forward operating bases reduce the number of dangerous fuel convoys needed to resupply troops on the front lines.

Renewable technologies, such as solar devices for servicemen, renewable-powered unmanned vehicles and other ways of using locally-sourced energy, are key to fuel diversification goals. The military forces have increasingly turned to solar energy to meet their renewables targets. Additionally, energy efficiency is a matter of security and enhanced military performance. In situations of armed conflict, mobile solar-power units make soldiers less vulnerable to enemy forces, whereas convoys transporting diesel fuel through combat zones are at risk.

The paper presents modern and promising means of energy production, storage and distribution, positive and negative sides of individual systems, stationary and portable sources of alternative energies, as well as soldiers' individual energy storage systems. Provided RE and EE technology examples in the paper are grouped according to their different development stages: systems that are already implemented in military operations, including the ones at the testing level and promising technology solutions that are comparatively new and under development stage.

Unfortunately, in the analysis of technologies presented in this paper, the emphasis on price evaluation is not possible due to commercial secrets and the unavailability of prices.

4.1. THE BEST EXAMPLES OF EXISTING INNOVATIVE ENERGY TECHNOLOGIES

Renewable energy utilization and modern energy storage technologies, along with innovative energy distribution and energy consumer technologies, are developing by the day, enabling governments and national defence organizations to integrate those technologies into their system. Such types of technologies are critically important to improving military capabilities, unit autonomy and operational resilience on the battlefield. Cost-savings are a second important argument in favour of EE and RE. Thirdly, it has the potential to transform defence towards a more environmentally friendly.

For example, in 2019, the U.S. DoD's $1.6 billion annual investment in energy RDT&E reflects the U.S. military's characteristic pursuit towards advanced technologies as a force multiplier.

The U.S. DoD's $1.6 billion investment in RDT&E in 2019 addresses challenges in the following areas:

- Dismounted soldiers and small troop units carry ever more electronic gear that they can, without battery resupply, for longer-duration missions;
- Contingency bases face the growing demand for electric power, and must automate the control and distribution of power to and from multiple sources and loads;
- Fixed installations (bases), which rely on a vulnerable commercial grid, must be able to maintain continuous power to critical loads during extended grid outages.[101]

Currently, the main directions of clean military operational energy technologies are:

- Solar PVs: the military forces need solar PV materials that are more lightweight, flexible, and efficient than the currently dominant silicon, to use in the field, on drones, and possibly on arrays in space.
- Microgrids: stationary microgrids for fixed bases and mobile (tactical) ones for contingency bases.
- Energy Storages: militaries need better batteries for mobile missions and large-scale storage on their bases.
- Innovative hybrid engines for land vehicles and electrical engines for UAVs: to ensure the utilization of carbon-free lower-cost power sources, greater performance and quieter, stealthier operations.

4.1.1. SOLAR PANELS

There are three types of solar panels: solar photovoltaic (PV), solar thermal (T) and hybrid (PVT). All three types of panels absorb raw energy from the sun and use it to create usable energy; solar photovoltaic panels produce electricity, solar thermal panels produce heat, while hybrid solar panels generate electricity and heat simultaneously. The use of solar energy to acquire an inexhaustible, free, non-polluting, totally independent electricity production is sufficient to operate vital communications equipment during an operation and to save budgets.

- Once the solar panels are installed, they have no negative impact on the atmosphere. As a transformer of a sustainable energy source, it can meet the needs of the present without compromising the needs of the future generations and it is not subject to random price fluctuations based on the efficiency of some distant producer;

- Solar panels might be installed on any number of roofs, which wipes out the issue of trying to find enough space for solar panel arrangement. Not only does it save space, but it can save a lot of money as well;
- Large power plants are more vulnerable to terrorism, cyberattacks, and other malicious threats than solar panels installed on a military base or set up in a temporary camp that can operate independently of any centralized grid;
- While coal and nuclear plants take years to construct, mini-grids with solar PVs and battery storages can be set up within a month;
- Modern solar panels require less maintenance as they do not involve any moving parts and last for about 20-25 years. They require a few meters of space and cleaning a few times a year.[102]

In the case of the U.S. DoD, the primary stream of developing renewable energy sources is exactly the solar PVs. This trend applies to all service branches of the U.S. Armed Forces. In February 2020, at Lackland Air Force Base in San Antonio, a complete expeditionary microgrid system was demonstrated. For energy production, monocrystalline silicon solar PVs were placed on top of the tents. The hardware, software and lithium-ion batteries were on a 10-foot long trailer. The project evaluated energy reduction technologies such as shelter insulation and efficient heating, ventilation and air conditioning systems.[103]

The U.S. Army is one of the biggest users of solar PVs. There are more than 130 MW solar PV energy systems powering Navy, Army and Air Force bases in at least 31 states and the District of Columbia. These installations combined provide enough clean energy to power 22,000 houses. In addition, PV is 58% of the 1.9 GW renewable energy capacity additions set by DoD from 2012 to 2017.

In December 2019, it became known that by the end of the year 7 U.S. army bases went solar:

- Army Garrison Fort Detrick in Frederick Maryland (The 59,994-panel solar system was installed on 67 acres of land on Fort Detrick. It is capable of islanding as a microgrid and accounts for 12% of the base's energy needs.);

Figure 8: Solar panels at Patrol Base Boldak, Helmand province, Afghanistan

- Fort Campbell in Kentucky (5 MW solar system accounts for 10% of the energy needs of the base);
- Shaw Air Force base in South Carolina (the 5,865-solar panels that were installed were estimated to cut 40% of electricity use at Shaw Military Housing);
- The United States Marine Corps Recruit Depot at Parris island (5.5 MW solar system and a U-MW/8 battery storage system);
- Holloman Air Force Base (the 56 000-solar panels across 42 acres);
- Redstone Arsenal Army post in Huntsville, Alabama (10 MW solar array with 1 MW energy storage system);
- Naval Support Activity Mid-South in Millington (53 MW solar system across 348 acres).[104]

Finally, switching to solar energy would save the military forces – and, by extension taxpayers – massive sums of money. In the case of the U.S., one recent study found that while installing the volume of solar PVs needed for real energy resilience would cost the military forces around $42 billion, they would ultimately save $2 billion per year on their electric bills.

Overall, the military sector – the world's largest consumer of petroleum – has made real progress in reducing its consumption of fossil fuels and increasing its consumption of renewables. The U.S. military's oil consumption fell by 20% between 2007 and 2015, and its investment in renewable energy projects tripled between 2011 and 2015. Given the manifold benefits of solar, it is no surprise that solar PVs comprised 71% of the military forces' renewable energy additions between 2012 and 2017.

The military forces have utilized portable solar arrays to power "fixed-site" locations, many of which are very remote and depend on off-grid power. Solar reduces demand for traditional generators at these discreet locations and, in turn, limits the need for costly and dangerous fuel resupply missions that put personnel at risk. Operational solar also provides these bases with dependable power that is easily portable, compared to obtrusive, heavy, and, at times, unreliable generators that are often targets of enemy fire.

For mobile command centers, rapid deployment missions and field military exercises towable hybrid power systems are used. As a rule, they have different output power but the main components are the same – a diesel generator and photovoltaic systems. For example, a trailer produced by an American ZeroBase Energy enables rapid deployment of a complete energy system with an on-board generator capable of delivering up to 18 kW (there are three standard power models - 6 kW, 9 kW, 18 kW) of output power. It has 120V/60Hz, 230V/50Hz AC output and single, split and 3-phase options. By customers' order, it could be based on a commercial or military (M1102) trailer. Actually, such a trailer was used by French Forces during the military exercise - "Capable Logistician 2019".[161] It was equipped with a diesel generator (8.2 kW), photovoltaic panels (1.38 kWp) and a battery (19 kWh).

As an example of deployable solar thermal technologies, in 2015, during the NATO Smart Energy Exercise "Capable Logistician 2015", the German Bundeswehr demonstrated a solar thermal container with 20m2 solar panels on its roof to heat water directly by the sun; where hot water is used for showers: the solar thermal container is connected to a 2000 L water reservoir, a shower container and a wastewater basin; production: 2000 liters of hot water (70°C) during one day.[121]

4.1.2. MOBILE ROLL-ARRAY SOLAR POWER PLANT

Based on the SC concepts, British Renovagen Ltd has developed the highly mobile Roll-Array solar power plant. It was first used during the NATO Smart Energy Exercise "Capable Logistician 2015".

Based on Renovagen's Roll-Array, the HyPER-FST was developed. Being integrated into Rapid Roll systems, it delivers fuel savings by leveraging auto start-stop control of a diesel generator to reduce the number of running hours. The technology also facilitates the easy supplementation of hybrid power with solar energy – from 0% solar to 99% – actually depending on location and weather conditions. The presence of the generator eliminates "weather anxiety" and guarantees that backup power will always be available. Typically fuel savings of 50% to 95% can be realised in the HyPER-FST solar-battery-diesel hybrid. [74,105]

The Rapid Roll "T" trailer/tactical version provides an extremely mobile solution which can be airlifted by a wide range of medium and heavy-lift helicopters (gross weight from 1,500 kg) but packs enough power for energy-intensive operations. It could be easily mounted on an on-road or off-road trailer or flat-bed truck. The model designated is, for example, the RAPID ROLL 11\48 – indicating 11 kWp solar capacity and 48

Figure 9: Roll-Array Solar Power Plant designed by British Renovagen Ltd

kWh battery capacity. Rapid Roll “T” systems are available in single or 3-phase, 230V/400V 50Hz or 120V/208V 60Hz variants with grid-connect or HyPER-FST options. The most powerful variant - RAPID ROLL 11\120 could provide 10.8 kWp solar capacity and has 120 kWh battery bank nominal capacity.

Renovagen says that the 45 Commando Royal Marines have used the Fast-Fold system and given positive reviews. In a Command and Staff Training Exercise in Scotland (in 2017 and 2018), they replaced some of their 2 kW LFGs at their field headquarters with a Renovagen system and claimed it saved 87% of the fuel they would normally use.

The motorized PV Roll-Array rolls up into a trailer in 5 minutes; it provides many options for deployment to practically any imaginable global location.

4.1.3. HYBRID POWER GENERATION AND MANAGEMENT SYSTEM

From a technical point of view, the deployable modular HPGS deserves attention. The project was initiated by NATO ENSEC COE in 2015 and was aimed to create an effective modular HPGS; it was designed, developed and built in cooperation with a private company with financial support from the Canadian Government.

The prototype (the main developer PFISTERER was announced as a tender winner on 22 May 2015) can provide a maximum 150 kW peak generation. The HPGS is controlled via the MEMS. It also utilizes renewable energy sources - sun and wind - to further reduce fuel consumption. The HPGS can operate as a stand-alone generator system, but it can also be integrated into the existing power grid architecture.

It contains the following components:

- Two diesel generators (constant output 101.4 kVA @ cos phi 0.8: 80 kW, output voltage 230 V / 400 V / 50 Hz three-phase);
- PV system (peak power 25.2 kWp, output voltage 400V/50 Hz three phases, PV modules DAS 300 Wp (84 pcs), dimensions (set up) approx. 37 m x 7.5 m);
- Wind turbine (output voltage 400V/50Hz three phases, rated output power 6.5 kW, peak output power 7.5 kW, propeller diameter 5.3 m, mast high 12.5 m);
- Electrical Storage and MEMS (battery technology Lithium MNC, capacity: 100 kWh, module capacity 75 Ah (x 12), the battery inverter 280 kW, MEMS software ADS-TEC).

The MEMS is the core component of the HPGS, giving the flexibility to manage power sources and loads by automatically controlling them. During the operation of the HPGS, the MEMS controls the operation of the generators in such a way that it uses the generators as little as possible. Once the battery charge level falls below the set limit SOC (40%), one of the generators will automatically switch on until the upper SOC limit (80%) is reached. Besides innovative technical solutions and high efficiency, one of the main advantages of the HPGS is its easy deployment and transportability. The full system is housed in two 20’ ISO standard containers. The first container with batteries, inverters and generators weighs approximately 15 tons, the second container with PV system, wind turbine (including mast), cooling/heating system and spare parts is around 11 tons. The total weight of the HPGS is approximately 26 tons.

For analyzing the performance characteristics and effectiveness of the HPGS, from March 2016 till October 2017, nine tests (in national, multinational and NATO exercises and trainings, as well as in military installations/barracks) were conducted. The duration of tests was different (from 2.5 hrs up to 10 days) as well as weather conditions and average loads (from 7 kW up to 64 kW). The maximum loading was 43% for a duration of 2.5 hours and the minimum tested was 5% only; under this condition, the HPGS achieved its maximum fuel efficiency (3.8 kWh/l). During the period from March 2016 to September 2018, multiple tests have been conducted in a number of military exercises and demonstrations in Europe (France, Germany, Lithuania) where the ambient temperatures ranged from -1°C to 21°C and different average loads were set between 7 kW and 64 kW (nearly 5% to 45% of HPGS nominal maximum load).

Figure 10: Deployable Modular Hybrid Power Generation and Management System designed within the NATO ENSEC COE's project

The HPGS was also successfully deployed for a four months period testing campaign under extreme winter conditions on Canadian soil from January till April 2019.

The extensive use of this system during several military exercises has demonstrated its potentiality to improve energy efficiency, to reduce the military dependence on fossil fuels as well as to maximize autonomy and, ultimately, to reduce the logistic footprint.[79, 106-108]

4.1.4. THE UTILIZATION OF RE IN HARSH WEATHER ENVIRONMENT

As part of Exercise Guerrier Nordique, an easy-to-transport mini electric power station was designed and built by members of 35 Canadian Brigade Group to reduce fuel dependence. The system leverages wind and solar energy in harsh weather environments, it is non-polluting, totally autonomous and sufficient to operate communications equipment. It has two batteries capable of storing 265 amperes, four 140-watt solar panels and two windmills. A weather station was also acquired to collect highly precise data on wind and solar conditions and their impact on electrical production capacity.

At Colville Lake, the Hybrid Power station was implemented with 136.5 kW solar power + 232 kWh battery storage + 350 kW diesel generators. As a result, it achieved a 27% reduction in diesel plant use. Besides that, diesel generators could be turned off during the summer.

During 2017 in Kotzebue, Alaska, where the Pacific Air Forces Regional Support Center and 611th Civil Engineer Squadron operate a remote radar range 40 miles north of the Arctic Circle, an energy-harvesting wind turbine was successfully tested. It was developed by the AFRL Advanced Power Technology Office as a rapidly deployable and independent energy source for remote military sites. Plus, the test location was chosen especially for its extreme weather conditions.

Along with the original Distant Early Warning, or DEW Line, this arctic location was once part of a line of radar stations set up to detect and warn of an invasion by enemy forces. Here, the AFRL team, along with University of Dayton Research

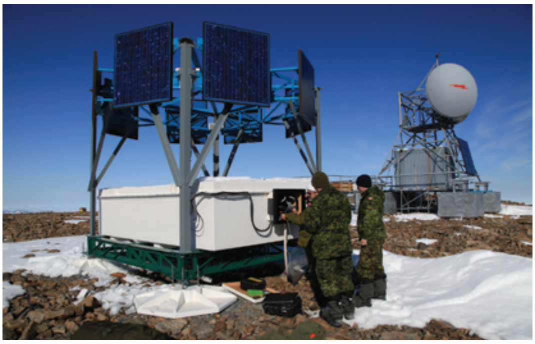


Figure 11: Technicians of the Canadian Army work at a radar site, at the Northern Military Base

Institute personnel, installed two wind turbines that are expected to generate 12 kilowatts of power to offset the grid load.

The unique aspect of these wind turbines is their transportability, ruggedness, and easy installation that make them ideal for this austere environment. The towers, developed by ARE Telecom & Wind, were palletized at the request of AFRL to make them easily transportable and able to be quickly set up by a minimal crew. The AFRL team assembled and installed the 15-meter-long assembly in less than four days with five people. [109]

4.1.5. LARGE ENERGY STORAGES FOR FIXED INSTALLATIONS

In the military field, energy storage is as important as its production. Energy storage systems primarily offer value to power systems by absorbing power during periods with low demand and injecting power during periods with high demand. In 2017, Go Electric Inc. was awarded a $1.7 million contract by PMSI to provide a 1MW/1MWh grid-tied battery storage system to the TEAD (a premier active joint ammunition storage site for the U.S. Army and it covers roughly 24,000 acres) in Tooele, Utah. In turn, it will help ensure TEAD being self-sufficient when it comes to power and energy supply, enhance power and energy reliability and resilience, and cost-effectively insulate TEAD from the volatility of energy prices.

One of the U.S. military's first utility-scale renewable energy projects, the TEAD's 1.5 MW solar energy array consists of 430 parabolic-mirrored dishes spanning 17 acres that concentrate and focus the sun's thermal energy onto a Stirling electricity generator. Upon commissioning, TEAD's concentrating solar thermal energy system was expected to generate 30% of the Army Depot's energy – equivalent to the amount used by 300-400 average houses. By reducing grid energy consumption, the solar array was expected to yield estimated annual cost savings of around $260,000.

For the project, PMSI was interconnected to Go Electric's new generation BESS to TEAD's existing 46 kV line. Go Electric's advanced BESS includes its 1 MW lithium-ion battery and microgrid controller, enabling TEAD to manage and optimize multiple alternating currents and direct current distributed energy resources.

The BESS and microgrid controller to be installed at TEAD are designed to help provide the base with multiple key energy services: peak demand shaving, "black start" and uninterruptible power supply capabilities for TEAD, ancillary frequency and voltage regulation services for the utility grid.

By reducing grid power purchases during expensive peak demand periods of the day, the former should reduce strains on the local utility grid, as well as TEAD's monthly utility bills. "Black start" and uninterruptible power supply capabilities should result in the BESS and microgrid automatically switching to "island mode" operations in the event of a grid outage, tapping into the en-

Figure 12: Utility scale lithium-ion Battery Energy Storage System (BESS) installation at Fort Carson, USA

ergy stored in the LiB to power the facility's critical needs.[110]

4.1.6. WEARABLE BATTERIES

In the XXI century, SP has become one of the main important parts of RE and EE in the military field. It focuses on the energy needs for soldiers and small combat units that operate on foot, typically in remote areas and under harsh conditions.

In 2001, when the U.S. first arrived in Afghanistan, a typical unit required 2 kWh of electricity to power its devices for 72 hours. Today's soldiers carry a host of energy-consuming devices, including night-vision goggles, emergency location beacons, laser telemetry devices, networked radios, and ruggedized smartphones. Comparable unit power consumption now exceeds 30 kWh, and the Army expects soldiers' power requirement to double by 2025 as they acquire augmented reality gear, next-generation squad weapons, and other new equipment. One of the challenges which is driving U.S. DoD's RDT&E investments in SP is providing longer-duration missions without resupply: the U.S. Army wants to extend its standard patrol from 72 to 144 hours, and the Marine Corps has a 2025 goal of being able to go ashore anywhere carrying only mobility fuel. The power demand means the warfighter carries an additional 7 kg of batteries, equivalent to an unloaded automatic weapon, on top of the 27-54 kg of standard gear.[101]

Actually, a decade ago, the NW program was launched. It involved mobile server stacks that create a tactical wireless network on the battlefield and an array of tech gear that allows individual warfighters to stream video from drones and ground-based robots with overlays displaying friendly troops and command and control points. Then, the main challenge of NW was to reduce soldiers' battery burden design and develop effective CWB.

CWB are manufactured in a thin, flat, flexible package that fits into the soldier's tactical vest and body armor. They conform to the human body shape and can be worn in the chest, side, or back pouch areas. CWB are available as both primary (not rechargeable) and secondary (rechargeable) batteries. They typically weigh approximately 900 g, but offer as much as 16 amp-hours of capacity and 250 watt-hours of energy. [111]

A solution called the Soldier Wearable Integrated Power Equipment System, known as SWIPES, was developed by the U.S. Army Communications-Electronics Research, Development and Engineering Center. It provided an integrated solution for mission-critical electronics that can flex and stretch with the body while reducing weight. In SWIPES, all electronics carried by the warfighter were integrated into one tactical vest.

Currently, the conformal battery has shown potential benefits to replace swappable batteries. Significant improvements to the battery chemistry, level of conformability, and fabrication cost are critical to the military forces' effort to power mission-critical electronics. The availability of numerous battery chemistries such as magnesium, aluminum, iron, zinc, and Li-ion has been explored for rechargeable batteries; there has been significant interest in Li-ion and many of its sub-chemistries due to their high theoretical specific energy (5,928 Wh/kg) and high cell voltage (2.96 V).

Despite the benefits (such as low self-discharge rate, high round-trip efficiency, and longer lifetime), studies are underway to create more effective chemistry to replace Li-ion batteries. The main reason for this move toward the sodium-based battery is simply because sodium is one of the most abundantly available resources in the Earth's crust.

Zinc-based batteries are inherently safer, inexpensive and more abundant, especially in the U.S., compared to Li-ion. And more importantly, zinc batteries have a relatively high specific energy (1,218 Wh/kg) and volumetric energy density (6,136 Wh/L). Recently, a U.S. Naval Research Laboratory team developed a rechargeable, nickel-3D zinc battery as an energy-dense, safer alternative to lithium-ion. By implementing a porous zinc structure, the formation of dendrites is mitigated while maintaining a high capacity of 216 Wh/L along with tens of thousands of recharge cycles.[112,113]

This zinc chemistry presents a safer and cheaper battery chemistry alternative to Li-ion with an estimated cost of $160 per kWh, when the average Li-ion battery prices are not expected to reach that value until 2025.

Researchers at the University of California, San Diego, initially used printed batteries for small patches to power wearable electronics. However, screen printing can be utilized to coat the entire inner area of a military vest. A typical military vest for an average male torso covers a surface area of 0.6-0.7 m^2. The areal capacity of printed batteries will be greater than 3.5 mAh/cm2 to achieve nearly three times the capacity of the current conformal battery (7.3 Ah) used by SWIPES.

The use of conductive inks and printing technologies allows for battery conformability, enabling them to stretch, bend, flex, and twist. While most applications do not require a significant amount of stretch (other than electronic textiles), flexibility is an essential form factor. Blue Spark Technologies Inc. developed a printed battery with a capacity of less than <1 mAh/cm^2, and they combined printed batteries and temperature sensors for a disposable temperature monitor for newborns. However, this battery has a poor capacity of <1.5 mAh/cm^2 over the course of 100 recharge cycles.[113]

The printed batteries concept is based on modern SS. In the case of SPINE, which is being developed by British BAE and Broadsword, the system is built around printed batteries integrated into textile. According to research, graphene (an allotrope of carbon in the form of a single layer of atoms in a two-dimensional hexagonal lattice in which one atom forms each vertex) and other related materials can be directly incorporated into fabrics. Within the fabric, the materials produce charge storage elements such as capacitors, paving the way to textile-based power supplies, which are washable, flexible and comfortable to wear.[114]

The group of researchers led by Dr. Felice Torrisi suspended individual graphene sheets in a low boiling point solvent, which is easily removed after deposition on the fabric, resulting in a thin

Figure 13: Conformal Wearable Batteries

and uniform conducting network made up of multiple graphene sheets. The subsequent overlay of several graphenes and hexagonal boron nitride fabrics creates an active region, which enables charge storage.[115,116]

In July 2018, it was announced that Ultralife Corporation had started producing the new UBBL35 type of rechargeable conformal battery (width 228.6 mm, thickness 16.51 mm, length 203.2 mm, weight 960 g). It was specifically designed for harsh military environments, where reliability and ruggedness are key factors. The Li-ion battery (voltage range 12.0V to 16.8V, capacity 7.3 Ah, cycle life >300 cycles) has no memory effect, meaning it can be charged after short missions without any damage to the battery.[117]

Another type of rechargeable battery, which was created specifically for military use and based on modern technologies, is SLB-101 (nominal voltage 14.4 V, voltage range 10.0 to 16.8 V, capacity 11 Ah). That flexible battery is conformable to many surfaces while providing high reliability with high energy over a wide temperature range (-20 to +60ºC). Produced by Eagle Pitcher Technologies, the benefits of SLB-101 include: high energy storage in ergonomic format (width 194.6 mm, thickness 17.8 mm, length 221.0 mm), little weight (1180 g), five-level state of charge indicator, interface capability with BMS.[118,119]

The CWB can be easily inserted directly into the outer tactical vest and it is capable of powering all peripheral devices, effectively reducing the warfighter's burden by decreasing the need to carry multiple batteries. Moreover, one of the main benefits of CWBs is that they are lightweight, flexible and their ergonomic design allows warfighters to carry more mission control equipment while also maintaining the ability to remain agile and more efficient in the field.

4.1.7. SMART GRIDS

To effectively integrate a growing amount of intermittent energy sources like solar and wind into the grid, smart grids, including microgrids, are key. A "smart grid" is a digitized infrastructure of the electricity system that uses computer technology to create a two-way communication between all nodes of the electricity network – supply, distribution, and consumption – creating a more efficient, reliable, and resilient system. Automated technology relays information from sensors and smart meters employed at home and offices, allowing the utility to adjust and control power flows in real-time in each individual device, or in millions of devices, from a central location.

The intelligent systems will provide data to power software that can display the status of a system in an easy, intuitive manner. Finally, the EIO (Energy Informed Operations) will provide users with planning capabilities that allow the best use and deployment of resources.[120]

A microgrid is a decentralized group of electricity sources and loads that normally operates connected to and synchronous with the traditional wide area synchronous grid, but can also disconnect to "island mode" and function autonomously as physical or economic conditions dictate.
Microgrids have been identified as a key component of the Smart Grid for improving power reliability and quality, increasing system energy efficiency, and providing the possibility of grid-independence to individual end-user sites.

Concerning the development of modern technologies in the field of RE and EE, the U.S. Navy is not far behind. By the end of 2019, it became known that Northern Reliability, Inc. was selected by the EPRI to design and build two transportable microgrids BESS for the U.S. Navy (the $2 million contract was finalized in August 2019). Both systems were gone through testing at the Port Hueneme Naval Base in Ventura County, CA. They will then go through testing and operational use at the Naval Surface Warfare Center - Port Hueneme division data center in Southern California.

Each BESS is using 250 kW, 4-hour lithium-ion-based systems contained in transportable shipping containers. Additionally, both will be fitted with Navy-approved supplemental fire protection components and incorporate an innovative lithium-ion battery cell off-gas detection device, which is integrated with the fire protection/suppression system.

Figure 14: Tactical Mobile Microgrid System

The benefits of microgrids include:

- Enabling grid modernization and integration of multiple Smart Grid technologies;
- Enhancing the integration of distributed and renewable energy sources that help to reduce peak loads and reduce losses by locating generation near demand;
- Meeting the needs of end-users by ensuring energy supply for critical loads, controlling power quality and reliability at the local level, and promoting customer participation through demand side management and community involvement in electricity supply;
- Supporting the macrogrid by handling sensitive loads and the variability of renewables locally and supplying ancillary services to the bulk power system.

Other potential benefits include addressing vulnerabilities in critical infrastructure, managing peak loads, lowering emissions, using fuel resources more efficiently, and helping customers manage energy costs.

4.1.8. ENERGY MANAGEMENT SYSTEMS

From a technological point of view, another interesting British project is the DEMS. It was designed and developed by BAE Systems and it is a plug-and-go solution, incorporating an energy management system that controls generators, maintains storage and manages demand to meet operational requirements and energy use patterns.

DEMS, which is proven in an operational tasking to save up to 30% in fuel and maintenance costs, integrates equipment currently in use, plus it is designed to have the flexibility to accommodate commercial generators and current and future fuel-saving technologies, such as solar power and wind. The system works by being seamlessly plugged in between the generator and the distribution system. The generators charge a battery system controlled by the DEMS console, which switches the generator off when the batteries are fully charged. It is also highly configurable to enable locations of small operating bases or large operating bases (from powering a single item to a 500 men camp) to plug in the necessary components to get the most efficient power solution for any type of deployed operations and can be controlled in theatre or remotely.[74,121,122]

An ideal solution for an energy management system for FOB could be the THPS, designed by the

American Solar Stik.Inc. Facilitated by improved energy management, it could reduce fuel consumption and consequently decrease the resupply of fuel. The THPS reduces fuel consumption and runtime of fossil fuel generators by sourcing stored energy first and maximizing renewable power generation.

The capability to automatically start and stop the generator is an essential power management feature of efficient hybrid power systems and therefore a common attribute of all categories of THPS.

Hybrid power systems contain Power Generation, Energy Storage, and Power Management components. Power Generation components include fossil fuel generators and renewable power sources. Energy Storage is essentially a battery bank. Power Management components can include a Power Management Module, Power Distribution Module, and Solar Charge Controllers. The key to the THPS is a Power Management Module that can integrate various components with little to no manipulation.

The THPS has the capability to harvest energy from any source available whether it is renewable, vehicular, grid, or traditional generators. The THPS incorporates multiple power systems to form a single power source. Power Generation, Energy Storage, and Power Management components work in concert to ensure that the most operationally effective source is used first.

Figure 15: SPM-622 Squad Power Manager

At the tactical level and for individual use, the portable Power Manager kits are used. At the beginning of 2018, it was announced that Protonex Technology Corporation had received two purchase orders (in the amount of $1.6 and $1.9 million) for the supply of its Squad Power Manager kits SPM-622 for the U.S. Army Special Operations Forces and the U.S. Army Security Force Assistance Brigades.

The SPM-622 Squad Power Manager is an agile and rugged device that weighs less than a pound and enables units to pull power from any source to recharge batteries and keep electronic devices operational – including portable radios, GPS systems, field medical equipment and other mission essential electronics. The in-built intelligence in the SPM-622 allows it to draw power from solar panels or blankets, vehicle and aircraft power outlets, an AC wall socket, generator-powered microgrid, wind turbine, scavenged batteries, etc. to run equipment or recharge batteries.

Due to innovative technical solutions and the use of modern technologies, SPM-622 delivers critical benefits for military force, including: reliable energy regardless of changing battlefield conditions; reduction of the weight of the battery burden carried by soldiers in the field; reduction of logistical support; and energy flexibility for troops operating in austere environments. The SPM-622 Squad Power Manager system is developed to date in more than 5,000 units deployed by the U.S. and NATO Partner Nations.[123,124]

4.1.9. SMART ENERGY FIXED MILITARY INSTALLATIONS

On a level with the improvement of RE technologies and the introduction of new technical solutions in the military field, EE also plays an important role in reducing dependence on traditional energy sources.

In 2017, the Bundeswehr (Federal Defence Forces of Germany) conducted a huge research in optimizing the energy and utility supply in static field accommodations. Up to now, the energy supply of static accommodations has been based exclusively on the use of diesel fuels and the use of/ connection to locally available supply systems.

Energy and utility supply is based on the demand/ consumption for a static accommodation. Up to now, the measures to restrict and deliberately control the supply of energy and utility have been very limited. Means of transport, logistic support channels, steps to be taken for energy conversion and the energy required for maintaining the security of supply depend on numerous actors and cannot be influenced directly. Among them are primary and secondary energy factors.

The former shows the ratio between the amount of the fossil and renewable primary energy quantity used and the amount of the delivered final energy; this depends on the design of the energy supply chain in theatre. While, in the latter case - energy is defined as a type of energy which is generated by converting, refining or processing primary energy.

The energy/utility supply of a static accommodation requires the use of different forms of energy (electrical energy/heating and/or cooling energy). Depending on climatic conditions in theatre and other mission-specific framework conditions, suitable energy generation chains shall be defined and taken into account in the plant technology employed. Being of the utmost importance, the rapid implementation of the planning, establishment and operation of a static accommodation has priority.

Identification and measurement of energy and utilities consumption are necessary to control the reference variables. For this purpose, basic data as reference values (e.g., usable areas, volumes, number of persons, consumption of energy and water) must be identified by the operator of field accommodations and further used to compile specific variables.

To limit PE demand in operational infrastructure, the following measures must be considered: use of power generating units with high electrical efficiency; use of waste heat from technical processes; use of renewable energies to produce electricity and heat; power generation from waste incineration; use of energy-saving cooling techniques; use of water- and energy-efficient

Figure 16: Fixed military installation equipped with solar panels. Basic expeditionary airmen skills training at Lackland Air Force Base in San Antonio

laundry technology; use of power generating units which can be operated using different energy sources (oil, gas, wood, diesel); use of motion detection for efficient lighting control; use of LEDs for lighting.[65]

4.1.10 SMART ENERGY TENTS

For increasing the EE of a base camp and reducing dependence on different kinds of energy sources, even factors such as the energy efficiency of buildings themselves play an important role. In 2015, in the NATO Smart Energy Exercise "Capable Logistician 2015", the Smart Energy Tents, produced by the Italian DEFSHEEL (a brand of G&G Partners), were tested for the first time. The tent's construction is based on a complete range of re-deployable, modular structures with a low environmental impact. By using modern technologies and technical solutions, it was given the opportunity to improve a number of indicators. The most important innovation, introduced on the "structures" specific market, consists of Carbon Hybrid: aluminium profiles reinforced with special fibers, which guarantee high performances both in terms of lightness (reduced weight up to -35%), volume reduction (less volume up to -50%) and transportation cost. But the main feature of this system is the thermos canvas membrane. It increases insulation and comfort by reducing the transmission of heat irradiations. The silver color treatment on the surface increases environmental comfort and brightness, as it reflects more radiation from the sun than other coatings. Moreover, the tent has a modular construction and, on its ceiling, it could easily be installed several light and flexible photovoltaic panels. High-performance thin-film silicium Polycrystalline photovoltaic cells could produce 130 Watt on a square meter (for example: 6.0x6.0 m tent can produce 4 kW with 32 panels).

Official tests, carried out on the Field Tent with dimensions of 6.0x6.0 m by the Italian Air Force and Italian Fire Brigade, have been detected, with an external temperature of 36°C and an internal tent temperature of only 28°C. In comparison with traditional tents, thanks to a reduction of thermic transmission of about 50% in summer and of 35% in winter, thermos canvas strongly reduces the energetic needs by optimizing air conditioning employment. Thus, less energy is used for powering HVAC units, which are the largest power consumers in deployed camps. Also, the silver colour treatment on the internal surface enhances brightness and avoids unpleasant PVC smells. In recent years, these smart tents are actively used by the Italian Armed Forces. [74,121,125]

Figure 17: Smart Energy Tents, produced by Italian DEFSHEEL, military exercise CL 2019

4.1.11 UNMANNED AERIAL VEHICLES

According to the last 10 years' tendency, UAVs have become one of the most important parts of the armed forces. New technologies from smart skin to structural components and intelligent motors with integral gearing will be employed. Near-silent operation and virtually no noise or gaseous emissions are both major benefits.

Electric power makes the use of wheel power possible for take-off because electric motors can give maximum torque from stationary. It gives us near silent operation, in the air and on the ground, with virtually no noise or gaseous emissions, something valued in both military and civil applications.

One of the biggest UAVs, which is using solar energy to fly is Zephyr. The original target mission of the Zephyr is to provide local persistence at an affordable price with a re-usable solar-powered aircraft, providing a wide scope of applications, ranging from maritime surveillance and services, border patrol missions, communications, forest fire detection and monitoring, or navigation.

Operating in the stratosphere at an average altitude of 21 km, the ultra-lightweight Zephyr has a wingspan of 25 meters and a weight of less than 75 kg.

The Zephyr was originally designed and built in 2003 by the British Defence contractor, QinetiQ. In Summer 2018, the improved version - Zephyr S remained aloft for 25 days 23h 57min. It used Amprius lithium-ion batteries with silicon nanowire anodes for a 435 Wh/kg specific energy up from 300-320 Wh/kg for conventional graphite anodes. High efficiency, lightweight, and flexible inverted metamorphic (IMM) multi-junction epitaxial lift-off (ELO) GaAs solar cell sheets, manufactured by MicroLink Devices, provided solar power with specific powers exceeding 1,500 W/kg and areal powers greater than 350 W/m2.
The vehicle uses sunlight to charge a lithium-sulphur battery during the day, which powers the aircraft at night. During the day, Zephyr uses its solar cells spread across its wings to recharge high-power lithium-sulphur batteries and drive two propellers.[126,127]

One of the modern electrical UAVs is PHASA-35, which made its first flight on February 17th, 2020. Sponsored by the UK's DSTL and Australian DSTG, the flight trials took place at the Royal Australian Air Force RAAF Woomera Test Range in South Australia.

PHASA-35 has been designed, built and now flown in less than two years as part of a collaboration between BAE Systems and Plasmatic Ltd. The wingspan of the UAV is 35 m, while the weight will is approximately 150 kg. The ultra-lightweight design and efficient structure will enable the PHASA-35 to fly at a maximum altitude of 70,000 ft (21,336 m).[128-130]

In November 2017, it became known that the Polish Defence ministry purchased Warmate-1 Micro Combat Unmanned Aircraft System kits from the WB Group company. This UAV is considered as an alternative to anti-tank guided missiles, allowing soldiers to hit targets at a longer range. The drone is equipped with an electric motor that accelerates it to a maximum speed of 80 km/h (150 km/h during an attack).[131]

One of the most successful examples of minimizing the size of a flying reconnaissance platform using an electric salt installation is the Black Hornet Nano - a military micro UAV developed by the Norwegian Prox Dynamics AS and in use by the armed and special forces of the United States, France, the United Kingdom, Germany, Australia, Norway and the Netherlands. Its Development was initiated by Prox Dynamics in April 2008. The first customer was the UK MOD, which had been awarded a $31 million contract to deliver 160 units of Black Hornets for its armed forces. During the "Herrick" operation in Afghanistan, British troops were using Black Hornet (weight 33 g, main rotor span 123 mm) from the front line to fly into enemy territory.

Capable of flying for 20-25 minutes on quiet electric motors, it has been used to look around corners or over walls and other obstacles to identify any hidden dangers and enemy positions. The pocket-size and nearly silent Black Hornet is connected to the operator via digital data-link and GPS, so live videos and HD still images are displayed on a small handheld terminal, which can be used by the operator to control the UAV. By 2015, the UAV has been deployed by the U.S. Marine Corps special operations teams. By September 2016, the PD-100 Black Hornet was in use by the militaries of 19 NATO-allied countries.

In January 2019, it was announced that FLIR Systems received a $39.7 million initial contract for the next-generation Black Hornet 3 nano-UAV. It is capable of operating in wind, with a speed ranging between 15 kt and 20 kt, and in temperatures between -10ºC and 43ºC. Deliveries of the Black Hornet 3 PRS units started by the end of 2020 to support the U.S. Army's platoon, small unit-level surveillance and reconnaissance capabilities.[132-134]

In the case of this type of UAV - the main benefit is the electric propulsion system. The use of rechargeable batteries in conjunction with an electric motor allows designers to create relatively compact drones, whose main advantage is the absence of noise during the flight. Actually, the absence of engine noise as an unmasking factor increases the combat vitality of the drone.

Figure 18: UAV Zephyr S, designed by QinetiQ

4.1.12 UNMANNED GROUND VEHICLES

On a par with unmanned aerial platforms, over the past 5-10 years more and more attention has been paid to ground combat robotic systems equipped with the electric propulsion system. If earlier the main direction of these robotic systems was considered reconnaissance and demining, nowadays priority is given to combat infantry robotic platforms. According to research, the global military unmanned ground vehicle market is expected to reach $2,596.1 million by 2026.

The modern battlefield requires soldiers who are able to adapt quickly to any mission and as robots join them, they will have to do the same. In 2016, during the Singapore Airshow by the Estonian defence company Milrem, it was shown the robotic Tracked Hybrid Modular Infantry System (THeMIS). The main benefit of THeMIS is its modular design. In the case of THeMIS, the basic system consists of a pair of tracked pods separated by a central platform. Each pod has independent electronics as well as power packs that are either electric or diesel driven. When assembled, they form a two-track remote-controlled or autonomous robot measuring 2.5x2x0.6 m and weighing 750 kg, with the capability of carrying the same in payload. THeMIS has a hybrid (diesel engine & electric generator) propulsion system. In the case of using a Li-ion battery pack, THeMIS run time is 0,5-1,5 h and, with a hybrid one, – 12-15h.

After a couple of years from the first presentation, during the international military exhibition IDEX 2019 in Abu Dhabi, it was shown the upgraded THeMIS. MBDA, Electro Optic Systems, ST Engineering and Nexter, except Milrem itself, were taking part in its modernization program, aimed at increasing its combat capabilities. The UGVs were displayed in four different configurations - anti-tank unmanned ground system, with a precise and powerful 30 mm cannon, a light 12,7 mm machine gun system complimented with a 40 mm grenade launcher and with a 20 mm turret. It should be noted that in 2018, four THeMIS UGV were tested in the UK during the Army Warfighting Experiment by NATO soldiers. [135,136]

Ever since Milrem debuted its robotic THeMIS in 2016, the company has been expanding the capabilities of its combat platform, which can be equipped for a wide variety of missions. The Type X RCV is a heavily armed, unmanned mini-tank that could act both independently and alongside manned vehicles.

Type X has a hybrid diesel-electric drive and onboard batteries that allow for one hour of silent

Figure 19: The Type X Robotic Combat Vehicle, designed by Milrem Robotics

driving or 24 hours of silent surveillance. Based on a modular design and equipped with the CPWS II turret, the Type-X is a platform for below-12-tonne unmanned armored vehicles built for rapid deployment.

Key to this, is the CPWS II, which is a remote-controlled turret that can carry the M242 25 mm x 137 mm Bushmaster cannon or the 230LF, 30 mm x 113 mm cannon as well Anti-Tank Missiles. Type X, armed with anti-tank missiles, could travel alongside vehicles carrying infantry troops, ready to defend them from enemy tanks. An RCV, armed with a small caliber autocannon, could pair up with main battle tanks, taking on lightly armored fighting vehicles and anti-tank missile teams.[137,138]

Basically, the main advantage of electrical UGVs is low or zero noise signature as well as low thermal signature. This means that, during night operations, it would be practically impossible to detect such a UGV with a thermal imaging camera.

4.1.13 UNMANNED UNDERWATER VEHICLES

At the beginning of August 2020, the Royal Navy demonstrated a very interesting conceptual project - a commitment to drone technology for future operations. It is based on twin components - aerial and underwater electrical drones. In the case of the former – the T 150 UAV is used. Produced by British Malloy Aeronautics, this aerial vehicle can lift up to 68 kg in all weather. The T150 uses a simple laptop to send the vehicle autonomously to any point selected on the Google map's type interface – with no manual flying. Through the use of rechargeable batteries, the T 150's endurance during max. take-off weight is 36 minutes.

For the Royal Navy, the T-150 UAVs offers 3 new capabilities: deployment of a Hydroid UUV, ship cargo transfers and life-raft delivery for sea rescue. The work of the Royal Navy's NELSON digital acceleration lab supports this idea. They have continued the development of the "plug in and play" MAPLE system that, when integrated into the Royal Navy ships, will simplify the process of accessing and using autonomous and un-crewed technology; as an undersea system, it is using the REMUS 100 type undersea electric drone, designed and produced by Hydroid. With a maximum operating depth of 100 meters and a mission duration of up to 12 hours, it is ideal for rapid, low-logistics deployments. At the beginning of 2020, the system was tested in Norway on HMS Albion.[139,140]

One of the biggest undersea drones ever built is the Boeing Echo Voyager, which can operate autonomously at sea for months. The Echo Ranger is a 26 m long, 50-tonne massive underwater drone able to reach depths of 3 000 m and hit ranges up to 6,500 nautical miles, according to Boeing data.

In order to deliver such long periods of operation, the vehicle uses a hybrid rechargeable power system which incorporates lithium-ion and silver-zinc batteries and a diesel generator. The batteries are able to provide power for up to a few days and, subsequently, are charged by a diesel generator. Then, the vessel surfaces when required to discharge the exhaust. Boeing Echo Voyager is the latest innovation in Boeing's UUV family, joining the 10 m Echo Seeker and the 5.5 Echo Ranger.

The U.S. Navy, over the past few years, has shown an increasing interest in the development of an unmanned underwater fleet. Among such UUVs, the Navy has tasked several companies for the designing and the development of two large UUVs, the Orca XLUUV and the LDUUV.

These two undersea drones are scheduled to be capable of conducting undersea reconnaissance, sharing data with submarine motherships, searching and destroying mines, and launching attacks on enemy surface and undersea vessels. The Orca will be an XLUUV, while the other UUV (yet to be named) is to be a LDUUV. Recently, on February 13, 2019, Boeing has been awarded a $43 million contract to build four Orca XLUUVs for the U.S. Navy. Boeing's XLUUV Orca is based upon its Echo Ranger undersea drone.[140,141]

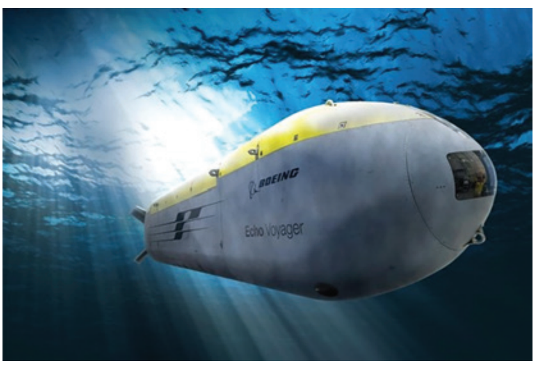


Figure 20: Echo Voyager, an autonomous underwater vehicle built by Boeing

4.1.14. BIOGAS

One more trend based on EE and RE technology solutions is biogas. According to experts, along with other modern technical solutions, biogas has wide future prospects. In 2019, it was announced that the UK's first military base RAF Marham is running almost completely on green electricity. Power is generated from the anaerobic digestion (AD) of locally grown crops at Redstow Renewables, built and run by Future Biogas, one of the largest biogas producers in the UK.

Over 95% of RAF Marham's electricity is provided by Future Biogas, utilising Jenbacher 420 gas engines, engineered and installed by Clarke Energy. At Redstow Renewables, 4.5 MWe is generated, enough to power approximately 7650 households.

80/90,000 tonnes of crop per annum feed digesters, whilst heat, a byproduct from the power generation process, is used to dry digestate, returning organic matter back to the land. Further heat is planned to be used in the future via Economizer SE, a turn key pre-treatment system for the biogas industry, allowing once unusable products including straw, husks, shells and wood waste to be introduced to the anaerobic digestion process.

It is estimated that the deal will help to cut the UK MoD's emission by 14 000 tonnes per year, save around 300 000 pounds ($394 000) in electricity bills every year and help boost power resilience at the base by providing "multiple pathways to electricity".[142]

To improve the efficiency of biogas use, the UK Clarke Energy developed a Mechanical biological treatment technology. It is a waste treatment technology that processes waste mechanically

Figure 21: Biogas Power Plant near RAF Marham - Royal Air Force station and military airbase, UK

in order to separate recyclable elements from the organic component of the waste. The organic component is then treated biologically to stabilize the material.

Janbacher engines produced by Clarke Energy have the highest electrical efficiency in their power class. Based on the proven design concepts of Type-3 and Type-6, the modern Type-4 engines in the 800-1,500 kW power range are characterized by a high-power density and outstanding efficiency. The optimized control and monitoring provide easy preventative maintenance and maximum reliability and availability. [143]

MBT-AD is an advanced form of waste treatment which can be combined through the embedded generation with the utilization of Jenbacher gas engines. Gas engines can be integrated into MBT-AD plants in a number of ways. Primarily, the combustion of biogas in gas engines produces a source of renewable power well in excess of the power requirements of the plant itself.

The exhaust gas is also an attractive energy source to dry outputs from the MBT-AD facility and it can be fed directly into drum driers or belt driers. Typically, siloxanes are rarely found to be a problem in food waste digestion projects. However, due to the mixed waste source of the feedstock for MBT-AD plants, it is possible that this could include materials that contain volatile silica. When designing the facility, correct gas pre-treatment should be installed according to the expected properties of the biogas.

4.2. THE LATEST PROMISING SMART ENERGY SOLUTIONS

The introduction of new technologies is usually associated with some issues - will their apparent technological promise be fulfilled? How long will it take to develop them to a sufficient state of maturity in order to have a practical application (and how much will that cost?) How might they be most effectively utilized? Such issues are important because new technologies have the potential to change the environment in which militaries operate and a radical new technology can change the balance of power or create new forms of insecurity. New technologies can make existing defence systems obsolete or provide new and more effective military capability.

One of the main aims of the paper is a consideration of the link between emerging technologies and military capabilities as well as the importance of institutional factors and the acquisition system in determining the speed of adoption of emerging technologies. It is argued that technological and economic change means that this is an increasingly important issue; defence is playing a declining role as a sponsor of advanced technologies and it will become a follower rather than a leader in many areas of technology. Newest or emerging technologies have the potential to change “the rules of the game”, whether that “game” is the balance of military power between security actors or the balance of competitive advantage in a market between incumbent companies and new entrants.

A review of futures studies conducted by the UK MoD DCDC’s Strategic Trends Programme, the U.S. National Intelligence Council Global Trends Program, the French MoD and the EDA shows that emerging technologies feature prominently. They identify emerging technologies such as: autonomous systems and robotics; swarming autonomous micro aerial vehicles; developments in nanotechnology sensors; cyberspace; directed energy weapons, among many others. Advances in microsystems, nanotechnology, unmanned systems, communications and sensors, digital technology, bio and material sciences, energy and power technologies and neuro-technologies are all identified as likely to have important applications in the defence sector.

4.2.1. BIOMECHANICAL ENERGY HARVESTERS

One of the best examples of the newest EE technology solutions could be converting natural movements into usable energy. "Energy harvesting" is one of the SP's branches and its aim is to reduce the addition of batteries during tactical operations.

It is based on technologies that could convert soldiers' movements into usable energy to power wearable electronic devices. The U.S. Army's Communications-Electronics Research, Development and Engineering Center, or CERDEC, is investigating an entire suite of alternative energy options that will work in tandem to achieve tactical energy independence for the soldiers and small units.

Based on experiments, an energy-harvesting mechanism was embedded into a combat boot heel insole so that each time a soldier's heel strikes, it activates a generator, which spins to produce energy. It was also examined the counter-torque forces produced from the generator's spinning mechanism and it was produced a user-friendly design that works with the body to offset the counter-torque for a more comfortable step.

The EHAP is another CERDEC technology that converts soldier movement into power. The EHAP could free up space in rucksacks for other critical materials such as food, water or ammunition.

The EHAP consists of a rack-and-pinion generator with a spring-loaded, double-frame suspension system attached to a standard rucksack. With each step, the rucksack glides up and down, while the generator captures small amounts of

Figure 22: Energy Harvesting Assault Pack

kinetic energy and converts it into useable electrical energy that would otherwise be lost.

Research is also underway on a boot-mounted technology to harvest energy from the torque around the ankle. The harvester is embedded into the midsole of a combat boot and includes a bracing structure that goes up the boot top. Insofar as the ankle experiences the largest torque of any joint in the body, it is a great source for an energy harvester.[144,145]

4.2.2. HYBRID ELECTRIC FIGHTING VEHICLES

In September 2020, the German Flensburger Fahrzeugbau Gesellschaft mbH (FFG) displayed the GENESIS full hybrid technology demonstrator for the first time. This is the first 8×8 Armoured Fighting Vehicle with a full hybrid drive.

With the presentation of the completely self-financed study, FFG intended to showcase the know-how currently available in the company in the fields of propulsion technology, software development and electronics in order to position itself as a technological supplier for the successor of the future reconnaissance vehicle or the MGCS.

The GENESIS is based on a modular concept similar to the BOXER multirole armoured fighting vehicle, consisting of separate driving and mission modules. The propulsion of the former is diesel-electric and has a total installed power of 1,368 kW, with the diesel generator only used to generate electricity for the electrical storage unit, which is also located in the front part of the vehicle. The electrical energy stored there is used to drive the eight electric motors located in the axles. The heart of the drive is the vehicle's all-electric drive by a wire control system. According to FFG, the technology is fully scalable and also suitable for 4x4 or 6x6 vehicles.[146]

Under the other Transaction for Prototype Authority agreement, issued by the Army RCCTO on July 16, 2020, in the amount of $32.2 million, BAE Systems will deliver two vehicles retrofitted with HEDs. The entire effort, from contract to delivery, is expected to take 24 months. The HED – consisting of an upgraded engine, a transmission replaced by an electric drive motor, and the addition of lithium-ion batteries – turns engine power into electricity for greater mobility and operating additional onboard equipment.

The U.S. Army anticipates reduced fuel consumption by as much as 20% and, with a smaller number of parts, vehicles with HED technology should be easier to maintain. Under the contract, the U.S Army will use the A2 Bradley as the surrogate vehicle. BAE will integrate two HED vehicles, which will then undergo contractor performance assessments, testing and validation, ultimately leading to the transition to PEO GCS.[147]

The BAE Systems claims that a combat vehicle powered by HED will be 10-20% more efficient than a diesel-powered alternative; it will also offer faster acceleration and maneuvering, and a higher degree of fault tolerance through system redundancy and reduction in moving parts. The traction drive system will be half the weight of the equivalent mechanical systems. According to BAE Systems assessment, the dual engine architecture could reduce system abort failures from 1,106 failures experienced in traditional (diesel) systems to only 272 in HED, so a potential 75% increase in reliability.[148,149]

HEDs, used today in commercial cars, buses, heavy trucks and other vehicles, could sig-

Figure 23: GENESIS 8x8 - full hybrid technology demonstrator, based on BOXER multirole armoured fighting vehicle

nificantly reduce Army vehicle costs related to maintenance and fuel consumption, increase reliability, and improve performance, with no added size, weight and power demands.

4.2.3. MOBILE NUCLEAR POWER PLANTS

In the case of energy production, one of the examples of technology development and the creation of experimental samples is the vSMRs. In 2019, the U.S. DoD's $1.6 billion annual investment in energy RDT&E, among other things, was aimed specifically at vSMRs.[101]

In 2018, the U.S. Army Deputy Chief of Staff commissioned a special study to analyze the potential benefits and challenges of MNPPs with vSMR technology, in order to address the broader operational and strategic implications of energy delivery and management. The Army recognizes the fundamental change in the character of warfare with a confluence of evolving threats and an increasing technological sophistication of our adversaries spanning the competition continuum, as opposed to the obsolete peace/war binary.
The MNPP delivers independent power, it can reduce the logistics footprint and lessen the reliance on contested or extended supply lines while increasing reliability, associated transport risk vulnerabilities and operational costs.

MNPPs are configured for rapid setup, rapid shutdown, and ease of movement. Its small size allows the transportation via multiple means - trailer-mounted, containerized rail, military truck, watercraft, or aircraft to operating sites worldwide. At the end of its fuel life (projected at 10 to 20 years), the MNPP is returned to the U.S. for refueling and reuse or disposal.

Some key performance parameters and design considerations of an MNPP concept are:

- Sized for transport by different strategic, operational, and tactical military platforms;
- Once installed, provides stationary “load-following” and conditioned electric power as well as possible process heat. Capable of meeting a camp’s variable electrical base power load demand;

Figure 24: 3D model of future Mobile Nuclear Power Plants

- Provides electrical power for mission systems, life support, quality of life functions, and other future applications during contingency operations in remote locations;
- Must be simple in design and operation. Reactor design and fuel must be inherently safe. Does not require special or extensive on-site construction or unique material handling equipment;
- Installation and connection to supported location power distribution system should be a turnkey operation and should have “plug and play” simplicity and ease to shut down for maintenance and transport;

In March 2020, it was announced that the Pentagon awards contracts for the development of a mobile microreactor. The DoD has awarded three teams - BWX Technologies, Inc. Lynchburg, Virginia; Westinghouse Government Services, Washington, D.C.; and X-energy, LLC, Greenbelt, Maryland. Each team can begin the design work on a mobile nuclear reactor prototype under a Strategic Capabilities Office initiative called Project Pele.

Project Pele involves the development of a safe, mobile and advanced nuclear microreactor to support a variety of U.S. DoD missions. After a two-year design-maturation period, one of the three companies may be selected to build and demonstrate a prototype.

To technically assess the feasibility of a mobile reactor, it is necessary to complete a high-fidelity engineering design to confirm its safety, resiliency and reliability, and to reduce technical, regulatory and manufacturing risks.[150,151]

4.2.4. FUEL CELLS

One of the trends in the sphere of the newest EE and RE technology solutions is fuel cells. Increased energy consumption has led to research and development efforts into replacing fossil fuel-based sources of energy. Among the prospective candidates are fuel cells, which present the advantages of high energy density (power to weight ratio).

Fuel cells are devices that produce electricity through a chemical reaction of two or more types of fuel. Contrary to batteries, they produce energy as long as the fuel flows through them.[152]
They work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes - a negative electrode (or anode) and a positive electrode (or cathode) - sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and the air is fed to the cathode. In a polymer electrolyte membrane fuel cell, a catalyst separates hydrogen atoms into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they reunite with oxygen and the electrons to produce water and heat.

Canada, France, Germany, Spain, and the U.S. are among NATO members currently developing hydrogen-powered, fuel cell-based, military capabilities. The basic operations of all fuel cells are the same; special varieties have been developed to take advantage of different electrolytes and serve different application needs.[153]

AFC - use an aqueous potassium hydroxide or an alkaline membrane as an electrolyte. AFCs benefit from high performance, thanks to the high rate of electrochemical reaction. They can operate from a temperature of 100 degrees Celsius and are also cheaper to produce than other fuel cells, as a wider range of materials can be utilized.

PAFC – PAFC's electrolyte is a liquid phosphoric acid. They were the first types of fuel cells to reach the stage of commercial use, for stationary power generation or large vehicles. Contrary to AFCs, the PAFCs can endure carbon dioxide or other fuel impurities. Their electrical efficiency performance rate is between 37% and 42%, which is slightly higher than combustion generators, which generally perform at 33% of efficiency.[152]

Fuel Cells also could be used as electricity storage. In December 2019, it was announced that the newest fuel cells could help fix the renewable energy storage problem. In sunny California, for example, solar panels regularly produce more power than needed in the middle of the day, but none at night. Some utilities are beginning to install massive banks of batteries in hopes of storing excess energy and evening out the balance sheet. Another option is to store the energy by converting it into hydrogen fuel. Devices called electrolyzers are doing this by using electricity - ideally from solar and wind power - to split water into oxygen and hydrogen gas, a carbon-free fuel. The second set of devices called fuel cells can then convert that hydrogen back to electricity to power cars, trucks, and buses, or to feed it to the grid.

To get around this problem, researchers have been experimenting with a newer type of fuel cell, called a PCFC, which can make fuel or convert it back into electricity using just one set of catalysts.

PCFCs consist of two electrodes separated by a membrane that allows protons across. At the first electrode, known as the air electrode, steam and electricity are fed into a ceramic catalyst, which splits the steam's water molecules into positively charged hydrogen ions (protons), electrons, and oxygen molecules. The electrons travel through an external wire to the second electrode - the fuel electrode - where they meet with the pro-

Figure 25: Fuel Cells mounted on German Dingo heavily armored military MRAP

tons that crossed through the membrane. There, a nickel-based catalyst stitches them together to make hydrogen gas (H_2).[154]

Submarines are the main military field of application for fuel cells, as fuel cells provide crucial advantages in submarine warfare, stealth, and autonomy. Indeed, combined with the AIP, an anaerobic engine technology that allows submarines to stay submerged for a longer time, they can become virtually silent.

Currently, different types of fuel cells are being used on the German (Type 212A Class), Italian (Todaro-Class) and Spanish (S-80 Plus Class) submarines. In 2016, the French company Naval Group unveiled their SMX 3.0, a submarine concept ship aiming to show what their vessels will look like in 2025. The model would be equipped with an AIP FC2G.[150]

The American GM and the U.S. Army TARDEC have been testing the Chevrolet Colorado ZH2 model, which is a hydrogen fuel cell powered off-road vehicle. Unlike other tactical military vehicles, the ZH2 is stealthy because its drive system does not produce smoke, noise, odor or thermal signature. When the vehicle is not moving, it can generate 25 kW of continuous power or 50 kW of peak power.

For instance, the fuel cell produces from 80 to 90 kW of power and, when a buffer battery is added, nearly 130 kW. The prototype's range on one fill-up is about 150 miles, since this is a demonstrator.[155]

Besides tactical vehicles, scientists from the U.S. Army Combat Capability Development Command GVSC and the U.S. Army Research Laboratory continue developing new hydrogen combat vehicles, including tanks and infantry fighting vehicles.[155]

4.3. RECOMMENDATIONS BASED ON THE BEST EE AND RE TECHNOLOGICAL SOLUTIONS

Energy is an essential yet costly element to military success. By investing in EE and RE, the military sector has already saved millions. These changes not only reduce costs, but also enhance operational success and environmental awareness. These projects have increased energy security and warfighter efficiency. Based on analyses of countries' experience and technology development tendencies, some aspects are recommended in order to improve the nations' prospects of improving the energy efficiency and sustainability of their defence sectors.

Solar panel technology has advanced considerably in the last decade. Calculating ROI depends on several factors, such as the plot available for infrastructure, location, and amount of solar radiation per year. If roof space is limited, mono panels could offer consumers the most output. If a location is large enough to accommodate poly panels, this type of infrastructure could produce the same output as the mono panels, with savings from 10 to 20%. The long-term value of a solar installation will largely depend on how it is financed. Buying the system upfront yields the best ROI, but even a $0-down solar loan could provide savings of $10,000 or more.

Unfortunately, though solar energy can provide cost savings for owners, no energy infrastructure is without its impact on the environment. Solar energy is no different. Large-scale solar farms may influence land degradation and habitat loss. Utility-scale solar facilities require large plots, and could interfere with wilderness areas, mineral production, military uses, and protected natural environments.

In the case of tactical military camps or overseas bases, a mobile roll-array solar power plant could be one of the best solutions. From a technical point of view, it provides an extremely mobile solution. It could be easily transported by helicopter or cargo vehicle. The price range is £17,000 – £34,000 at present, at least three times more than domestic six-panel solar installations.

The HPGS MEMS and electrical components are vulnerable during transportation and need greater protection against vibrations. In addition, due to its size, weight and restrictions on transportation of lithium batteries, the deployment of HPGS is more complicated and expensive compared to a similar power conventional generator. Lithium batteries have certain limitations for transportation, particularly for air convoy due to civilian safety regulations. For long-term bases, HPGS could be an ideal technical solution. Almost four years of wide-ranging usage offer the opportunity to deeper define the system's advantages as well as points of weaknesses. Indeed, the benefits of a Hybrid Power Generation and Management System are: fuel savings and increased deployed force infrastructure energy resilience. Additionally, the amplified mean time between the maintenance benefit for the gensets has been proved. The advantages and drawbacks in different environments discussed above regarding renewable power emphasize the benefits in the modularity of the system when selecting specific deployment conditions.

Large energy storages for fixed installations and BESS reduce demand charges to taxpayers. It is profitable especially in the case of day-night electricity tariff. The battery system charges overnight, when electricity costs are lower, and provides electricity during the day, resulting in lower utility bills.

The rapid development of wearable technology has received another boost from a new development using graphene for printed electronic devices. The current hurdle with wearable technology is how to power devices without the need for cumbersome battery packs. Devices known as supercapacitors are one way to achieve this. A supercapacitor acts similarly to a battery but allows for rapid charging which can fully charge devices in seconds. An increase in wearable technology use has also created a need for high-performance batteries that could be used in military uniforms and even new classes of wearable computers. However, creating a flexible battery for wearable technology, such as clothing, has proved difficult up until now.

A large-scale microgrid is more economical to design, build and maintain than commissioning stand-alone backup generators. It can save millions of dollars over the course of its expected lifespan. A microgrid solution would enable an installation to generate its own power, which would result in saving costs by avoiding reliance on a local utility for power. Energy rates can be unpredictable and are based on variable market factors such as availability and demand, so military facilities would benefit from long-term price certainty by producing their own energy. Best-in-class microgrid applications operate under a consolidated control and energy management system that utilizes smart meters.

For the military, among armoured personnel carriers and infantry fighting vehicles, using HED offers packaging flexibility, allowing for the design of more spacious, mission adaptable platforms. Increased power availability also results in more available power for new capabilities, such as thermal and signature management (cooling, ECS, stealth), and exportable power generation. Proponents of electric and hybrid-electric vehicles for the military forces can offer lower-cost power sources and greater performance.

In the case of UAVs, the practical advantages given by electric engines are the same as those of combat vehicles - low or zero noise signature as well as low thermal signature. It means that, during operations, it would be practically impossible to detect such UGVs with a thermal imaging camera as well as shot them down with a man-portable air-defence system, that operates as an infrared homing surface-to-air missile. According to these factors, on a tactical level, internal combustion aviation engines would be replaced by electric ones very soon.

No single human motion produces enough excess power to charge MIL-STD batteries in a reasonable amount of time, so CERDEC is investigating an entire suite of alternative energy options that will work in tandem to achieve tactical energy independence of the soldiers and small units. These include efforts to leverage standard soldier equipment, such as combat boots and rucksacks. The rucksack glides up and down with each step as the generator captures small amounts of kinetic energy that would otherwise be lost. There is a hope that these technological advances will eventually generate as much power as soldiers need for their missions.

Today, RE can be produced from larger biogas sources such as wastewater facilities and landfills at prices competitive with other renewable resources. Advances in gas cleanup and conversion technology such as digesters and gasifiers will expand the amount of feedstock that can be economically converted.

The latest EE and RE innovations from NATO and PfP member countries will only advance operational technologies and strategies that increase military capabilities, competitive advantages, and combat lethality in theaters of conflict. Hence, efforts focused on improving the environmental or energy performance of military activities could induce additional innovations in warfighting capabilities, such as reduced logistics requirements or costs, resilient and low-signature off-grid power systems. Through these examples, military and defence innovations are now showing positive developments in the field of EE and RE and contributing to mitigating a major international problem - anthropogenic climate change.

5. CONCLUSIONS

Given that climate change and energy security are growing challenges to the security of the world and individual nations, unions and countries need to integrate climate and energy risks into all of their planning processes, including in the military sector, which means activating energy transition issues. In the previous centuries, the energy transition goals were successfully achieved; the dominant energy resource was changed from wood to coal, then from coal to oil and gas. Now, the goal is to replace fossil-based sources with carbon-free energy sources. Given that technologies and accessibility to energy sources determine the balance of current and future armed forces, the military sector has always been technologically advanced, as history shows. For centuries, both the combat environment and the dominant military energy source have been changing. For powering the current armed forces worldwide, the main sources are fossil fuels, which are not evenly allocated on the world energy map. The uneven allocation of dominant energy sources is one of the major motivators for developing alternative energy solutions, including within the military area, because the fossil fuel industry has a huge ability to influence even policy decisions. Many nations and industries are taking action and investing large amounts of money in developing alternative energy solutions to reduce the dependence on fossil fuels. A large number of new energy technologies are being developed to support the world's energy transition process. Many new technologies are very promising and offer opportunities to save energy and/or to replace fossil fuels with other power sources. Most of the latest technologies in the world are focused on switching required energy from fossil fuels to electricity. Some of the technological solutions in the civilian energy transition are also beneficial for the military energy transition. But many technologies of interest for military capabilities are not expected to become the focus of civilian developments, which require different approaches.

Considering that the defence sector consumes a huge amount of fossil energy in both peacetime and wartime, the military forces recognise the importance of energy security and climate change issues and their impact on the armed force's capabilities. In parallel with the changing nature of war, the need for energy sources has dramatically increased, causing the necessity to transform its characteristics. The future expected technological environment also requires the preparation of defence capabilities with essential changes in their power sources. The principal determiner for the decision-making regarding the transformation in both the military and non-military sectors is cost-benefit issues. Many nations have already developed and implemented "green" solutions for defence in recent years, but such types of activities are less introduced in the military sector than in the civilian one. The introduction of smart solutions is quite rare and mainly at the pilot level, especially in military operations.

In most cases, the issue of energy transition seems less relevant for the defence sector, based on the assumption that such transformation could become a cause of the reduction of the armed forces' capabilities, since the current combat operations environment is mainly formed according to the characteristics of traditional fuels and most of the countries' combat technologies are run on fossil fuels. The main indicator that this issue is not fully recognised in the defence sector is the energy metering problem. Without relevant energy data, it will be very difficult to assess the effectiveness of the massive introduction of regulations or technologies.

In order to widely introduce suitable smart energy technologies, decision-makers in both the military and civilian sectors first need to be confident that it will be profitable in terms of both finances and capacities. Without the data-based argumentation that such transformation will be cost-effective in the long run, such projects will remain only as rare pilot projects. As the primary goal of defence systems is to ensure resilience and flexibility, a more detailed analysis of what types of energy sources and in what proportions are needed in the long term would be useful. Whether these are sustainable or unsustainable energy sources, based on the best above-mentioned or other examples, it is clear that using energy-saving technologies and procedures has a huge potential to reduce the cost and environmental impact of military operations. More problematic is the introduction of renewable energy technologies that require several types of new technologies: energy production, storages, smart grids, energy management systems and renewable-powered technologies. It seems more complex than to power fossil-powered technologies by traditional sources. Based on the above-mentioned examples, it can be said that sustainable energy can reduce military operations' demand for fossil fuels, extend their range and duration, and mitigate risks. The deployment of renewable energy production technologies in the military field can increase the diversification of their energy portfolio and thereby create more energy security and resilience. In armed conflict situations, mobile renewable energy-power units can make soldiers less vulnerable to enemy forces, as they can use local energy sources which are less dangerous in the case of an explosion. Along with renewable production technologies, storages, smart grids and energy management systems help to have less reliance on grid-supplied electricity and increase the opportunity to balance energy supply and demand better. Additionally, sustainable energy-powered, hybrid-powered and energy-efficient technologies increase the utilization of local sources and decrease dependence on fossil fuels while minimizing the environmental footprint. Overall, smart energy technological and non-technological solutions improve military capabilities, unit autonomy and operational resilience on the battlefield and reduce defence budgets and the environmental impact.

The development and widespread introduction of such types of technologies need huge investments, but in the long-term perspective, it could be a cheaper solution because of the opportunity of using free energy without transportation costs. Due to the nature of the military procurement cycle, technology upgrades and supply chains must be planned years in advance. To effectively introduce smart energy technology in the defence sector, a feasibility study of the military energy transition is required at first. It must cover the long-term development perspectives and take into account the various aspects, such as: technical, economic, financial, political, environmental, legal and others. It should be done at both national and NATO levels, under the leadership of the relevant body responsible for defence in cooperation with other relevant governmental and industrial organizations; plus, it should be subject to periodic updating, given the speed of technological development. By analyzing different possible development scenarios, there will be more opportunities for the defence sector to identify the most cost-effective development scenario and to define a limit for military energy mix transformation without decreasing the armed forces' capabilities. After this type of analysis, it will be easier to develop more purposeful effective plans and steps. The military energy transition program should cover the entire area of defence energy with all its directions, including land, naval and air operational energy. As part of the defence development process, the program should be both long-term and short-term, covering the processes ranging from the development of relevant policies, strategies, and action plans to the evaluation of their implementation.

ACRONYMS

- 29Reg RLC - 29 Regiment Royal Logistics Core
- 7SEBC - 7 Steps to Energy Behavior Change
- ACT - Allied Command Transformation
- AEMRR - Energy Management and Resilience Report
- AFC - Alkaline Fuel Cells
- AFRL - Air Force Research Laboratory
- Ah - Ampere hour
- AIP - Air Independent Propulsion
- BESS - Battery Energy Storage System
- BMS - Battery Management System
- BTU - British thermal units
- CAF - Canadian Armed Forces
- CF SEDSS - Consultation Forum for Sustainable Energy in the Defence and Security Sector
- CFB - Canadian Forces Base
- CJOC - Canadian Joint Operations Command
- CLPs - Combat Logistics Patrols
- COE - Centers of Excellence
- CPWS II - Cockerill Protected Weapons Station Generation II
- CSDP - Common Security and Defence Policy
- CWB - Conformal Wearable Batteries
- DCDC - Defence Concepts and Doctrine Centre
- DE&S - Defence Equipment and Support
- DEES - Defence Energy and Environment Strategy
- DEMC - Defence Energy Managers Course
- DEMS - Deployed Energy Management System
- DIO - Defence Infrastructure Organisation
- DND - Department of National Defence
- DoD - Department of Defense
- DSTG - Defence Science and Technology Group
- DSTL - Defence Science and Technology Laboratory
- ECMs - Energy Conservation Measures
- EDF - European Defence Fund
- EE - Energy Efficiency
- EHAP - Energy Harvesting Assault Pack
- EnMS - Energy Management System
- ENSEC COE - Energy Security Center of Excellence
- EP - Environmental Protection
- EPC - Energy Performance Contracting
- EPRI - Electric Power Research Institute
- ESAs - Energy Supportability Analyses
- ESCO - Energy Service Company
- ESPC - Energy Savings Performance Contract
- EU - European Union
- FC2G - Fuel Cell Second Generation
- FOB - Forward Operating Bases
- FP - Force Protection
- GENESYS - Global Energy Information System
- GGC - Greening Government Commitments
- GGF - Green Fleet
- GHG - Greenhouse Gas
- GIS - Geo-Information System
- GM - Generals Motors
- GVSC - Ground Vehicle Systems Center
- HEDs - Hybrid Electric Drives
- HPGS - Hybrid Power Generation and Management System
- HQ SACT - Headquarters of Allied Command Transformation
- HVAC - Heating, Ventilation, and Air Conditioning
- HyPER-FST - Hybrid Power Emissions Reduction – Fuel Savings Technology
- Hz - Hertz
- IEA - International Energy Agency
- ISAF - International Security Assistance Force
- KW - Kilowatt
- KWH - Kilowatt-hour
- KWP - Kilowatt-peak
- LDUUV - Large Diameter Unmanned Undersea Vehicle
- LFGs - Lightweight Field Generators
- Li-ion - Lithium-ion
- mAh - milliampere-hour
- MBT-AD - Mechanical Biological Treatment with Anaerobic Digestion
- MECM - Military Energy and Carbon Management
- MEMS - Mobile Energy Management System
- MGCS - Main Ground Combat System
- MILENG - Military Engineering Center of Excellence
- MNPPs - Mobile Nuclear Power Plants
- MoD - Ministry of Defence
- MW - megawatt
- NATO - North Atlantic Treaty Organization
- NATO STO - NATO Science and Technology Organisation
- NDPP - NATO Defence Planning Process
- NW - Nett Warrior
- OE - Operational Energy
- OES - Operational Energy Strategy
- PAFC - Phosphoric Acid Fuel Cells
- PCFC - Proton Conducting Fuel Cell
- PE - Primary Energy
- PEO GCS - Executive Office Ground Combat Systems

- PHASA - Persistent High Altitude Solar Aircraft
- PMSI - Perini Management Services, Inc.
- POEMS - Project Oriented Environmental Management System
- PV - Photovoltaic
- RAAF - Royal Australian Air Force
- RCCTO - Rapid Capabilities and Critical Technologies Office
- RCV - Robotic Combat Vehicle
- RDT&E - Research, Development, Testing, and Evaluation
- RE - Renewable Energy
- ROI - Return on Investment
- SC - Smart Camp
- SEAS - Shipboard Energy Assessment System
- SENT - Smart Energy Team
- SOC - State of Charge
- SP - Soldier Power
- SPP - Sustainable Procurement Program
- SS - Soldier Systems
- STANAGs - Standardization Agreements
- TARDEC - Tank Automotive Research, Development and Engineering Centre
- TEAD - Tooele Army Depot
- THPS - Tailored Hybrid Power System
- U.S.C. - United States Code
- UAVs - Unmanned Aerial Vehicles
- UESCs - Utility Energy Service Contracts
- USMA - United States Military Academy
- UUV - Unmanned Undersea Vehicle
- V - Volt
- vSMRs - very Small Modular Reactors
- XLUUV - Extra Large Unmanned Undersea Vehicl

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