NATO ENERGY SECURITY
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ENERGY HIGHLIGHTS

Content

REPORT

Military aspects of energy security with emphasis on interdependencies between the civil energy sector as a supplier and military as a consumer

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I. INTRODUCTION

Since the beginning of the 20th century, energy security has been a vital strategic factor in military considerations and still plays an important role in our common security. According to NATO, energy security has three dimensions: supply security, economic competitiveness and environmental issues (NATO, 2012). The operations in Afghanistan plus growing environmental concerns have highlighted security challenges related to the extensive use of fossil fuels; not only it is a financial issue, but it also increases operational vulnerability of military forces and endangers environmental sustainability.

The military is fully aware of the social and environmental impacts that climate change will have in the coming decades. Climate change is a threat multiplier, affecting every society in the world and also military operations. Indeed, it could directly affect military capabilities and strength, as extreme weather conditions may place additional burden on military forces. The military, with its own emissions, can and must effectively contribute to energy transition by changing its energy behaviour and it is essential that NATO countries integrate climate change considerations into their defence strategies and policies.

NATO, concerned about the negative impact of energy dependence on military security, has recognised that militaries' energy consumption has reached unprecedented levels and it is unsustainable in the long run. Therefore, it is a strategic imperative to implement new energy solutions and increase After 'energy efficiency (EE)' at home and in theatre for NATO forces (NATO Parliamentary Assembly, 2013).

Overreliance on fossil fuels of NATO forces creates a constant increase of spending, threats the security of supplies and troops, creates concerns over climate change and has an impact on operational effectiveness. Making the armed forces greener and implementing new energy solutions is seeking to limit the detrimental impact of military forces activities on the environment, to save money and to optimize operational effectiveness, in such a way that energy supply and security could be strengthened.

This report evaluates the energy security challenges related to the dependence of military forces on fossil fuels and their inefficient energy use during military operations. By focussing on operational contexts, financial, operational and strategic risks are found to be associated with the extensive use of fossil fuels during military operations in expeditionary circumstances, putting at risk supply security and, more in general, energy security of the troops. Hence, EE measures and the replacement of fossil fuels with alternative and/or renewable energy sources (RES) are key in transforming the way the armed forces operate and in enhancing energy security.

The approach to this report is both qualitative and quantitative. Indeed, to perform adequate content analysis a qualitative type of research is needed, based on primary and secondary sources. At the same time, however, a quantitative approach is pivotal to proper quantify and measure some of the existing issues. To develop the analysis, different kind of sources were considered: official governmental documents such as national energy security strategies, operational energy strategies, national and annual reports of NATO countries (Canada, France, Italy, United Kingdom, United States), as well as NATO and European Defence Agency official sources. While, secondary sources primarily refer to previous researches, academic sources and journal articles.

The report first provides an overview of different definitions of operational energy, energy security, EE and renewable energy in both civilian and military spheres, concentrating on several NATO countries definitions and the different steps taken in national military operational contexts in improving EE and enhancing energy security. Then, it broadly assesses RES in relation to their impact on energy security of military forces. In the following section, it presents some "green initiatives" at NATO level which provide some guidelines to Allied countries in greening their armed forces and highlight what potential benefits they could have in enhancing energy security in operational contexts. Lastly, a focus is given on the existent and possible cooperation between the military sphere and the civilian industry in contributing to energy technology innovation.

II. OPERATIONAL ENERGY IN A MILITARY ENVIRONMENT

Energy is an essential enabler to military operations. Whether it is electricity, fossil fuels or other sources, energy sustains every military mission and operation and ensures an effective performance. Military forces use large quantities of energy and a considerable amount of energy consumption is dedicated to electrical power generation for deployed force infrastructure, weapons deployment, cargo transport and personnel movement.

NATO military forces are essentially dependent upon steady and reliable energy supplies. These are used to provide electricity for heating, cooling and lighting on bases and, in addition, for transportation. As a matter of fact, they need energy to transport the quantity of energy they need to perform their duties in operational theatres. Hence, the transport of energy is "an essential activity to guarantee operability and functionality of the Armed Forces" (Testarmata, 2011).

Because energy is essential to combat missions, the military is one of the largest energy consumers worldwide. For instance, the US Department of Defense (DoD) consumed 708,000 billion British Thermal Units (BTUs) of operational and installation energy in just one year, accounting for 75% of the federal government's total energy consumption (Robyn D. & Marqusee J., 2019). Among the total spending, 74% of the total energy consumption can be attributed to operations, while the remaining 26% was consumed by facilities (Department of Defense, 2011a). While, another NATO country, the UK, consumed 664

Fig. 1
Capability & Equipment Energy Consumption-Annual Performance against baseline
Source: Ministry of Defence, 2018.

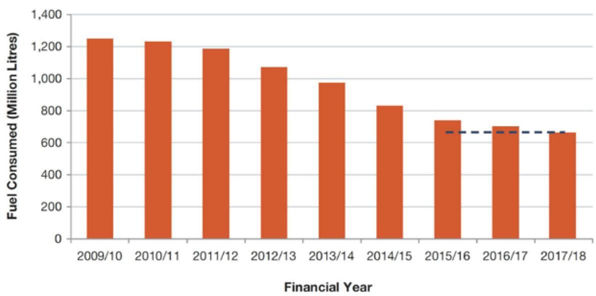
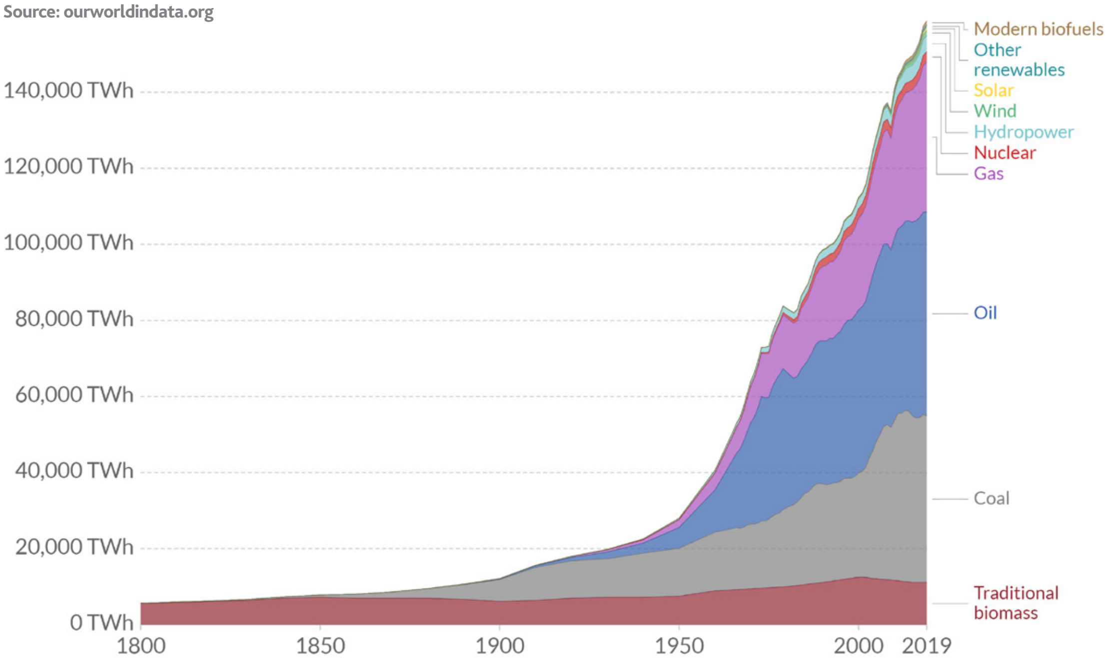


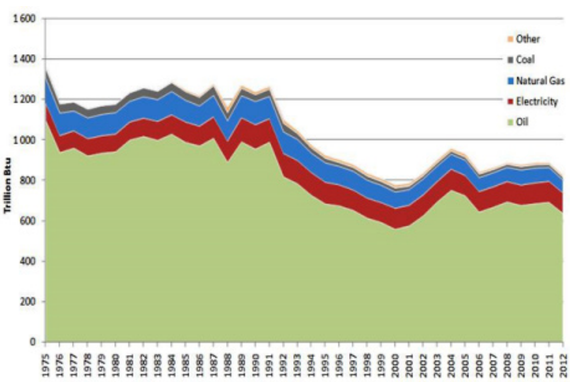
Fig. 2
Global direct primary energy consumption
Source: ourworldindata.org



million litres of fuel in 2017/2018, achieving a 10% reduction from the previous year and almost cutting its energy consumption in half since 2009/2010 (Ministry of Defence, 2018) (Fig.1) France attributes 73% of its military forces' energy consumption to the energy required to power their fleet of vehicles on land, water and in the air. In 2019, the total energy consumption by the French Ministry of the Armed Forces accounted for 835.000 m^3 of oil products (Thobel V., 2020)

Globally, the total amount of direct primary energy consumed in operations has constantly risen. This is in line with a strong industrialisation and urbanisation, the growth of global population and an increase in transportation (Fig.2).

Fig. 3
US DoD Total Energy Consumption
Source: oilprice.com



However, since the end of the Cold War until the beginning of the 21st century, a drop can be noted in energy consumption. This is true especially for the US DoD, which experienced a 40% drop in those years. Energy consumption started increasing again with the War on Terror, peaking in 2004 and then declining regularly since then (Fig.3).

The meaning of Operational Energy (OE)

By creating a division between the energy used in military operations and the amount used in facilities, and proven that the former one is the major source of consumption and spending, one needs to properly define the meaning of 'energy used in operations' or "operational energy" (OE) in the military area.

In the civil sector, many definitions of OE can be found. Among them, OE is defined as the "energy consumed for lighting, heating, cooling and ventilation excluding energy used for hot water generation and life-style appliances such as computers, washing machines, entertainment gadgets, etc., commonly referred to as plug loads." (Praseeda K.I., Reddy V.B.V., Mani M., 2017). Thus, OE is mainly associated with the energy for operating building appliances and it is opposed to Embodied Energy, which refers to the "energy demand required for off-site and on-site building processes, including raw materials extraction, components manufacturing, products final assembly and transportation." (Giordano R., Serra V., Demaria E., Duzel A., 2017).

The definition of OE has not an agreed definition in NATO yet. So far, the only NATO country which has defined it by law is the United States. Section 2821(a) of the US FY2012 National Defense Authorization Act defines OE as "the energy required for training, moving, and sustaining military forces and weapons platforms for military operations. The term includes energy used by tactical power systems and generators and weapons platforms." (Public law 112-81, 2011).

Therefore, according to the US definition, OE is the energy used in forward operating bases (FOBs), vital in supporting expeditionary capabilities of NATO forces in operational theatres. A subset of OE includes logistics support throughout the supply chain and in-theatre energy consumption.

The US DoD refers to OE as the energy used in:

- Military deployments across the missions,
- Direct support of military deployments,
- Training in support of unit readiness for military deployments (Department of Defense, 2016).

OE needs to address all these security challenges and, as General Allen, commander of the International Security Assistance Force (ISAF), stated in 2011 "Operational energy is about improving combat effectiveness. It's about increasing our forces' endurance, being more lethal, and reducing the number of men and women risking their lives moving fuel." (Gen. Allen J.R., 2011).

The US DoD also launched the 'Operational Energy Program', whose aim is to focus on the energy associated systems, information, and processes required to train, move, sustain forces and systems for military operations. There, an additional definition can be found: "Operational Energy incorporates elements of Soldier, Basing and Vehicle Power. It is a key enabler for operations, essential for combined arms maneuver and required for Soldier sustainment." [ASA (IE&E), 2020].

Another basic definition which could explain what OE includes, is "the fuel utilised by our aircraft, ground vehicles, and ships." (Kendig R.J., Seaton A.D., Rodgers R.J., 2016). However, this definition is somewhat limited when compared with the other definitions, since it does not take into account the energy used for weapons platforms, tactical power systems and soldier's equipment. Plus, it refers only to 'fuels', not considering other forms of energy.

One of NATO Allies, Canada, does not have a proper definition of OE, but it clearly distinguishes two types of energy consumed by the Canadian Armed Forces (CAF): the energy consumed in installations and the one used for mobility purposes by the fleets. Hence, while the energy used in installations (buildings) includes energy from electricity, natural gas, fuel oils, kerosene and solar photovoltaic, the energy used for military and expeditionary operations refers to the aviation and ship's fuel, combat equipment and the one used in domestic operations, such as training (Labbé et al., 2015).

France has not an agreed official definition for OE too, but, according to the French Ministry of the Defence (Ministère des Armées) and the Military Fuel Service (Service de l'énergie opérationnelle) there is a difference from the energy used in installations, and the one used to supply petroleum products to the Armed Forces.

Hence, the role of OE inside a military operation is pivotal and has a direct connection to energy security. Indeed, a shortage of fuel and power could result in impacting military's readiness or even halting operations.

III. NATO'S STANCE ON ENERGY SECURITY

Energy security is a vital element of resilience and has become more important in the past years due to the new security context (NATO, 2020). Energy is of the utmost importance for the Alliance given its military nature: fuel is fundamental for military operations and energy supply is the key enabler to the stability and the security of its Member States. In the 1991 and 1999 Strategic Concept, NATO first mentioned as risk the 'disruption of the flow of vital resources' and the 'disruption of energy supply' (NATO, 1991, 1999). Following the 2006 cut off of Ukraine's national gas supply by Russia, during the 2006 Riga Summit it was declared as a NATO priority "to consult on the most immediate risks in the field of energy security, to define those areas where NATO may add value to safeguard the security interests of the Allies" (NATO, 2006). NATO's role in energy security was first defined in 2008 at the Bucharest Summit and has since been strengthened (NATO, 2020). In November 2010, the Allies highlighted that the potential risks related to energy supply and infrastructure could also affect military operations. This statement was reiterated in the following summits, the 2012 Chicago summit, the 2014 Wales Summit and the Brussels Summit in 2018, where a focus was given on the need to improve EE and the use of sustainable energy sources in NATO military forces. Finally, in November 2019, the Alliance developed a set of recommendations on consolidating its role in energy security, including a strong focus on how to provide secure fuel supply to the military (NATO, 2020).

Accordingly, one of the three main areas where NATO fulfils its role relates to the need to enhance energy supply and EE in the military; while the other roles focus on raising awareness and consultations among the Allies and supporting the protection of critical energy infrastructure by sharing best practices (NATO, 2020). The former task involves sharing best practices, demonstrating EE equipment, and developing military EE standards (Grubliauskas J. & Rühle M, 2018). NATO recognises the importance of EE as means to improve combat power and agility. The high fuel demand of NATO forces "diminishes their performance, increase their vulnerability, and may require the diverting of combat forces to protect supply lines" (NATO, 2020). Hence, a reduction in the fossil fuel consumption in military operations is of paramount importance in order to develop more autonomy, lessen the environmental footprint and simplify logistics.

NATO's role in energy security takes a military security focus and reflects the need for the Alliance to conduct practical and logistical planning in order to assure the protection of energy supplies and to maintain effective operational capacity. This involves considering military threats to energy facilities and supply lines. By the same token, energy security in the military sphere is considered as a critical priority for the military, an integral component of mission readiness and unit preparedness- it is an operational imperative. Since the military is a large consumer of energy, energy security needs to be prioritised as means to make the military force more effective.

The definition of Energy Security

Energy security is a complex term and it can have Implications in various areas: political, economic, military and social. There is still no an agreed definition yet in NATO, but the concept can have various meanings according to different national, institutional perspectives.

The US DoD provided a definition of Energy Security related to the military dimension: "Energy security is the assured access to reliable supplies of energy and the ability to protect and deliver sufficient amount energy to meet operational needs." (Department of Defense, 2009.) In 2009 the US Army published the 'Army Energy Security Implementation Strategy' which indicated five strategic energy security goals for military missions, where EE and the use of alternative and RES are one of the most important pillars. These five Strategic Energy Security Goals (ESGs) are:

1. Reduced energy consumption
2. Increased EE across platforms and facilities

3. Increased use of renewables/ alternative energy

4. Assured access to sufficient energy supplies

5. Reduced adverse impacts on the environment

According to the US Army, the most important characteristics of energy security are:

- Surety, meaning to prevent losses of energy sources and access to power;
- Survivability, which aims at ensuring resilience in energy systems;
- Supply, namely the access to alternative and RES;
- Sufficiency, which refers to the adequate provision of power to critical missions; and
- Sustainability, meaning the support for the Army's mission and the environment (Army, U. S., 2009).

In 2011, the US DoD published the Operational Energy Strategy to set a general direction for operational energy security. The Strategy comprises the goals for the US Forces to: reduce the overall demand for operational energy and increase EE (more fight, less fuel); diversify its energy sources and have a more reliable energy supply (more options, less risk); and integrate operational energy considerations into the planning and force development capabilities (US Department of Defense, 2011). Reducing energy demand, improving EE and diversifying energy sources will mean that the military will use less energy and redirect operational capability to the battlefield, instead of protecting vulnerable energy supply lines. Improved EE means less amount of energy used, less personnel to protect resupply convoys, hence tactical, operational and strategic benefits and an improved energy security for the military.

The Italian Ministry of Defence (*Ministero della Difesa*) also proposes its definition of Energy Security, which stands for "All the activities aimed at reducing the vulnerability resulting from the use of energy resources, ensuring a safe and sustainable access to them." (Stato Maggiore della Difesa, 2019).

France and its Ministry of Defence proposes a very detailed definition of Energy Security: "The energy military security is the ability (of men, equipment, doctrine, training) to assure at all times and places the energy supply (electricity and fuels) to military installations and deployed weapons systems, even in the event of a disruption to outsourced energy flows (current concept of fuel support), during a minimum period established (notion of autonomy)" (Col. Chauvancy, 2009).

Even though there is not an agreed definition of Energy Security at NATO level yet, the NATO Energy Security Centre of Excellence (NATO ENSEC COE). developed and provided a working definition of it, by focussing on the Operational dimension: "*Operational energy security* [is the] uninterrupted access to reliable supplies of energy resources, capability to employ alternative energy sources in operational environment, efficient and environmentally friendly use of energy resources, and the ability to protect and safely deliver sufficient energy resources to meet operational needs without limiting combat capability" (NATO ENSEC COE, n.d.).

In the civil sector, the main definition is provided by the International Energy Agency (IEA), which defines Energy Security as: "the uninterrupted availability of energy sources at an affordable price, in line with economic developments and environmental needs" (IEA, 2019). The IEA definition includes two of the four main characteristics which explain energy security: availability and affordability, the other two being accessibility and acceptability. The latter indicates an environmental acceptability, while the latter reflects the ability to access modern energy resources.

As previously mentioned, there is not an exclusive agreed definition on what energy security means, but, instead, it can differ from country to country, depending on what its priorities are in terms of energy policies. The most distinctive difference in energy security concepts is found between energy importers and exporters, whose priorities are respectively: security of supply and security of demand.

As a net importer of energy, the EU's Energy Security definition can be stated as: "the European Union's long-term strategy for energy supply security must be geared to ensure, for the well-being of its citizens and the proper functioning of the economy, the uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial), while respecting environmental concerns and looking towards sustainable development" (European Commission, 2000).

On the contrary, Canada, as an exporter of oil, natural gas, coal and electricity, refers to Energy Security in terms of "protecting critical energy infrastructure" (National Energy Board, 2014) and "energy efficiency" (Natural Resources Canada, 2013).

IV. MILITARY USE OF TRADITIONAL ENERGY SOURCES AND THE IMPACT ON ENERGY SECURITY

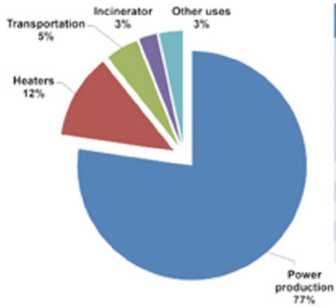
NATO military forces are dependent upon fossil fuels for their missions. These sources of traditional energy are mainly used to provide electricity for heating, cooling, lighting a base and to power tactical vehicles, transport materials and personnel. The majority of energy consumption is composed by fossil fuel-based sources, mainly oil, coal, natural gas or electricity produced from these in the forces of NATO countries.

Military specification fuel, produced from petroleum, is commonly used in combat systems and in systems that support them, such as aircraft, ground vehicles and naval vessels. Electricity needed in FOBs is generated by the same fuel needed to power combat systems (Strategy, D. E. 2008).

However, the dependence of some NATO countries from oil reveals another dependence: petroleum-based sources are often coming from foreign countries. For example, Italy is highly dependent form the imports of oil and its main suppliers are Azerbaijan, Iraq and Russia (Statista, 2020). In 2019, the US imported approximately 9.10 million barrels per day (MMb/d) coming from 90 countries, such as Canada, Mexico and Saudi Arabia (U.S. Energy Information Administration, 2020a). Even though the amount of oil imported by the US is steadily declining since 2006, this represents a strong vulnerability. Indeed, petroleum-based fuels, especially jet fuel, are the largest sources of energy used by the US DoD, accounting for two thirds of its total energy consumption. Jet fuel, together with diesel, were the most used fuels by the US DoD for mobility purposes, with a total of 468.000 billion BTU consumed in 2019. (U.S. Department of Energy, 2019).

Nowadays, temporary military camps are totally based on electricity. Until the WW1, the army did not use electricity at all, since the only small electrical military devices, such as telephones, were powered by batteries. From the WW2, the nature of temporary military camps changed, since no modern armies can exist without electrical energy. This is especially true for military operations taking place where no infrastructure exists, so wired power supply is non-existent. If we want to proper understand the importance of energy and fuels in a military environment, we have to look at the general use of energy during military operations. Usually, in a typical military base, two thirds of the fuel that a diesel generator burns is blown out as heat, while the remaining part is converted into electricity. Energy use is mainly divided into three categories: infrastructure and equipment, including lights, computers, air heating and cooling, appliances, solid waste collection; utilities, such as water heating, refrigeration and water treatment; finally, the transportation of aviation and vehicles and their maintenance.

Fig. 4
Main Consumers of Fuel from CPX ENERGEX 2012-NATO
Source: Energy considerations 2017 Ver1.0



Activity	Fuel consumption liters (l) / month
Power production:	**(total 90 000)**
Accommodation	36 000
Offices	11 700
HQ	8 100
Kitchen, mess-hall	7 600
Communication	4 500
Recreation	4 500
Others	17 600
Heaters	14 000
Transportation	5 500
Incinerator	3 000
Other users	3 900
Total	**116 400**

From the CPX ENERGEX 2012-NATO, a Command Post Exercise (CPX) intended to analyze how energy supply could affect sustainability of military capabilities in an operational environment, emerged what are the activities which consume more fuel per month. In the chart below (Fig. 4), it is shown that power production, including accommodation facilities and offices, is found to be using the greatest amount of fuel, counting for 77% of the total fuel consumption during operations (CPX ENERGEX 2012 was chosen as a general example showing energy usage during operations).

Similarly, Fig. 5 shows the US Army estimated consumption patterns during a scenario of a wartime contingency operation. The majority of energy consumed comes from the facilities (37%) and the generators (22%) [Office of the Assistant Secretary of the Army (Installations & Environment), 2010].

Fig. 5
US Army Energy Consumption during contingency operations
Source: Office of the Assistant Secretary of the Army (Installations & Environment), 2010.

It is clear then, how much the energy needed to power FOBs constitutes a great share of the military's overall energy consumption.

Access to fuel was pivotal for NATO forces operating in Afghanistan and Iraq. Fuel was used to power ground and air vehicles, surveillance systems which enabled the forces to monitor their surroundings, follow enemies and destroy targets. Afghanistan, known as the largest operation in NATO history, is a clear example of how the security of energy supply and fuel consumption might affect military operations. In 2012, the ISAF amounted to more than one hundred thousand troops, who consumed more than 6.8 million litres of fuel every day, 99% of it coming by trucks from abroad (Samaras C. et al., 2019). Around half of the fuel consumed was provided by NATO countries in support of ISAF during the operations in Afghanistan.

Fuel supply to ISAF deployed forces was enabled by several local and foreign private companies, among them are AFG CO, DK Group Afghanistan, Red Moon Logistics & Supplies, Key Brand Logistics, Akrami Brothers Trading Co, Golden Eagle Logistics, Equipment and Service Company, and foreign companies KBR, NCS, SUPREME (Molis, 2012). These huge amounts of fossil fuel that FOBs require could only be sustained by sending convoys delivering fuel. During the Afghan operations, there were approximately 5396 fuel convoys supplying US military forces daily, plus some 1306 NATO energy fuel trucks (NEDP, 2013). The fuel was travelling through Pakistan but, after an air attack killed some Pakistani soldiers, the border was closed and NATO forces were obliged to change the fuel supply route to the North, through the Northern Distribution Network (NDN).

Hence, transporting large quantities of fossil fuels over vulnerable supply lines might be considered as one of the military's weak spots. However, NATO military forces operate under the Single Fuel Policy (SFP), which concerns the capability to use jet fuel F-34 for every system requiring fuel, such as ground vehicles and land based military aircraft (EDA, 2017). F-34 for air transport is turned into F-54 by adding certain additives so it can also be used for other systems and engines.
F-34, a high sulphur aviation fuel used under this NATO policy, was aimed to simplify the logistic effort during military operations. Consequently, since every system uses the same fuel even though it was not designed for it, some vehicles

are less efficient and more likely to experience mechanical problems. Despite the problems related to maintenance and readiness which underline SFP's shortcomings, it also created several benefits. Keeping and using just one fuel instead of many on the battlefield has the advantage to facilitate transport and storage, but it can also reduce the dangers of interchanging fuels which could possibly cause a system failure. Relying on just one fuel lessen the possibility to waste and disperse the wrong fuel, on this way enhancing fuel efficiency.

The risks associated to an overreliance on fossil fuels

The international operations in Iraq (since 2003) and Afghanistan (since 2001) have highlighted the problem of energy supply in modern battlefields and the related consequences it may have on the success of a military operation and on energy security in general. Indeed, the delivery of fossil fuels to FOBs in Afghanistan and Iraq resulted in a costly operation in terms of number of casualties and finances.

The main challenges related to an extensive use of fossil fuels during military operations can be **financial, operational and strategic** (Schwartz M., Blakeley K., Ronald R., 2012).

- **Financial** risks and challenges relate to long-term increase fuel costs and to the burden of energy transport.

1) Over the first decade of the 21st century, petroleum costs have substantially risen. If, at the end of 2001, the crude oil price was almost 29$ per barrel, within 7 years it reached 167$ (Macrotrends, n.d.). Precisely, the cost of buying fuel has risen faster than any other defence budget category, such as health care or military personnel. Hence, a long-term of increasing fossil fuels costs could require nations to devote an increasing share of defence budget to fuel, which could endanger spending on other priorities. Only in 2010, the US Armed Forces consumed nearly 5 billion gallons of fuels during military operations with a total cost of $13.2 billion. This represented a 255% increase over the amount spent in 1997 (Roughead, Carl & Hernandez, 2012). A substantial increase in price of fossil fuels can directly affect the operational capacity of military forces. Indeed, it has an important consequence on military security.

2) Energy costs are a massive drain to national defence budgets. Apart from the total energy costs, conveying fuels to remote FOBs, especially to underdeveloped countries, can increase the cost tenfold. The transportation of fuels to FOBs represents the maximum share of energy costs and it can have serious consequences on other aspects, such as possible human casualties.

If we take the example of Afghanistan, the Pentagon revealed that delivering fuel to remote FOBs in Afghanistan could cost "$400 per gallon" (Evans-Pritchard A., 2013). Moreover, for each gallon of fuel, up to 4 gallons were consumed for transporting fuel to remote FOBs.

- **Operational** challenges can be related to: the task of moving fuel to the battlefield, the impact of fuel requirements on the military's combat effectiveness and mobility and, lastly, the vulnerability of supply lines to possible disruptions.

1) Moving and protecting fuel requires the use of personnel and materials. This condition is extremely costly and can also endanger military combat capability. Hence, these resources, which could be otherwise used for other military requirements, need to be replaced to protect energy supply.

2) Fuel requirements can slow down and affect the rate of advance or the battlefield operations.

3) Supply lines are vulnerable to several types of disruption; whether it is an enemy attack or natural events, it can damage or destroy important infrastructure needed to supply military forces during their operations. Protecting the infrastructure means additional personnel taken from operational settings, increasing the risk of moving resources away from the battlefield.

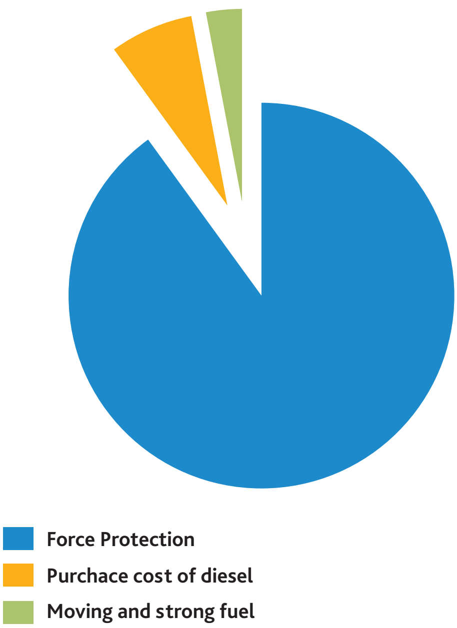
The transport of adequate and timely energy supplies to military forces in operational theatres is a strategic vulnerability to the success of military campaigns. The protection of vulnerable supply lines needs force protection assets which, in turn, creates risks for the safety of the soldiers. Fuel convoys can be objects of thefts, damages and insurgent attacks by enemy fighters. In 2012, there have been approximately 1110 attacks on ISAF fuel trucks in Afghanistan, and in 2007 alone, one American soldier was wounded or killed for every 24 fuel resupply convoys (Eady, D. S., Siegel, S. B., Bell, R. S., & Dicke, S. H.,2009).

Furthermore, when addressing energy, it is important to take into consideration the fully burdened cost of energy (FBCE). The FBCE includes all operational elements in the energy supply chain, such as infrastructure, transport, manpower, storage of energy, maintenance. As depicted in Figure 6, force protection required for fuel trucks accounts for 90% of the fully burdened cost of energy.

In 2010, the Marine Corps estimated that the fully burdened cost of fuel in Afghanistan was between $9 to $16 per gallon if delivered by land, and between $29 to $31 if delivered by air (Samaras C. et al., 2019).

Fig. 6

Source: Cave G. et al., 2011



- **Strategic** challenges and risks relate to moving fuel towards the overseas operating area and the reliance over foreign energy sources.

1) Overseas operations are supported by supply lines which may cross international borders. This represents a vulnerability since a foreign country may have the ability to attack or disrupt the flow of energy supplies. This increases the logistical effort in delivering the necessary fuel to military battlefields.

2) The fuel consumed in overseas operations is generally bought from sources near where it is used. The Agencies responsible for purchasing the fuels incur varying costs for obtaining petroleum at different locations around the world, depending on local fuel costs. As previously noted, many NATO countries heavily rely on foreign oil resources and this factor is problematic for a number of reasons. From a geo-strategic perspective, most of the countries exporting oil are authoritarian regimes, corrupt or countries that are not friendly to NATO. Hence, the need to maintain friendly relations with oil exporting countries limits certain foreign policy actions. Plus, there is an element of uncertainty regarding the amount of petroleum remaining reserves, since the estimates are considered as state secrets by some oil exporters. Overall, this results in an unnecessary dependence on sources coming from unreliable foreign countries.

Noticeably, NATO forces rely too heavily on fossil fuels. Today's missions require large amount of energy with vulnerable and costly supply lines which are a burden for nation's defence budgets and soldiers' safety. Power production by fuels faces not only high costs, but also suffers from low efficiency and has a harmful impact on the environment. The massive consumption of traditional energy resources has become a security challenge for the Allies on a tactical, operational and strategic level. An extensive dependence from fossil fuels puts soldiers' lives at risk, makes them vulnerable to attack and forces them to redirect forces from operations to the protection of supply routes. Plus, any energy loss threatens to undermine mission readiness and unit preparedness.

Hence, any reduction in their consumption will inevitably have an impact on logistical costs and casualties, as well as it would enhance military security. More efficient systems would enhance range, persistence and endurance (Strategy, D. E., 2008). They would also reduce the burden to move, protect and resupply fuels during a military operation.

V. ENERGY EFFICIENCY AND USE OF RENEWABLE ENERGY SOURCES

The term 'energy efficiency' (EE) can have different meanings depending on the context in which it is used. EE for a basic consumer can be understood as a means to maximize energy usage while minimising individual carbon footprints (Smith J., n.d.). Hence, it basically means using less energy to perform the same task while eliminating energy waste. EE has several benefits: it can reduce greenhouse gas emissions, reduce demand for energy imports and lower overall costs on a household and economy-wide level (EESI, n.d.). Also, it is considered as the primary way to reduce fossil fuel consumption. Nowadays, EE is believed to be an important resource, as well as the cheapest energy source, as it is capable to yield a significant amount of energy and demand savings without the need to produce any alternative energy in the first place.

The EU broadly described what EE means in its Energy Efficiency Directive. According to the European Parliament and Council Directive 2012/27/EU (2012) "Energy efficiency means the ratio of output of performance, service, goods or energy, to input of energy". In this way, EE is measured as the amount of output for a given energy input.

As it was highlighted before, there are several serious energy challenges, from financial risks to operational and strategic ones, which are affecting the Armed Force capabilities and posing a real threat to energy supply and security. Therefore, the need to improve EE is largely discussed in the defence sector, whose aim is to promote sustainability of the Armed Forces by reducing expenses in energy and promoting a more efficient energy management. Generally speaking, there are two main ways to achieve EE; the first one through the adoption of new technological solutions, research and development for procurement options and improvements in procedures; the other one is via non-technological solutions, such as behavioural and cultural changes (NATO ENSEC COE, 2019).

According to the US DoD, EE means "providing the same or an improved level of service with less energy" (Greenley H.L., 2019). EE is regarded as "a force multiplier, because it increases the range and endurance of forces in the field and can reduce the number of combat forces diverted to protect energy supply lines as well as reducing long-term energy costs" (Department of Defense, 2010). Indeed, the need to increase EE for the military by reducing the demand and use for fuels highlights how it helps improving operational capabilities, reducing risks and losses, and ultimately enhancing energy security. As mentioned both in the 'Army Energy Security Implementation Strategy' and in the 'Operational Energy Strategy', the US DoD firmly indicates that increasing EE and using alternative energy sources are directly linked to an improved energy security for the military.

An exact definition of the concept 'energy efficiency' is not provided by the other NATO Allies, but nevertheless they stand together in accepting the added value of an improved EE in the military and providing guidelines (Stato Maggiore della Difesa, 2019; Government of Canada, 2020; Ministry of Defence, 2018).For instance, Canada has set several targets for its Defense Department and the Armed Forces to achieve in the sphere of EE and sustainable energy. Among them, the need to improve EE by providing more efficient power solutions, and to reduce reliance on fossil fuels by using cleaner fuels (Government of Canada, 2020).

Moreover, EDA and NATO, having recognised the numerous energy challenges that the Armed Forces face, have set parallel actions to use energy in a more efficient way. In 2015, EDA, together with the European Commission, organised the "Consultation Forum for sustainable energy in the defence and security" where experts from academia, nations and industry discussed how to promote EE and reduce energy expenses in the military. Moreover, EDA has a specific program, namely the EDA's Energy Environment Programme, which aims at supporting the Member States' Armed Forces in their transition towards a low-carbon and sustainable Army, increasing their resilience to existing vulnerabilities to energy security, coming from the excessive dependence on fossil fuels. The program is made up of four major themes: Data collection & Analysis, Energy Efficiency, Alternative Energy, and Defence Sustainability (Fig. 7) (Atlantic Organization for Security, 2016).

Fig. 7
Energy & Environment Programme
Source: eda.europa.eu/eden

Among the main goals projected, there is the need to explore the opportunities to reduce fuel and energy consumption on operation for sea, land and air capabilities; assess the impact of future energy policy and new technologies on military capability; disseminate best practices for the development of alternative energy facilities at military sites and identify areas of common interest in the energy and environmental fields; and lastly to conduct Technology Watch in support of military EE, alternative fuels, energy storage and reduction of emissions (EDA, 2014).

Links between energy efficiency (EE) and energy security (ES)

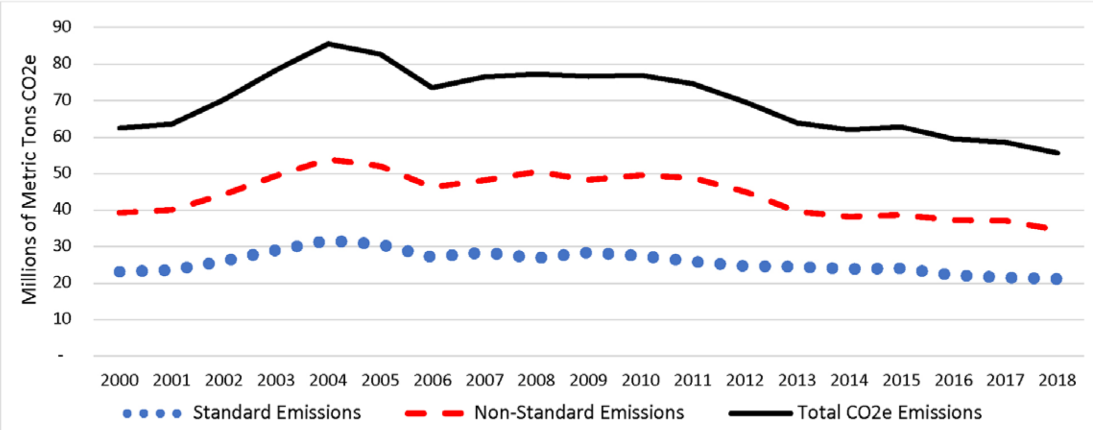
The increased costs of traditional fossil fuels, the logistical and strategic security challenges associated with fuel transportation and the increasing concerns around climate change have forced militaries to rethink and evaluate new solutions, focussing on reducing the consumption of fuels, both in military installations and operational contexts.

Environmental concerns play an important role in NATO's effort towards reducing fossil fuel consumption. A study estimated US military greenhouse emissions from FY1975 to FY2015, noting that following the 9/11 attacks and the start of the wars in Afghanistan and Iraq, US emissions rose dramatically, from slightly more than 60 million metric tons of CO2e in 2000 reaching almost 90 million metric tons in 2004 (Crawford, N. C., 2019). From the Figure 8, it can be observed that overall the US DoD greenhouse gas (GHG) emissions declined from 1975 until today, but it can also be deducted that there were significant peaks whenever the US Army was engaged in military exercises and wars.

Global warming and the threats coming from climate change have begun affecting military's thinking about the implications it might have on national security; therefore, several countries' military forces have added security implications of climate change to their national security concerns. By reducing their role in creating GHG emissions, the military could have a huge impact in reducing the consequences of climate change.

Indeed, according to NATO, "Energy efficiency is important not only for logistics and cost-saving in theatres of operation, but also for the environment" (NATO, 2020). It is in NATO's collective interest to reduce the environmental impact of the armed forces and protect the environment, indeed this goal has been included in its ES policies, such as the 2010 Strategic Concept. Over the years, NATO has established working groups to address the various climate change challenges. Among them, the Specialist Team on Energy Efficiency and Environmental Protection (STEEEP)

Fig. 8
Estimated Total DOD Greenhouse Gas Emission, CO2e, FY1975-2018
Source: Crawford, N. C., 2019



which "aims to integrate environmental protection and energy efficiency regulations into technical requirements and specifications for armaments, equipment and material on ships, and for the ship to shore interface in the Allied and partner nations' naval forces." Then, the Smart Energy Initiative, started in 2011, whose aim is to address security issues of the armed forces coming from the dependence on fossil fuels and to explore opportunities of new energy sources and energy-efficient technologies. (NATO, 2015a). Hence, a reduction in use of traditional fossil fuels and technical energy improvements could surely shrink the military logistic and environmental footprint.

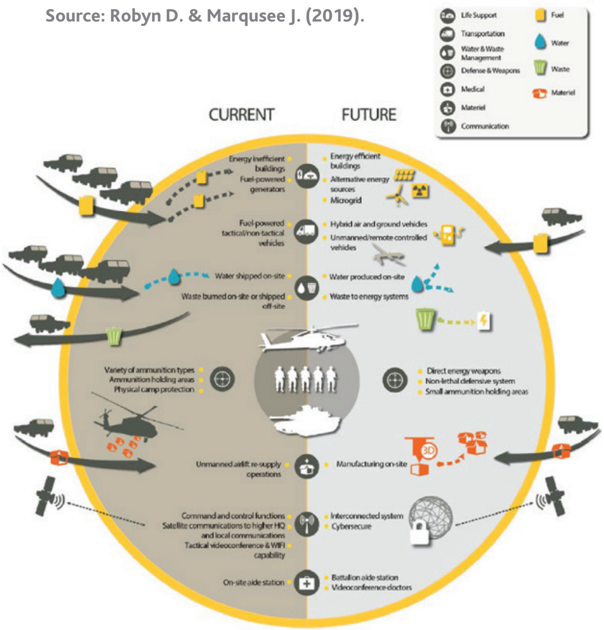
By shrinking the logistic footprint, another security challenge could be tackled, namely the security of the troops. Attacks on NATO fuel convoys in Afghanistan have highlighted the importance of assuring energy supplies to military operations (Grubliauskas J., Ruhle M., 2018) and the top priorities now are to reduce the frequency of resupply and minimise risks to soldiers. The challenge here lies in finding the necessary solutions to reduce the amount of fuel needed in operational contexts and, consequently for resupply; in other words, energy-efficient solutions to limit security risks to soldiers in deployed locations. Removing the dependence from fossil fuels can also improve operational flexibility, efficiency and effectiveness; qualities that have been constantly hindered by growing fuel requirements. The use of RE and EE techniques applied to new energy technologies does not have to compromise mission's effectiveness and soldiers' endurance, it should instead bring the same effects as when fossil fuels are being used in a military operation, without affecting or slowing down the mission's success.

A study conducted by Deloitte found that "there has been a 175% increase in gallons of fuel consumed per US soldier per day since the Vietnam conflict." Several aspects have driven the fuel consumption up, such as the mechanisation of technologies, the expeditionary character of conflicts, rugged terrain, and irregular warfare (Deloitte, 2009). Numerous means to reduce the amount of fuel used were proposed by Deloitte: new conservation techniques, renewable resources (solar and wind), renewable carbon-based resources (like biomass), nuclear fission, hot/cold fusion, fuel cells and other advanced electrical systems (Deloitte, 2009); at the same time emphasising that green military solutions can reduce the number of casualties in operational contexts.

Another important dimension to tackle when examining the impact of EE on ES are costs. Indeed, an inefficient use of fuel burdens the military by increasing the overall fuel costs and the defence spending in general. A more efficient use of energy is needed since it can help countries to use funds more efficiently, in such a way that the defence budgets can be devoted proportionally to other security issues for the Alliance, or to be invested in new energy solutions. Indeed, activities aimed at conserving and reducing energy consumption increase budgetary savings and provide additional funds for other requirements.

However, despite the reduction in traditional building loads, the demand for electrical energy is expected to grow as a result of future technologies load (Robyn D. & Marqusee J., 2019). These new technologies will include new weaponry and all the activities aimed at reducing the logistic burden of the troops on a base. Figure 9 clearly illustrates the differences between a traditional current contingency base and the possible future base, showing how it would look like in the future, when and if certain EE measures are applied.

Fig. 9
A view of Future Contingency Bases
Source: Robyn D. & Marqusee J. (2019).



Renewable energy (RE) and alternative energy

Together with the foremost importance of EE and the reduction of traditional fuels in the military context, a shift to RE is necessary to gradually move away from traditional and non-renewable sources, in particular fossil fuels. A two-track approach based on EE and RE could surely benefit mission effectiveness, endurance, the environment and unleash the armed forces from the burden of fuels.

The U.S. Energy Information Administration defines RE as coming "from sources that are naturally replenishing but flow-limited" (US Energy Information Administration, 2020b). Hence, it is a useful source of energy that is collected from RES, present in our natural environment. The European Environment Agency terms RES as "Energy sources that do not rely on fuels of which there are only finite stocks" (EEA, n.d.). The most widely known RE sources are: wind, solar, biomass, hydropower, geothermal, ocean (tidal, wave, current and thermal).

The definition of Alternative Energy comprises any source of energy (e.g., nuclear, clean coal technologies, hydrogen) that can supplement or replace fossil fuels (oil, coal and natural gas) and other conventional energy sources. One form of alternative source are alternative fuels, like biofuels or synthetic fuels. Currently, the biofuels often used by the militaries incorporate hydrotreated renewable jet fuel and hydro processed renewable diesel fuel, made from feedstocks (Osman B., 2013).

Some NATO countries already included RE in their energy strategies, such as the US DoD, which has the goal to produce or procure 25% of its total facility energy use from renewable sources by 2025. Already in mid-2010, the US military was implementing more than 450 RE projects at home bases and abroad (Osman B., 2013). Indeed, between 2011 and 2015, the military actually doubled its RE production, and tripled the number of its RE projects. The UK, too, has been able to implement successful strategies to improve energy supply for the military. The Defence Sustainable Development strategy was created to increase sustainability from 2011 to 2030, reduce fossil fuel consumption and diversify energy supplies. Moreover, the UK MoD set a 50% fuel reduction at its Afghan military base in

2009 to be achieved through a more efficient use of fuels and an improvement of insulation and waste energy capture (Bitoun J., 2014).

Canada, having fulfilled 82% of the Defence Energy and Environment Strategy (DEES) targets for the 2019-2020 period, has set ambitious commitments to improve EE of military bases and to implement innovative energy solutions for military operations. Among the goals of the 2020-2023 DEES, there is a strong commitment to develop a strategy for aviation fuels which supports the Government's aim of achieving net-zero GHG emissions. Canadian Defence is also considering sustainable fuels that meet NATO technical standards in order to maintain interoperability with the Allies. Another relevant point of the Strategy is the willingness to design and implement more efficient soldier equipment, wearable power sources and to achieve an EE of 85% in major deployed camps in order to improve soldier's ability to operate and minimise the logistic footprint.

Most of other NATO countries, even though they still have not set tangible RE targets, are developing plans to make their armies more energy efficient and sustainable.

EDA's project 'GO GREEN' aims at unleashing the RE potential, starting with solar power generation, in order to reduce energy expenditure, deploy new alternative energy sources and increase RE production and use to meet military's growing energy needs (EDA, 2012). GO GREEN is part of the innovative Military Green EU initiative, a strategic tool to promote the development and implementation of environmentally responsible technologies by meeting the requirements of Environmental Protection during military operations. It tackles EE and reducing consumption by driving the development of new eco-friendly materials and munitions (EDA, 2012a).

France advanced some projects in the field, such as the "Eco Camp 2025", aimed at creating more autonomous programs, reducing consumptions and developing "eco-reflexes". This means that the Army needs to be reflective of recycling programs and innovative in energy consumption optimisation (Parly F., 2020). Additionally, France wishes to involve other EU and NATO countries (Belgium, Italy, Spain) in the process of energy transition of the military, by launching a permanent structured cooperation on "Energy Operational Function" (EOF). This project has several objectives, among which the development of new systems of energy supply for camps deployed in joint operations and for soldiers' devices and equipment (PESCO, n.d.).

Energy storage is considered as an increasingly important element in the electricity and energy systems, as well as a positive contributor to ES with a key role in the transition to a carbon-neutral economy. The EU provides a proposed definition of energy storage: "Energy storage in the electricity system would be defined as the act of deferring an amount of the energy that was generated to the moment of use, either as final energy or converted into another energy carrier" (EC, 2016). Basically, it can be defined as a conversion of electrical energy from a power network into a form in which it can be easily stored until it is converted back to electrical energy.

As energy storage technological solutions are able to store surplus energy and balance power grids, they represent an effective means to improve EE and the integration of RE into electricity systems. In this way, energy (also in the case of variable energy sources, like renewables) could always be available to meet energy demand when needed, even during peak loads, without recurring to fossil energy sources.

That is why, evaluating the potentiality of energy storage is pivotal when considering military operational contexts. Energy storage solutions, integrated with RES, enable to rely on intermittent energy sources, providing a constant energy output and, by the same token, operational flexibility.

VI. NATO'S "GREEN" INITIATIVES

As previously highlighted, operational, strategic and financial risks related to an inefficient consumption of fossil fuels, not only put at risk the survivability of the armed forces, but also endanger ES and combat endurance. Hence the need to render NATO forces more efficient and sustainable in their use of energy resources.

At the 2010 Lisbon Summit, NATO Allied countries stated that "key environmental and resource constraints, including health risks, climate change, water scarcity and increasing energy needs will further shape the future security environment in areas of concern to NATO and have the potential to significantly affect NATO planning and operations" (NATO, 2010). Therefore, with this document, stability and reliability of energy supplies and the diversification of energy sources and suppliers have become of critical importance for the Alliance. This statement was repeated in the Chicago Summit in 2012, where the Allies also highlighted that "we will work towards significantly improving the energy efficiency of our military forces" (NATO, 2012a), effectively calling for a drastic change into military energy behaviour.

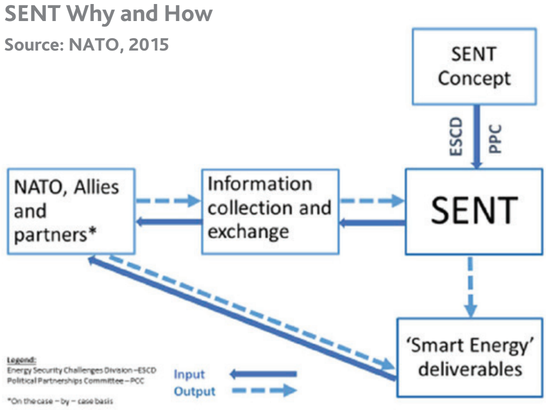
In November 2011, NATO's Emerging Security Challenges Division (ESCD) presented a conference on Innovative Energy Solutions for Military Applications (IESMA), which took place in Vilnius, Lithuania. IESMA was organised jointly with the national Energy Security Centre in Vilnius, which was accredited one year later and became the NATO ENSEC COE. Since then, the NATO ENSEC COE operates as a widely recognised international military organisation with the aim of providing qualified and appropriate expert advice on questions related to operational energy security. The event IESMA 2011 gathered experts from NATO, allied countries and participants from the private sector who discussed altogether the necessary measures to reduce military's dependence on fossil fuels. The conference provided a platform to share best practices, exchange information among the Allies and revealed some new technological solutions for power supplies, EE and waste. Following this event and the introduction of the topic of EE in the military agenda as 'smart energy' - through the initiative of NATO HQ's ESCD in 2011-, the Smart Energy Team (SENT) was established in October 2012 as part of NATO Smart Energy Agenda.

Smart Energy Team (SENT)

SENT was established with the support of the NATO Science for Peace and Security (SPS) Programme with a two-year mandate and included subjects matter experts from six Allied countries (Canada, Germany, Lithuania, the Netherlands, the UK and the US) and other two partner countries (Australia and Sweden). The Team was created as an interdisciplinary group composed by experts from various fields tasked to generate cross-cutting knowledge and contribute to the integration of SE into NATO Defence Planning Process through reports, fact-finding studies to identify best practices for multinational SE projects within the Smart Defence Framework and SPS Programme (NATO, 2015).

Among SENT's goals, we find the need to examine how a reduction in the energy requirement can decrease the logistical footprint of NATO Forces, thus improving operational capabilities and reducing the protection of vulnerable supply lines. SENT also provided a definition of 'smart energy', which refers to "the methods of providing energy to the user in a practical, effective, sustainable and environmentally responsible manner." (NATO, 2015). Therefore, SENT's work focuses on EE and technological innovations which could limit the use of traditional energy sources and, at the same time, enhance operational capabilities and endurance. Its work agenda involved the improvement of the measurement of energy consumption on military bases and the development of smart technological applications, such as new

Fig. 10
SENT Why and How
Source: NATO, 2015



measurement tools, smart grids and alternative energy technologies (Fig.10).

Green Defence Framework

In February 2014, NATO adopted the "Green Defence Framework". This Framework represents a step ahead for the Alliance in addressing the link between environmental concerns and security and aims at highlighting several initiatives capable of facilitating the development of green policies in NATO countries. In the Framework, a definition of Green Defence explains that it is "a multifaceted endeavour cutting across a wide range of activities, including operational effectiveness, environmental protection and energy efficiency." (NATO, 2014).

The NATO Framework is based on three pillars as indicated in the document, namely on: 1) reinforcing efforts of NATO bodies; 2) facilitating Allies' efforts; and 3) improving NATO's "green" profile (NATO, 2014). Moreover, it provides a basis for knowledge-sharing and research coordination among the Allies, which can encourage the development of green defence solutions in order to address the contemporary security challenges, particularly ES, climate change, defence spending and logistical challenges. Indeed, NATO and the Green Defence Framework can represent an important platform for coordination, research and best practices on EE initiatives which could potentially reduce costs, lower security risks and reduce the Alliance's environmental footprint. Hence, the Green Defence Framework represents the development of a coherent policy for green defence solutions which can be a reference point for NATO countries to further introduce innovative energy solutions.

Innovative Energy Solutions for Military Applications (IESMA)

As it has already been mentioned, the first edition of IESMA, organised by NATO ESCD and NATO ENSEC COE, took place in Vilnius in 2011, and since then, it has been held three more times, in 2014, 2016 and 2018. The first edition emphasised solutions both in the EE sphere and in RE, in order to shrink military dependence on fossil fuels, but also to discover alternative technologies to be applied in operational contexts. The solutions ranged from power storage and EE applications, including waste incineration, to solar energy. (Bitoun J., 2014). The last edition in 2018 focussed on camp energy management and installation improvements, operational EE in navy and air forces, while also including a session on hybrid power generation and micro grids, using innovative solutions that have sensor stations and observation platforms (NATO, 2018).

IESMA's goals are to identify best practices and exchange information and experiences for advancing EE and sustainability in the military. Thanks to IESMA, experts in the field from NATO nations, NATO partner nations and representatives of private sector industry and scientific field gathered and discussed cutting-edge technological advancements and their importance for military application.

Exercise Capable Logistician (CL)

The SENT Concept identified six deliverables, among which it had to provide a SE component, consisting in SE solutions, to the military logistics exercise "Capable Logistician". The exercise CL was first held in Slovakia in 2013. CL offered an opportunity to private companies, civil and military experts from NATO nations to demonstrate practical implementation of EE advancements by showcasing advanced energy generation and saving technologies in a SE camp (NATO, 2013). This exercise allowed participants from 38 nations to share best practices and actually test and employ new technologies in the field of EE and alternative energy.

The idea of a SE camp was reiterated during CL 2015 taking place in Hungary, where two SE camps where made up of functional microgrids (Michaelis S., 2015). CL 2015 demonstrated the great potential in energy savings, together with enhancing military efficacy and saving lives. Additionally, two more dimensions of CL 2015 need to be highlighted. First of all, it allowed private companies to install and run their equipment by interacting with other units, so it provided a platform for interoperability between participants.

Then, it also turned out to be a great chance to transpose public-private dialogue into action, by allowing private companies to provide their equipment and solutions, in this way facilitating a dialogue between industry and the military.

CL 2019, which took place at the Drawsko Pomorskie Training Area (DPTA) in Poland, aimed at reducing fuel consumption and improving the functionality of deployed camps by optimising the power generation and improving energy storage, distribution and consumption. Among the innovative equipment presented, hybrid power generation units, photovoltaic panels, microgrid controlling software, insulated tents, LED lights, energy-efficiency air-conditioning, sun shades, non-intrusive energy metering kits (Michaelis S., 2019).

In all three CL exercises, a SE unit was established with innovative equipment and personnel from NATO countries. The overall aims of SE in CL exercises were to display the potential of innovative solutions to reduce fossil fuel consumption and wastage in deployable camps; to show the benefits of SE in enhancing operational capabilities; and to test interoperability and NATO standards. Indeed, it was demonstrated how the use of modern equipment saves fuel consumption and increase operational effectiveness. Nations could apply these innovations which allow to better manage and plan energy flows in deployable camps, and in turn could reduce fuel wastage by 5-20% (Michaelis S., 2019).

VII. NEW ENERGY SOLUTIONS IN NATO AND THE IMPACT ON ENERGY SECURITY

From the previously revealed challenges to military operations, it resulted that EE measures and the development of new energy technologies are key to address those risks and, at the same time, enhance ES in the military sphere. Operational, financial, strategic and environmental challenges related to a fossil-fuel based era will be limited (or even better eliminated), if EE measures and RES technologies are developed in a suitable way. The present report will limit its scope to new energy solutions and, more generally, to primary energy sources which are available (or could be applied) in an operational context, referring to NATO forces operating in forward/remote operating bases.

As new energy technologies are developed for deployed military forces, it is crucial to take into consideration and planning the environments in which those technologies will be used, so that the energy production system does not become a limitation to operational functions but rather an enabler. Specifically, NATO Armed Forces need to rely on solutions which could be deployed to any necessary location despite harsh climate conditions, the austerity (such as infrastructure, landing fields, railways, ports) or the hostility situation. Additionally, these new energy solutions have to integrate the ability to remain agile, mobile and mutable to be ready to be deployed in an operational environment. Hence, energy technologies must be deployable, re-deployable, suitable for any hostile location and possible hostility levels in which the military is requested to operate.

Until recent times, the individual diesel generator was generally used by the Armed Forces, given its ability to operate under almost any harsh condition without compromising its functionality. However, to ensure that military operations are not constrained by the selection of energy sources, several conditions must be taken into consideration when selecting new energy technologies. The US Task Force on Energy Systems for Forward/Remote Operating Bases assessed several considerations regarding energy technologies when providing energy to forward and remote locations across conflict environments, such as:

- Transportability: ability to move the system into and out of a location with transport systems.
- Deployability: ability to place the system in foreign countries, according to foreign rules and regulations.
- Compactness: contribution to the base's footprint.
- Logistic Supportability: ability to support with already existing logistics capabilities.
- Simplicity: ability to be operated by personnel with little training.

- Safety: ability to survive to several types of attack.
- Security: consequences of abandonment or penetration, or capture by the enemy.
- Reliability: ability to operate with minimal down time and maximum operational availability (Department of Defense. Defense Science Board, 2016).

Other considerations to take into account for new energy technologies are: mobility, integration, distance, dependability, flexibility, durability, peak-time, availability, modularity and economy.

- Mobility refers to the flexibility of a system to be easily set up and be transported to other location.
- Integration: energy systems need to be integrated using by-products or other materials to produce energy in place and to decrease the use of primer energy source and resupply.
- Distance has to be considered as the system should be able to operate independently without any input or using input that are locally available, following the dispersal of troops in non-linear battlefields.
- Dependability consist of long-life, easy operation, little maintenance which make a system reliable enough to be operated.
- Flexibility means that one system could be operated for many different tasks.
- Durability: the system needs to be durable and able to withstand adverse impacts of the environment.
- Peak-time has to be taken into consideration to provide the proper energy level at high operational tempo period.
- Availability. Energy systems are more effective when freely available environmental sources are used, without the need to transport primary energy on site.
- Modularity: the system needs to be modular when supporting the troops when different locations and environment are involved in an operation.
- Economy: the system has to be economical or at least more economical than the fossil-fuel based systems they are replacing (GERŐCS, I., 2012).

Before starting to consider and describe several new promising energy technologies, it is essential to assess what RES are available, if these sources could reduce the demand for fossil fuels and, finally, how these could be suitable in an operational environment.

Recently, many studies concerning the feasibility of RES and technologies for expeditionary military operations revealed the potentiality of RES only in limited cases. For instance, solar energy was found to be the most promising so far, with many applications by several armed forces on camps, dismounted soldiers, Unmanned aerial vehicles (UAVs) and for sensors. Table 1 was provided by the US Task Force on Energy Systems for Forward/Remote Operating Bases in 2016. It basically gives an overview of the various RES and technologies which could potentially offer benefits for operational use.

From this study, it was found that few RES, such as solar and wind, could reduce the need for fuels, whereas many other RES, like hydro and geothermal, are limited by location, time of the year and storage capacity. The Task Force found that solar energy, available globally, could be a useful source of power through the use of photovoltaic (PV) devices. While installing PVs in small FOBs can be beneficial in reducing the amount of fuel needed, they still require cleaning and they could be a visible target. Additionally, to produce a large portion of power, PVs require a significant land area, which makes them more suitable for small bases. Wind power, in the form of small wind turbines, could be a potentially beneficial source of energy too, since installation is technically feasible and maintenance is minimal. However, they would still require to be integrated with electrical energy storage systems in order to capture a significant amount of energy. Plus, its visibility and the possibility it could interfere with communication signals and aircraft routing, are issues to take into account when considering an operational application.

Table 1.
Alternative Energy Sources and Technologies
Source: Department of Defense. Defense Science Board, 2016

Energy Source	Availability	Technical Maturity	Operational Considerations
Solar Power	Available globally; varies with location, season, weather, time	Widely deployed on the civil grid and military installations; limited deployment of tactical units	Small rugged panels can be beneficial; possible visible target; glint/glare concerns; requires cleaning
Wind Power	Available globally; varies with location, season, weather, time	Widely deployed on the civil grid and military installations; small units exist, but are typically not attractive for military use	While potentially beneficial, concerns with small wind turbines include reliability, visibility, and interference with communications
Hydrokinetic Power	Common but not everywhere; varies with location, season, weather, time	Utility-scale hydroelectric dams are mature and common; small portable tidal, wave, and micro-hydro power systems are under development	Requires sophisticated technologies and potentially a large material footprint; variable but more predictable than wind and solar
Geothermal Power	Exists in limited locations worldwide; where present, heat output is often steady	Very mature for civil applications	Requires considerable time and initial capital cost for construction; likely attractive for some enduring locations
Ocean Thermal Power	Exists in the deep sea and near specific islands	Under civil sector development and under evaluation for use on U.S. Kwajalein Army Base	Requires significant initial capital cost and large structures; may be attractive for some enduring locations
Waste to Energy Systems	Solid waste, wastewater, and other energy-containing wastes are available wherever humans live and operate.	Mature for large civilian applications; the military has deployed small incinerators, and is evaluating systems capable of extracting heat or power from waste.	Requires dedicated equipment and is operationally complex; the scale of energy generated from waste resources would make up a small fraction of civilian or military needs.
Indigenous or Cultivated Biomass	Available throughout much of the world, but variable by location and time of year.	Common for simple heating and cooking tasks, and mature for industrial use, but mobile reliable systems are under development.	If reliable, could reduce need to deliver fuels to remote locations; biomass logistics and infrastructure must be considered.
Wireless Power Transfer/Beaming	Potential energy inputs (grid or solar panels) are available, but transmission technology is not currently available.	Requires significant implementation costs despite advanced knowledge of the physics; the DoD continues to monitor and make limited investments in R&D.	Likely requires a large structure to receive energy; an accident could have severe consequences; requires evaluation of vulnerabilities before implementation.
Host Nation Grid	Often available but not consistently reliable.	Interconnection of military base power systems with a local transmission network is straightforward and well understood.	Could reduce costs, but may be unreliable, requiring back-up power generation systems (as is the case with intermittent renewables).

Table 2.
The important features of RES in terms of military applicability
Source: Végvári, Z., 2018

Renewable	Biomass	Hydro	Geothermal	Wind	Solar
scalability	n/a	bad	medium	good	very good
reliability	good	good	very good	medium	bad
mobility	n/a	none	very bad	medium	good

Another study, published by the Hungarian National University of Public Service, analysed the feasibility of some RES for military application according to three main characteristics: scalability, reliability and mobility (Table 2). (Végvári, Z.,2018). Solar and wind were found to be the most suitable choice for deployed military forces. Indeed, they are scalable, mobile enough to be easily and quickly transported and do not need many infrastructural parts. The only real problem concerns their unreliability. This means that wind and solar cannot be used individually, nevertheless they can represent a great added value when combined with conventional generators in the same grid.

Considering biomass, there are several projects around the world aiming at integrating biomass into the fuel supply chain. Biomass, in form of biofuels, could reduce the dependence from traditional non-renewable fossil fuels, and it could be useful for the military during peace-time activities; however, it was assessed as not suitable for deployed forces, as its energy density is less than the refined petroleum derivate (Roos D., 2012).

In sum, RE solutions offer new possibilities for the production of electricity; however, being intermittent, renewables should be deployed together with conventional generation systems as backup. In this way, only through hybrid solutions they could meet the energy needs of the armed forces.

The following paragraph is not meant to list all the existent new energy solutions for military purposes, but its main purpose is to assess in what ways these innovative technologies could enhance ES by reducing fuel demand and improve combat effectiveness and readiness for military deployed forces.

Solar energy and solar PVs

Since solar energy was repeatedly found to be the most versatile and suitable source for military deployed forces, a focus will be given on new energy technologies which exploit its benefits and on what impacts solar energy and related solutions could have on supply security and ES of NATO militaries without affecting operational capabilities. During the last decade, the US, which are considered leaders in RE solutions for military applications, conducted several experiments concerning RE technologies and their impact on ES in the military field.

It is in operational contexts that the militaries today face more challenges related to energy. Since FOBs are located in remote and harsh environments, the logistical efforts in transporting the necessary amount of energy and forces dedicated to protect vulnerable supplies make OE costs higher than in fixed installations.

Overall, RE offers lower chances of disruption since it can be produced onsite, without the constant need of resupply and of fuel convoys vulnerable to enemy attacks; plus, it would also save manpower, funds and the lives of personnel dedicated to delivering supplies to remote sites.

Another added value is represented by the impressive constant decline in RE costs since 2010, particularly solar energy costs, which declined by 82% in less than ten years. For the first time, the price of on-shore wind and solar PV-generated power has fallen below $0.05/kWh, while fossil fuel-fired power generation costs between $0.05/kWh and $0.18/kWh. The costs have fallen thanks to a combination of reasons, including better technologies and production at scale, and

Fig. 11

Power generation costs in 2019 and falling power generation costs

Source: International Renewable Energy Agency

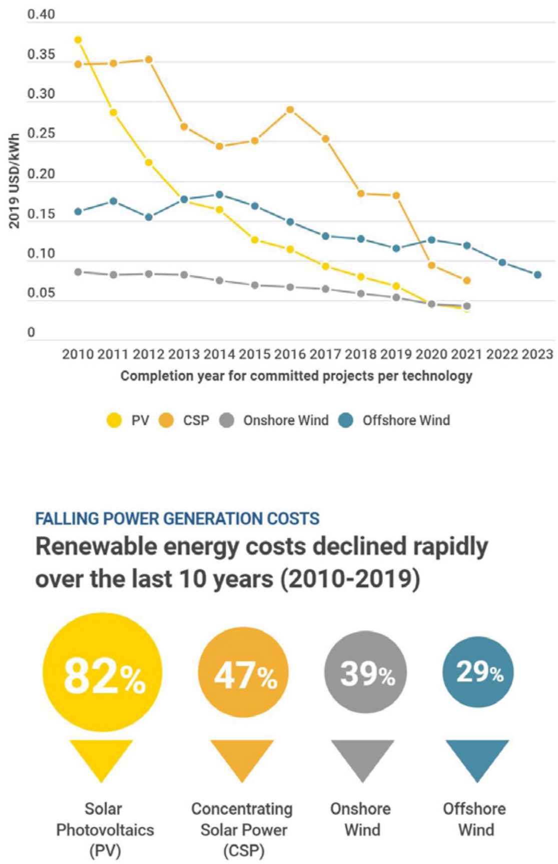


Fig. 12

Fuel savings vs Capacity for PV and wind energy

Source: McCaskey N.C., 2010.

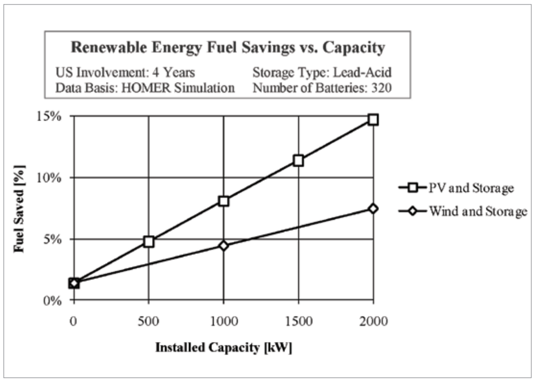
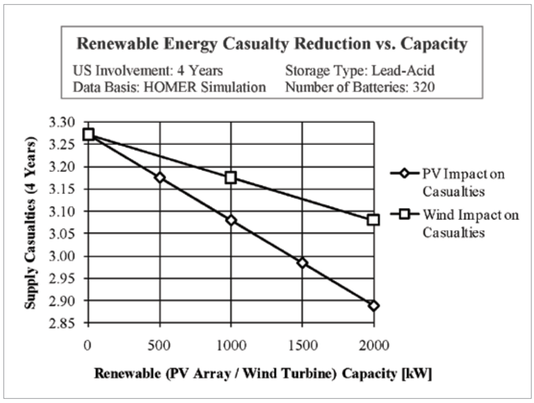


Fig. 13

Supply casualties VS Capacity for PV and wind energy

Source: McCaskey N.C., 2010.



more experienced renewable developers (Fig.11) (IRENA, 2020). Therefore, RE is not only cheaper than fossil fuels, but also it could have a spill over effect on emissions, energy bills and market share.

Solar energy could offer significant benefits in the operational context. The biggest advantage that solar energy has over conventional fossil fuels is that its on-site production would considerably reduce the need for fuel resupply to remote FOBs, hence the number of human fatalities connected to the protection of vulnerable supply routes. Solar PV technologies are designed for efficient packaging, they are lighter and scalable to meet the power generation requirements for FOBs (Adams R.H., Lindsey M.F., Marro A., 2010).

A study conducted in 2010 revealed the impact of installing RE systems at FOBs on fuel reduction and supply-line casualties. To help estimating the impact of RES on a hypothetical base at forward location, a specific existing base was chosen: Marjah, Afghanistan. Fig.12 shows that there is a linear relationship between solar energy capacity and fuel savings. Indeed, the results indicate that for each megawatt (MW) of solar PV acquired, the FOB achieved 6.7% of fuel savings (McCaskey N.C., 2010). As showed in Fig.13, solar energy significantly reduces casualties.

By installing a 2 MW PV array, expected supply casualties can be reduced by 12%. These results helped justifying installing renewables at FOBs from the point of casualty reduction exposing additional benefits too, such as reduced operating costs and reduced maintenance, highlighting the attractiveness of incorporating RE into FOBs (McCaskey N.C., 2010).

From a tactical edge, solar energy provides a great advantage to the militaries. Not only it helps forces achieve energy self-sufficiency, improves mission effectiveness and readiness, but it is also suitable, as opposed to fossil fuels systems, for reaching more remote locations without the need for resupply. Solar PV technologies are also able to reduce the logistical footprint of military forces due to their lighter weight and easy transportability. They include simple operational maintenance training, low thermal signature and they are quieter than diesel generators (Bitoun J., 2014). However, one downside is the effect that solar PV could have on the shielding of the camps. PV panels need direct solar radiation; hence they cannot be camouflaged and they could be seen from afar.

Desert conditions in Afghanistan with their high level of solar radiation proved to be a perfect place for testing new energy solutions. Indeed, more than a decade ago, the US Marines tested six technologies into the theatre, such as: a solar field shelter; a portable hybrid photovoltaic/battery power system called the Ground Renewable Expeditionary ENergy System (GREENS); a ReGeneration that uses solar energy to power high-tech devices; a towable solar lighting system; a light-emitting diode (LED) lighting system; and the Solar Portable Alternative Communications Energy Systems (SPACES) that enables portable power to charge batteries (Fig.14) (Boland R., 2011). The GREENS consists of stackable 1.600-watt solar arrays and rechargeable batteries which provide 300 W of continuous electricity for the troops and it is meant to replace fossil-fuelled generators (Office of Naval research, n.d.).

These new technologies have been tested in an Experimental Forward Operating Base (ExFOB),

Fig. 14

Source: Boland R., 2011.

Expeditionary Forward Operating Base Alternative Technologies Fielded in Afghanistan

PRODUCT	FUNCTION	PROVIDER
PowerShade Solar Field Shelter	power lights, field communications	PowerFilm
Ground Renewable Expeditionary ENergy System (GREENS) battery	portable hybrid photovoltaic/ power system	Office of Naval Research and Marine Corps Systems Commands
ReGenerator	solar energy to power high-tech devices	ZeroBase Energy
Towable solar lighting system	lighting	NEST Energy Systems
LED lighting	lighting	Techshot Lighting
Solar Portable Alternative Communications Energy System (SPACES)	portable power to charge batteries, operate communications equipment and run electronic accessories	Iris Technology

where the main focus was on the expeditionary edge of the mission, hence readiness was the core element in searching for the most suitable energy solution. The biggest advantage in this case is that, through the use of these renewable-energy generators, the number of batteries needed per day would drop from seven or eight to one or two. Albeit these renewable energy systems cost more than the traditional fuel generators, the overall effect is that they result in fewer fuel trucks on the road, which, consequently, reduce costs and casualties. While the militaries are spending less time protecting supply lines or driving fuel trucks, not only it protects lives, but also increases the time that they can spend on other missions' activities.

Other applications where new PV technologies are suitable include the category of individual warfighter equipment, like communications

Fig. 15

Solar Portable Alternative Communications Energy System (SPACES)

Source: Martin-Aboord D., Dudis D., Wagner T., 2020

equipment optics, lighting or sensors. Some PV examples are the Solar Portable Alternative Communications Energy System (SPACES) (Fig.15), a PV-powered 124W communications suite; and the Battlefield Military Solar Lights Tower (Fig.16), which can be used for perimeter and airfield lighting. The former is a folding portable solar panel system which provides energy to recharge batteries and power external devices, while the latter is equipped with a solar PV and IQLED lights. These systems require no refuelling; hence they reduce operational risks and personnel workload, enhancing energy security (Martin-Aboord D., Dudis D., Wagner T., 2020).

Smart hybrid grids

Smart hybrid grids are a relatively new energy solution which not only allows to work independently from any power line connection (off-grid or "island" mode), but also to incorporate RES and conventional generators as a mix into a hybrid system. In this case, 'smart' reflects the possibility to manage the energy flow without the need of manual control, pivotal during military operations.

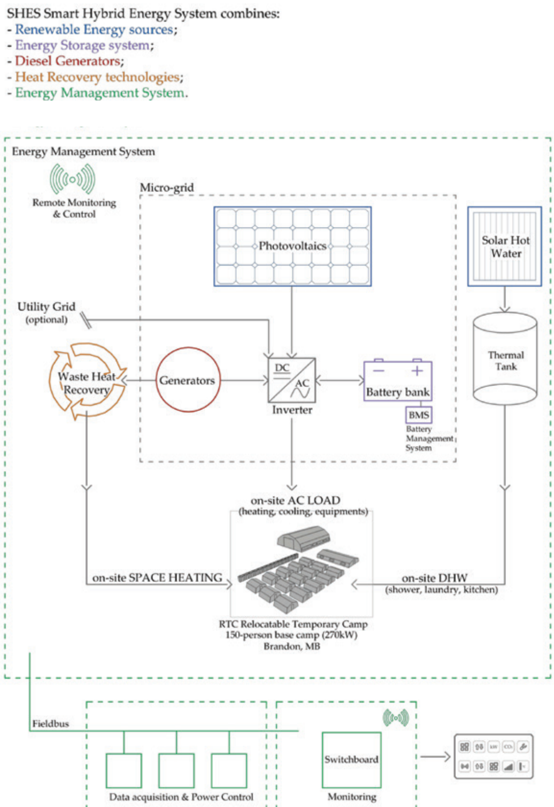
According to these elements, the Smart Hybrid Energy System (SHES) was presented as a scalable and transportable solution for providing energy-efficient services to military forces in deployed operations. This system combines the traditional diesel generations with solar power generation, energy storage and waste heat recovery technologies, all connected to a microgrid, in this way ensuring uninterrupted electricity flow.

The SHES includes the following technologies into a single integrated system (see Fig.17):

- A PV array
- An energy storage system
- Diesel generators
- Waste-to-heat energy recovery system for space heating
- Solar hot water system for domestic hot water
- Energy management system that monitors and manages base camp equipment and zones.

Fig. 16
Battlefield Military Solar Lights Tower
Source: Martin-Aboord D., Dudis D., Wagner T., 2020

Fig. 17
SHES
Source: Berardi, U., Tomassoni, E., & Khaled, K. (2020)



The System, being a demand-managed microgrid, provides power only where and when it is needed, instead of relying on a fuel generator. It also uses intelligent load management technologies to prevent grid collapse in the event of generator fault and prevents a stoppage of energy flow by shifting demand onto supporting generators. Hence, SHES provides redundancy to ensure continuous operation even in system failure (Berardi, U., Tomassoni, E., & Khaled, K., 2020).

The SHES presents many advantages if allocated and used in deployed military locations, since its components have been selected to be easily transportable in standard shipping 20ft containers. Plus, its modularity, scalable from the base camp for 150 people, is designed according to the available RES onsite and to be operational in different climate conditions. The hybrid solutions prioritise renewables, followed by battery power, resulting in less generator runtime, thus requiring less maintenance.

The simulation results indicated a 37% fuel savings when all SHES components are implemented for accommodating 150-person in a temperate climate, in addition to a significant carbon reduction. Consequently, SHES reduces military dependence on fossil fuels lowering their environmental and logistic footprint since the transportation logistics are minimised and the use of trucks delivering fuel is also reduced.

Generally speaking, military smart grids are made in order to exploit RES power in the field. However, so far, the most advantageous RES which has been used in a smart grid was solar power. Indeed, it is almost the only type of RES to be very mobile and to satisfy military standards. Moreover, the advantage of military smart grids is that decreasing fuel consumption means longer independent mission time, less maintenance and more resilience of supply.

In recent years, other types of military smart grids have been built driven my military needs. Essentially, they are small-size mobile devices, able to be quickly installed for smaller military units. Their full installation takes approximately some minutes, RES exploited is only solar and the panels are quickly deployable and redeployable.

Hybrid Power Generation System

The Deployable modular Hybrid Power Generation System (HPGS) is an example of energy storage technology, able to incorporate renewable source of energy, such as solar PV or wind generation. It is designed to reduce fuel consumption by increasing power generation efficiency and, at the same time, achieving a constant supply of energy. The project was started by NATO ENSEC COE and the German company PFISTERER; it includes two diesel generators, battery storage, solar panel and wind generator together with Mobile Energy Management System (MEMS).

The system was proved to enhance energy security and energy supply security in military camps with great advantages like reducing the logistic burden in harsh environments and the resources needed and thus decreasing human casualties' risks. It was demonstrated that the HPGS can reduce fuel consumption by 20-30%, thus improving ES and resilience when fuel supplies are difficult to obtain, as it also incorporates an energy storage capacity linked to renewables. Even though the core elements of the HPGS were the battery storage and generators, the inclusion of RES to the system highlighted several benefits to the whole system's efficiency and effectiveness. Solar PV was found to be more promising than wing energy, which contributed only a little to the overall power generation. Indeed, the contribution of solar energy to the total energy production varied between 3%-24% depending on weather conditions.

The results also indicate that HGPS is able to save up to 30% of fuel running at 10% of its maximum load (15 kW) (NATO ENSEC COE, 2018). Hence, the HPGS was found to be a valuable solution in increasing ES at military deployed camps. Indeed, its deployment could limit fuel usage, plus the addition of renewables could represent an optional add-on to positively increase ES. However, additional enhancements and testing are needed in order to improve HPGS transportability to be easily deployed in FOBs.

Summing up the main characteristics of RES, one can outline which advantages and drawbacks they could bring to military operations, assessing in what ways an extensive use of RES technologies could impact and enhance ES.

First of all, RES are not dependent on global market places that can be vulnerable to volatile price spikes. They also are a free and inexhaustible source of power, self-replenishing and some of them stand steady over annual periods. Given the nature of the majority of military operations, and the harsh environment conditions in which base camps are located, RES have the big benefit to be built and deployed almost everywhere and far more quickly than traditional fossil fuel generators. Finally, their environment-friendly nature makes them the best choice to lower pollution and the carbon footprint of our Armed Forces.

Apart from being a source of energy which is not available at all times and thus requires energy storage support, the main issue when dealing with RES technologies is related to planning and operating the systems. Indeed, engaging with RES systems is not easy; the required knowledge and experience is not available at all levels of the military. Hence, resources and skilled personnel are needed when planning RES technologies installation and operation in a military field, especially in remote FOBs.

VIII. MILITARY AND CIVIL SECTOR COOPERATION IN ENERGY INNOVATIONS

The cited new energy technologies are perfect examples of civil and military cooperation on energy innovations. In an era when EE and new technologies are primary concerns for industry, cooperation between the two actors, the military and industry, could be beneficial for both sides in achieving their objectives.

In the last few years, the cooperation on EE has evolved and the available platforms and mechanisms to enable this dual communication have multiplied.

The US Experimental Forward Operating Base (ExFoB) and the UK initiative UK POWERFOB are relevant examples of platforms enabling MoDs to engage with the RE industry in order to achieve energy savings through SE solutions.

Moreover, IESMA and CL are two important events at NATO level, where industry and private companies can showcase new energy solutions so that the military can identify the most promising ones and formulate recommendations for improving best practices on EE accordingly.

Other Allies too have looked at ways to reduce energy consumption during deployed military operations. Canada, with the Canadian Joint Operations Command (CJOC), have promoted several initiatives that have exploited the cooperation with other federal departments and private industry, as the Operation NANOOK 12. Through a close collaboration between the two sectors, Canada will be working to improve the environmental and energy footprint of military deployments, at the same time striving for a reduction of fossil fuel in deployed camps. The successful achievement of their objectives will be dependent on the cooperation between the military, science and technology and private industry (Major Chubbs L., 2014).

As presented in the study by Robin & Marqusee (Robyn D. & Marqusee J., 2019), there are several pathways which could be followed toward a closer collaboration between the military and the industrial sector.

First of all, the military represents an important base to invest in basic and advanced science, technology and engineering methods. Generally, the defence departments perform their own R&D to further develop commercial technology or adapt it for military use and, in turn, commercial technology developers take military's enhancements and incorporate them. This move back and forth between the military and the commercial sector takes the shape of a "spin-in" or "spin-back-and-forth" process and represents a way in which the military can leverage the commercial technology sector for innovation, at the same time avoiding the cost of developing unique solutions for the military.

In this sense, solar PV technology is the best example to illustrate this pathway of collaboration between the commercial and defence Research and Development (R&D). For example, the US

DoD is investing in R&D to develop enhanced solar PV technology that is more lightweight, flexible, mobile than the commercial version in order to enable longer missions and reduce even more the logistics footprint of their Armed Forces. This significant investment in solar PV is important not only to improve combat capabilities and ES of the military, but it can also have a spin-off effect on the commercial sector by improving the quality of commercial solar PVs.

Another way the military contributes to commercial innovation is by being a test bed to showcase and validate commercial technologies. The DoDs have resources, military bases with large areas that can be used for testing. Plus, the US DoD has a deep culture of test and evaluation that makes it ideal for commercial validation. Microgrids are essential to contingency bases to greatly reduce the need for fuel-based generators. The microgrids developed for FOBs are almost totally different from the ones created for fixed installations. Indeed, they must be mobile enough to be shipped to war zones and simple enough to be operated by every soldier, even the ones who lack technical expertise. Hence, Defence departments could play a pivotal role in the commercialisation and deployment of microgrids. Many developing countries and remote locations need those types of microgrid (one that is portable, mobile, easy to operate) and the military could be an early adopter and tester of this technology. This would also bring the cost down and help improve the technology.

The last pathway is directly connected to the previous point and it explains how the military could be an early adopter and purchaser of new technologies that have little commercial penetration. The military, indeed, is less sensitive to high prices for new technologies than commercial customers and private investors and it has been a valuable platform as first user for centuries. It is also in the military's interest to see a technology gain the commercial market because it can bring the costs down and enhance further innovation.
Solar PV, batteries and microgrids are the best cases to see the military as early adopter. Indeed, these solutions could benefit from the defence department's willingness to pay more for a higher performance, ensuring technology improvement.

Consequently, these solutions represent, as called by the authors of the study, the "pathways of influence", according to which the military and the departments of defence can cooperate with civilian companies to develop new energy solutions. Undeniably, each sector needs the other one to advance and present new technologies in order to effectively contribute to enhancing the EE of the armed forces.

CONCLUSION

This report assessed several challenges to ES which are related to the extensive use of fossil fuels by NATO forces in operational contexts. Strategic, operational, financial and environmental risks highlighted the need for change in military thinking and planning with regard to OE.

EE measures and new energy solutions incorporating alternative and RE sources are key in defining a new way of conducting operations and enhancing ES. Indeed, only through a reduction in use of traditional fossil fuels and energy improvements, the military logistics and environmental footprint could shrink. In addition, OE has to take into account combat effectiveness. New energy technologies have to support and increase military forces endurance, replacing fossil fuels-based sources with the same level of energy output, without affecting the conduct of military operations.

NATO and the Allies individually have taken significant steps to incorporate these initiatives in their Energy Strategies and military planning. SENT, IESMA, Green Defence Framework and CL are just some of NATO initiatives aimed at providing a platform for the Allies to share best practices, raise awareness and present new SE innovations which could tackle security challenges to OE.

RES are found to be key enabler of ES when combined with other RES or in the same grid with conventional generators. However, the report and some of the mentioned studies revealed that only solar energy and (rarely) wind power are the most suitable due to their characteristics which make them easily exploitable in expeditionary military operations.

Although RES, such as solar and wind, can produce a sufficient amount of power, it is from hybrid energy solutions that we can get more added value. Conventional generators systems could be used as a backup or as energy storage in order to be able to power military forces in a constant way during operations. Smart hybrid grids and the HPGS are just some examples of hybrid solutions that could be employed in expeditionary contexts exploiting RES sources and traditional generators.

Solar energy, mostly in PV technology, can represent a viable solution when used in certain applications. PV systems are not well suited for all power applications, but in individual warfighter equipment (like communications equipment optics, lighting or sensors), such as the mentioned SPACES and the Battlefield Military Solar Lights Tower, PVs outclass other energy technologies. PV technologies have reached a certain level of development that enable them to be modular, mobile, easily portable, deployable and redeployable for remote operations.

Furthermore, new energy technologies need a close cooperation between the consumer (the military) and the producer (the industry) in order to properly advance and build ad hoc solutions for operational fields. The military sector can represent an important source of investment for commercial technologies, in addition to its great role as test bed and early adopter of new energy solutions. Each sector needs the other one in developing new technologies and this "spin-back-and-forth" process can enable technology improvement.

In conclusion, climate change concerns and declining defence budgets are transforming the way military forces operate. By enhancing EE and deploying RE in military operations, NATO forces can operate in a sustainable way and strengthen ES. However, Allies need to be more committed and proactive in implementing new energy technologies. Only through interoperability and sharing best practices NATO could help Allies in agreeing on standards and on integrating new technologies.

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ANNEX

ABBREVIATIONS AND ACRONYMS:

BTU: British Thermal Unit

CAF: Canadian Armed Forces

CJOJ: Canadian Joint Operations Command

CL: Capable Logistician

CPX: Command Post Exercise

DEES: Defence Energy and Environment Strategy

DPTA: Drawsko Pomorskie Training Area

DoD: Department of Defense

EE: Energy Efficiency

EDA: European Defence Agency

EOF: Energy Operational Function

ES: Energy Security

ESCD: Emerging Security Challenges Division

ESGs: Energy Security Goals

EU: European Union

ExFoB: Experimental Forward Operating Base

FBCE: Fully Burdened Cost of Energy

FOB: Forward Operating Bases

GHG: GreenHouse Gas

GREENS: Ground Renewable Expeditionary ENergy System

HPGS: Hybrid Power Generation and management System

IEA: International Energy Agency

IESMA: Innovative Energy Solutions for Military Application

ISAF: International Security Assistance Force

LED: Light-Emitting Diode

MEMS: Mobile Energy Management System

MW: Megawatt

NDN: Northern Distribution Network

OE: Operational Energy

PESCO: Permanent Structured Cooperation

PV: Photovoltaic

RE: Renewable Energy

RES: Renewable Energy Source

SE: Smart Energy

SENT: Smart Energy Team

SFP: Single Fuel Policy

SHES: Smart Hybrid Energy System

SPACES: Solar Portable Alternative Communications Energy System

SPS: Science for Peace and Security

STEEEP: Specialist Team on Energy Efficiency and Environmental Protection