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Future of sustainable military operations under emerging energy and security considerations

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ABSTRACT

Due to limited energy sources and growing concerns about environment, secure, safe and sustainable energy has become one of the Grand Challenges at the global level. Likewise in many other aspects of life, energy is crucial for military forces. In parallel to the changing nature of warfare, the need for energy in military operations has increased dramatically. While energy consumption in the World War II was 1 gal per soldier per day, it was 4 gal per soldier per day during the Desert Storm operation in 1991. Not only the quantity, but also the type of energy required for military operations has changed dramatically. Shifts have been observed from individual man power to machines powered by fuel and electricity. Energy demand and type have changed further through the introduction of more sophisticated devices with new capabilities such as to enable night vision, designate targets with lasers, provide advanced sensing and communication capabilities and reduce human involvement in operations through drones and robotic technologies. Investigating the trends in changing nature of warfare and energy through review, technology mining and scientometrics, the present study develops future scenarios, and a strategic roadmap to identify priority technology areas and strategies for the future military energy R&D.

1. Introduction

Energy is a key component for the existence and continuation of modern societies. The world energy consumption continues to increase and is expected to do so in the decades to come. Primary energy consumption is expected to increase by 37% between 2013 and 2035 with an average annual growth of 1.4%. Although the share of renewables in energy consumption is increasing, coal, oil and gas are still the primary sources of energy (BP, 2015). The military domain is not an exception in terms of its dependency on energy and conventional energy sources despite all technological advancements. The vital importance of military and energy relationship can be understood easily by narrating the recent story of US–Pakistan oil crisis. On November 26, 2011 NATO attacked the Salala post on the Pakistan–Afghanistan border. During the attack 24 Pakistani soldiers were killed. Upset by the casualties, the Government of Pakistan reacted immediately by closing the Ground Lines of Communications for NATO oil supplies into Afghanistan through the port in Karachi and demanded an apology from the US Government. The lack of energy supply paralyzed the operation and unavoidably resulted with the formal apology of the US government on July 3, 2012. Immediately after, an agreement was reached between Pakistan and the closed border was re-opened. According to news report, the border closure costs the US at least $700 million (World News Tomorrow, 2013). This recent event may be considered as a good example to reflect the importance of energy especially for multinational forces. It was not the 'cost' the most critical point in this case, but the 'supply'[1] of energy and thus the 'sustainability' of the military operations.

In parallel to the changing characteristics of warfare, the energy dependency of military operations has increased dramatically. One of the indicators to understand the energy dependency is to look at 'energy consumption', which is one of the domains where comparable data is available. For instance, in the World War II, energy consumption was only 1 gal per day per soldier, whereas in the Desert Storm operation in 1991, this figure quadrupled by reaching 4 gal per day per soldier (LMI Report, 2007). Gaining new and superior capabilities has always been a key aim for operational forces to be powerful and win wars. This goal has so far been realized with more sophisticated machines and devices and resulted with an increasing energy dependency. Today,

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[1] Supply is defined by the US military as "*the procurement, distribution, maintenance while in storage, and salvage of supplies, including the determination of kind and quantity of supplies*" available at: http://www.militaryterms.net/s access date: 15.07.2015).

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a war fighter is considered to need more than 30 W to power his devices, which are designed to increase safety and enhance his combat ability (Seah and Tang, 2011). A dismounted soldier is overburdened with non-standard batteries and it becomes hard to carry them in a fight for a long duration.

Energy demand has been intensified with the developments in electronics with new capabilities such as to enable vision at night, designate targets at a distance with lasers, power small robotic vehicles, and provide sensing and communications. Alongside the individual level, military bases and facilities have also become more energy dependent. All security systems, radars, lightings, communication devices, military vehicles and other equipment are wholly dependent on energy. Consequently, it can be assumed that the absence of energy makes military forces blind and stagnant.

Beyond changing technologies and equipment, the type and nature of warfare and energy have been transforming considerably due to social, economic and political change. Consequently, energy has become even more crucial for the sustainability and success of military operations. The present study aims at analyzing the evolution of the relationships between changing characteristics of warfare and energy demand for military operations. Investigating the trends in both domains, the overall aim of the study is to identify priority technology areas and strategies for the future military energy R&D.

The paper begins with a review of changing characteristics of warfare and the technological developments in the energy domain. First, the review will aim to reveal the relationship between transformations in warfare in terms of changing concepts and technologies and implications of these changes for energy requirements of operational forces. Following, the state-of-the-art in the energy technologies will be analyzed. The energy field has also been developing rapidly. This provides new opportunities for military operations due to the possibilities for the dual use of technologies. Following an evolutionary analysis of military and energy domains independently, attention will be turned more specifically to 'energy research in military'. Next, the methodology of the study will be described. Besides literature review, the study benefits from the bibliometric analysis of energy patents to have a more concrete grasp of the technological evolution in the military energy domain. Following the identification of the technology trends through the bibliometric analysis, future scenarios are developed to demonstrate alternative trajectories of development in the military operations and energy requirements. By developing these scenarios, the study aims to provide new insights for the future military R&D and demonstrate the possible effects of changing operational needs and energy relationship. Further analysis of scenarios will help to outline the priority areas and strategies based on the operational level (i.e. from individual soldier to large military bases) and technological transformation stages of military energy use from short and medium to long runs.

2. Theoretical background

2.1. Changing characteristics of warfare and evolution of military technologies

Clausewitz (1968) defines war as: "*an act of violence to compel our opponent to fulfil our will*" (p. 2). The motivations, shapes, and sizes of wars have changed drastically over time. These changes were observed in the key characteristics of a war outlined in Clausewitz's definition, including 'opponent', 'violence' and 'will'. As the characteristics of war have changed, so have its definitions. A recent definition from Kaldor (2010) reflects the key characteristics of today's war: "*War is an act of violence involving two or more organized groups framed in political terms*". As Kaldor asserted, this definition is a new interpretation of Clausewitz's (1968) and indicates a new characteristic of warfare with the involvement of increasing number of actors in warfare.

Examining the evolution of wars through time, scholars such as Lind et al. (1989) and Hammes (2005) have identified three generations of warfare and propose a fourth one for future wars. Each generation is presented in relation to the type of energy demand as there seems to be close correlation between changing concepts and energy use. First generation is described as the "*tactics of line and column*". In this period, the power of armies was represented based on the calculation of number of barrels. Higher quantity of barrels represented higher power and keeping the line meant maximizing the firepower. van Creveld (1989) classifies this period from 2000 B.C. to 1500 A.C. and emphasizes that during this period, most military technology utilized its energy from muscles of men and animals.

Second generation's distinction came with the more intensive use of technology, higher mobilization, and the power of indirect fires (artillery). The shift from manpower to mass destructive power differentiated these first two generations. History of military technology describes this stage from 1500 to 1830 and calls it as "*the age of the machines*". During this period the military operations were characterized by mobilization, coordination and communication, which raised the need for energy dramatically (van Creveld, 1989).

Third generation is identified with "*Blitzkrieg*". According to Lind et al. (1989), in contrast to second generation's technology-driven aspect, the motivation in the third generation was 'ideas' and 'tactics'. Germany's superiority in developing novel tactics was seen as a radical development. Lind et al. (1989) explained this superiority with an offensive viewpoint as an "*attack relied on infiltration to bypass and collapse the enemy's combat forces rather than seeking to close with and destroy them*" and with defensive viewpoint as "*the defense was in depth and often invited penetration, which set the enemy up for a counterattack*" (p. 23). The history of military technology calls this stage as "*the age of systems*" and emphasizes the integration of technology into complex networks. The use of tanks, railways, highways, and improved means of logistics made this stage more complex with increasing integration. Hence, energy supply to military units became more critical than before for sustaining the ongoing operations.

The aforementioned generations are mainly concerned with the historical evolution of wars, but what about the present and the future? van Creveld (1989) describes the present state as "*the age of automation*". According to van Creveld (1989), after 1945, rapid technological progress and innovation have increased the amount of information needed for running military units, making online decisions, carrying out missions, and conducting operations, campaigns, or wars. This vast amount of information naturally required 'computerization' and a 'network structure' for the communication with the soldiers in the theater and dissemination of information to wider public. There is a greater demand for the seamless flow and diffusion of information between military units and other actors involved in wars. This continuous flow depends very much on the availability of energy sources and uninterrupted supply.

In addition to transformations due to technological progress, recent history has also witnessed the emergence of new war concepts. Besides the conflicts where nations used their own military powers individually, more recently an increasing number of operations have been witnessed, where international powers such as NATO and UN, or several allied forces involved to provide regional stabilization. In the cases, where the opponent party is not a nation and their capabilities are limited, an 'asymmetry' emerged between the sides involved. Due to this characteristic, this phenomenon has been called as "*asymmetric warfare*" (Grange, 2000), which is described by Arreguín-Toft (2001) as how the weak win wars. For the international level interventions, multinational forces are deployed temporarily to provide the regional stabilization until the host nation gains power and control. Because of the involvement of large number of multinational forces with international headquarters, bases, and troops, these multinational operations demand increased communication and coordination. Furthermore, due to the fact that the opponents are not organized as formal forces they may be distributed in largely populated urban areas or rural areas with difficult geographical conditions. This new asymmetric war context brings additional demand for increased flexibility, mobility, and networking of smaller and more distributed forces and introduces new challenges for communication, coordination and energy supply for sustainable and successful operations.

Regarding the future, Lind et al. (1989) and Hammes (2005) propose a "Fourth Generation Warfare". According to their views, the fourth generation can be considered as a twilight zone between war and peace, between civilian and military, and between tactics and strategy. Despite the counter-arguments for the existence of a fourth generation (Freedman, 2005 & Junio, 2009), it is generally accepted among the international security scholars that the characteristics of warfare are changing in an ever more complex context. Therefore, the main problem is how to handle the conflicts and ensure operational success in this new landscape.

To sum up, whereas the broad conception of war, 'violence,' has remained the same across time, the 'means' and 'ends' of wars have evolved fundamentally due to changing social, technological, economic and political systems, and specific concepts and technologies used by operational forces. By reviewing historical trend, Hegre et al. (2013) predicted that global incidence of conflict is likely to continue to decrease from the current level and probably the number of countries involved in conflicts will be halved by 2050. The study also concludes that over the next few decades, an increasing proportion of conflicts will occur in East, Central, and Southern Africa as well as in East and South Asia. This conclusion indicates that armed conflicts would still be on the socio-economic and political agenda as decades to come. What is noteworthy is that as the characteristics of wars have changed the type and quantity of energy required has changed from manpower to conventional energy sources like oil and gas and more recently towards more sustainable and renewable energy sources for increased efficiency, easier access and faster supply. The following section of the paper takes a closer look into recent developments in the energy domain. Breakthroughs in energy will certainly provide new opportunities for military forces and operations. Thus, it will be possible to discuss how the diversity and mix of energy sources will enable military operations in different concepts and scales will be the core discussion of the present paper.

2.2. Energy

The search of "energy" keyword in Google Scholar results with approximately 6,660,000 records, which is just one of the indicators of the criticality of the topic and widespread discussions around it. The energy ecosystem is very large and complex and therefore should be considered in a systematic way. In order to have a better grasp of the field, the present paper focuses on three sub-domains under energy with their distinct characteristics, challenges as well as unique research and technology development processes, including: (i) energy generation, (ii) energy storage, and (iii) energy transfer. Energy generation is concerned with the conversion of conventional and renewable energy sources into various forms of energy to be used by military bases, vehicles, machinery and other equipment. The next challenge is to store the energy generated to be consumed whenever needed during military operations, which may be remote from the sites, where energy is generated. Furthermore, energy storage is particularly crucial for the use of renewables, such as wind, wave and solar, which may not be stable and constant sources of energy. According to Hall and Bain (2008), the inherent intermittency of supply of energy generated from renewable sources requires a step-change in energy storage. Finally, energy generated and stored should be transferred for final use during military operations. A wide variety of energy transfer technologies are available ranging from pipelines, ships, trains, and trucks for fossil fuels, and power grids as well as more advanced wireless energy transfer technologies, which can supply energy to a particular location, at a particular amount and for a particular duration depending on the requirements of the operations. This will be considered in the third section, energy transfer.

The following sections aim at reviewing the broad range of technological developments for generation, storage and transfer respectively, which can be found in the energy literature. Technologies are presented and compared to support the subsequent sections of the paper where discussions will be undertaken to explore relevant and promising energy technologies for future military operations and changing characteristics of warfare.

2.2.1. Energy generation

Energy generation technologies are studied widely by many researchers. Besides the conventional energy sources, an increasing focus is observed on renewable sources with less or no environmental damage. In his study, Stein (2013) ranks the energy generation technologies by using multi-criteria decision making methods and proposed the following energy generation technology alternatives: wind, solar, hydro, geothermal, biomass, nuclear, coal, oil, and gas. Among the sources of energy, the role of renewables continues to increase in the electricity, heating and cooling and transport sectors (IEA, 2014). The present study posits that energy use in military operations will follow the similar trend and the share of renewables will increase dramatically in the coming decades. This will allow more sustainable, environmentally friendly and more efficient military operations.

Comparing different alternatives of renewables, Stein (2013) ranks wind as the highest among other energy generation technologies according to financial, technical, environmental and socio-economic-political criteria. On the global scale, the International Energy Association (IEA) estimated a global wind potential of 40,000 TWh/year (Evans et al., 2009) and wind capacity has been growing at 20–30% per year for decades. In addition, according to Delinea and Diesendorf (2013), wind technology is widespread because of the ease of setting up power plants for energy production.

Besides wind, solar power is the second highly ranking source of energy. Within solar energy generation, photovoltaic systems appear to be important sources for using abundant energy available from the sun. It is known that Earth intercepts over 170,000 TWh/year from the sun with irradiation varying greatly according to location and season. Among all, biomass appears to be a widely studied subject. It refers to any plant-derived organic matter available on a renewable basis, including dedicated energy crops, trees, feed crops, agricultural crop wastes and residues, aquatic plants, animal waste, and municipal waste. By harnessing energy without emitting carbon dioxide, the renewable technologies reduce the environmental impact to a minimum level.

One of the key challenges against the widespread use of renewable technologies is that they pose storage problems. For instance, despite the very high potentials of use, photovoltaics are currently limited by storage complications during nights and cloudy days when the sun cannot power the solar cells (Evans et al., 2009). Therefore, storage becomes an important challenge to address.

2.2.2. Energy storage

A wide variety of technologies are available for energy storage with their pros and cons. Hadjipaschalis et al. (2009) identify six categories for energy technologies: (1) flywheel technologies, (2) battery storage technologies, (3) supercapacitor storage technologies, (4) hydrogen storage technologies, (5) pneumatic storage technologies, and (6) pumped storage technologies. These technologies can be compared according to discharge time and rated power by Electricity Storage Association (ESA) as demonstrated in Fig. 1.

The product of duration and power is energy storage capacity, and thus Fig. 1 shows that Pumped hydro storage (PSH) and Compressed Air Energy Storage (CAES[2]) are used in large energy storage projects, Flywheels (FW) and Electrochemical Double Layer Capacitors (EDLC) are used in small energy storage projects, and batteries (all remaining abbreviations) are used in medium energy storage projects with extensions into the small and large categories. Leadbetter and Swan (2012) recommended sodium–sulfur (NaS) and vanadium redox battery

[2] These are called also as pneumatic storage technologies; see also Hadjipaschalis et al. (2009).

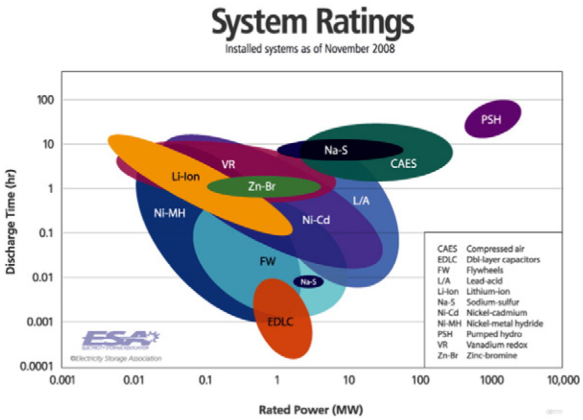

Fig. 1. Comparison of storage technologies (ESA, 2013).

(VRB) applications for battery energy storage technologies to meet specific grid services for a long duration. This finding can be interpreted as an important result for future grid services that are supported by the battery systems. Grid level energy storage systems are considered to be a cornerstone for future power networks and smart grid development.

In addition to discharge time and rated power comparison, Electricity Storage Association (ESA) compared storage technologies according to their advantages and disadvantages, which can be seen in Table 1.

When Table 1 is examined, it can be seen that pumped storage and CAES have the advantages of high capacity and low cost. However, special geographical sites are needed to construct this kind of systems, which makes it difficult for the portable use of these options during an operation. As the present study focuses on military energy systems, portability and flexibility are considered to be the two main concerns. From this perspective, NaS, Li-ion and Ni–Cd are considered to be more crucial, though they too have their advantages and disadvantages as illustrated in Table 1. For the final use, it is not enough to generate and store energy. There is a need to transfer energy to the sites, where it will be used.

2.2.3. Energy transfer

In order to increase efficiency, energy distribution networks must exploit new materials and advanced logistics systems. Aliberti and Bruen (2007) overviews advanced technologies in energy distribution and the design and production of smart grids and microgrids in detail. A more recent option in energy transfer is a wireless energy technology, which appears to be a potentially convenient and increasingly secure delivery option. Although mentioned more frequently recently, the wireless transfer technology can be traced back to Heinrich Hertz (McSpadden et al., 1996) and Nikola Tesla (1914) in history. Tesla claimed that electricity can be transferred wirelessly at 95% efficiency. Despite its premises, Tesla's technology had to be shelved because of the negative effects of transmitting such high voltages. Electric arcs generated during this process would have been disastrous to human and electric vicinity. In 2007, long after Tesla's experiments, Soljajic had a breakthrough in the principle of wireless energy transfer and carried out a middle distance wireless transfer by resonance coupling of electromagnetism, where the level of efficiency was about 40% (Kurs et al., 2007). By using electrodynamics induction Soljajic successfully powered a 60 W bulb wirelessly from a distance of 2 m. Called by Soljajic as Witricity, this scheme is non-radiative and anti-jamming. According to Visser and Vullers (2013) the far-field energy transmission issue requires a different concept than Witricity. For instance, energy can be transmitted from energy source to equipment by broadcasting the energy through rectennas. Among the cons of this technology are its health impacts. There are national restrictions regarding this issue (Visser and Vullers, 2013).

Table 1
Advantages and disadvantages of storage technologies (ESA, 2013).

Storage technologies	Main advantages	Disadvantages
Pumped storage	High capacity, low cost	Special site requirement
CAES	High capacity, low cost	Special site requirement, need gas fuel
Flow batteries: PSB VRB ZnBr	High capacity, independent power and energy ratings	Low energy density
Metal–air	Very high energy density	Electric charging is difficult
NaS	High power & energy densities, high efficiency	Production cost, safety concerns (addressed in design)
Li-ion	High power & energy densities, high efficiency	High production cost, requires special charging circuit
Ni–Cd	High power & energy densities, high efficiency	
Other advanced batteries	High power & energy densities, high efficiency	High production cost
Lead–acid	Low capital cost	Limited cycle life when deeply discharged
Flywheels	High power	Low energy density
SMES, DSMES	High power	Low energy density, high production cost
E.C. capacitors	Long cycle life, high efficiency	Low energy density

It is apparent that classifying generation, storage, and transfer technologies is useful for surveying relevant literature more systematically. However, it is important to underline that these technologies cannot be developed independent from each other and should be considered in a complementary stance in an ecosystem of energy. In the scope of the present study, the energy ecosystem will be described with the context of military operations.

2.3. Energy use in military operations

Trend towards rapid technological developments in mechanization, automation and communication continuously changes the nature of warfare, while increasing the critical importance of energy for military operations. This trend has accelerated significantly since the end of the World War II. Studying the mechanization of warfare, Closson (2013) identifies three dimensions with impacts on energy demand, including cost, combat, and climate. According to Deloitte (2009), from the Vietnam War to the operations in Afghanistan, energy demand in wartime has increased 175% per US soldier per day. She argues that the oil dependency impacts the combat effectiveness and causes higher combat casualty. Moreover, modern designs of military products have introduced new 'energy-starving' war machines such as tanks, warplanes and warships. For instance, the M1 Abrams Main Battle Tank needs the fuel capacity of 498 gal (1885 l)/505 gal (1907 l) for cruising ranges of 265/275 miles (426/443 km).[3]

Therefore, while technological evolution creates Revolution in Military Affairs (Krepinevich and Andrew, 1992) and promises greater opportunities for victory, energy remains as one of the key areas for keeping this promise. To be self-sufficient in energy to provide logistical support and uninterrupted operations is a challenge for military operations (Stein, 2009). The increasing dependency on high-technology equipment in military operations enhances this challenge further.

According to the LMI Report (2007), challenges in energy breakthrough should be handled with a range of incremental to breakthrough innovations in different time horizons. The report identified the following three phases for the US Defence system: (1) identify organizational and process changes that can be implemented immediately; (2) identify engineered solutions to improve the efficiency of current forces and those nearing acquisition using existing technology; and (3) invent new

[3] Available at: http://www.globalsecurity.org/military/systems/ground/m1-specs.htm (last visited on: August 06, 2015).

capabilities, employed in new operational concepts, for those technologies yet to be developed. Literature review reveals that there are a number of efforts at all these levels. Government sponsored real-time R&D studies increase the possibilities for intensive research in the energy domain. An important point to note is that energy research in military should not been seen merely from the technological point of view, but within broader framework conditions. Budgetary constraints make national bodies to think about more cost-effective ways of obtaining and using energy. However, more recently it became clear that cost is not the only factor. According to Horton (2011), for instance, sustainability paradigm is a critical factor in military energy research. She describes environment as a consistent source and victim of war beyond its capacity to regenerate itself. There is an increasing need for military R&D strategists to revise their assumptions about the environment in terms of resource use and impact. It is considered that in the future, not only the changing nature of operations will affect the military energy strategies, but also boarder expectations of the society and ecology. In summary, research and technology development about military and energy should consider military technologies, human, and energy resources in a holistic way.

3. Methodology

This study investigates the increasing dependency between military operations and energy and develops future scenarios and strategies on the direction of developments in this relationship to propose an agenda for the future military energy R&D. For this purpose, a research methodology was designed with the combination of qualitative and quantitative methods as illustrated in Fig. 2.

The study first involved a *literature review*, which aimed to describe the changing characteristics of military concepts and technologies with their implications for energy demand in operations. On the supply side, recent developments in the energy generation, storage and transfer technologies were summarized. Building upon this background, a *patent analysis* was conducted to identify trends in the military energy domain. The patent analysis method has been used at length to understand the invention and innovation processes (Schmookler, 1966; Griliches, 1990) and to recognize technology patterns (Porter and Newman, 2011). There are a number of different uses of patent data such as the analysis of the time-lag between the allocation of research funds and patent issues (Daim et al, 2007); to assess innovation diffusion (Nelson, 2009); or predicting the future directions of technological development (Choi et al., 2011). The patent analysis in the current study was performed with the use of the Vantage Point software (Watts et al., 1997).

Trends in the changing characteristics of warfare identified through the literature review were cross-fertilized with the trends in the energy generation, storage and transfer technologies to build future *scenarios*. Scenarios are presented as future narratives to anticipate the future. In this way, scenarios are expected to help direct attention to driving forces, possible avenues of evolution, and span of contingencies that may be confronted (Saritas and Aylen, 2010). Various typologies have been proposed for the development of scenarios, including (Miles, 2007):

1. Profile or matrix scenarios with the cross-fertilization of the extremes of two key trends, drivers or uncertainties. These are usually represented around a 2 × 2 matrix
2. Archetype scenarios, where α, β and δ scenarios are developed to represent 'business as usual', negative and visionary scenarios respectively
3. Success scenario, which explains a single normative scenario.

The present study made use of the profile/matrix scenarios by cross-fertilizing key trends in military concepts and energy use, and developed four scenarios, which are described in the subsequent sections of the paper. Following the description of the images of the future through scenarios, a roadmap is provided to explain the process of transformation in military energy use. Roadmaps are frequently used technology management, strategic and operational decision making and action planning. It is a normative and goal oriented method, where attempts are made to achieve a desired future state of development (Phaal et al., 2004). In the present study, the roadmap developed identifies priority technology areas and strategies for the future military energy R&D in three stages to cover near term, medium-term and long-term futures.

The study also benefited from expert consultations throughout. Experts were particularly instrumental in the patent analysis phase to identify the key technological developments and trends. They were

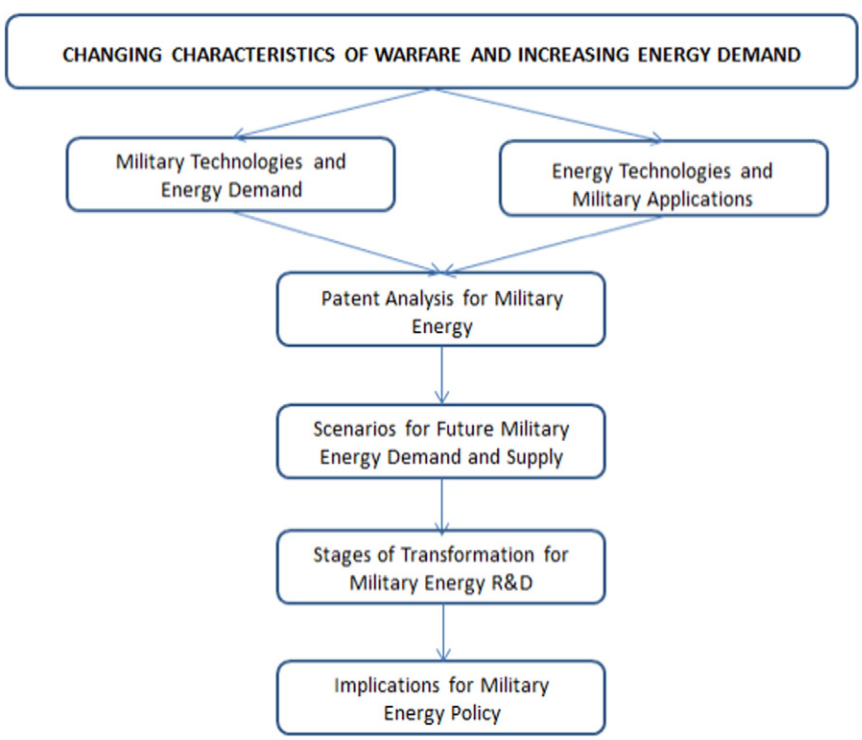

Fig. 2. Research model.

also consulted during the scenario development phase during the selection of the key dimensions of the scenario axes and development of the scenario narratives. Five experts were nominated from the ones with specialization on military strategy and policy, as well as international relations. Their names are kept anonymous as they were on-duty when the study was undertaken. Scenarios were further reviewed by two independent scholars for plausibility and coherence.

Following the description of the methodology, the subsequent section of the paper begins with the presentation of the military energy trends identified through the bibliometric analysis.

4. Military energy trends

In order to characterize the evolution of developments in the field of military energy, a patent-based trend analysis was conducted. All patents in the Derwent patent database (from 1962 to the present) were searched with 'military' and 'energy' keywords. The search yielded 3000 patents registered. A content analysis of the patents generated 55,305 phrases in the field. Through data cleaning, Natural Language Processing and expert consultations this number was reduced to 264 most frequent phrases. A clustering with the use of the Principal Components Decomposition function of the Vantage Point software reduced the total number of phrases to 104. Following various iterations of the cleaning, processing and clustering along with expert consultations; the seventh round of the analysis resulted in 32 phrases with the coverage rate of 33% of the total number of patents generated (i.e. 3000). This rate of representation was considered to be sufficient in terms of cost-efficiency and high level of descriptive capacity of the whole set of phrases. The final list of 32 phrases is given in Table 2.

For the analysis of trends it would be useful to look at the distribution of these terms across a timeline as illustrated in Fig. 3.

It can be seen in Fig. 3 that the number of patent registrations remained pretty much stable from 1993 till the beginning of 2000s. From the year 2002, however, a dramatic increase is observed in almost all the areas selected above. The sudden increase in patent registrations starting from 2002 can be interpreted as the beginning of a 'new energy-intensive period' in military R&D with the key drivers being efficiency, sustainability and mobility. This trend continues to increase by getting steeper up until the present time. When the figure is analyzed in detail, it can be seen that recent patents registered can be grouped under generation, storage and transfer categories as described earlier in the review section. The following sections will take a closer look of the military energy trends under these three categories.

4.1. Energy generation

Key military energy phrases identified for the energy generation are shown in Fig. 4 with their annual percentage distribution among all the patents registered. This illustration allows a proportional comparison of technologies in energy generation.

In the figure, a clear trend is observed towards a greater mix of sources for energy generation. This can be observed when the number of patent registrations is compared from the 1990s to the 2010s. While only two topics were covered by the patents in 1994, the number increased to over 10 topics in 2011. Regarding the types of energy, the figure depicts that the highest percentage of patents has been registered in the field of 'electric energy'. This is followed by 'natural gas' and 'nuclear energy'. Electric energy still keeps its dominant position in the patent registrations. This may be somewhat expected as most of the devices and equipment used both for civilian and military purposes today are powered with the electric energy. However, the ways electricity is transformed, generated and accumulated by using increasingly diverse set of sources should also be noted. As illustrated in Fig. 4, 'acoustic energy', 'natural gas' and 'nuclear energy' can be mentioned among those frequently used sources to generate energy. The search for alternative sources for energy brought alternative forms of generation on the agenda in recent years including 'radiation energy', 'photon energy' and 'fluid energy'. The mix of sources and ways for energy generation is expected to grow in the future.

Table 2
Key phrases identified for patent analysis.

	Energy phrases	Number of instances
1	Electric energy	379
2	Battery power sources	204
3	Energy storage device	133
4	Fuel cell	92
5	Laser energy	88
6	Thermal energy	82
7	Solar energy	68
8	Power converter	50
9	Natural gas	46
10	Nuclear energy	43
11	Optical energy	30
12	Wind energy	25
13	Wireless power transfer system	24
14	Wave energy system	22
15	Photovoltaic cell	19
16	Thermoelectric device	18
17	Acoustic energy	16
18	Hydrocarbon fuel	14
19	Portable energy source	14
20	Electrochemical cell	12
21	Renewable energy source	12
22	Infrared energy	11
23	Absorbing reflected energy	6
24	Chemical energy	6
25	Reflected energy	6
26	Ultrasonic energy	6
27	Electric double layer capacitor	5
28	Fluid energy	5
29	Alternative energy	4
30	Photon energy	4
31	Radiating electromagnetic energy	4
32	Radiation energy	4

The increasing demand for clean and sustainable energy generation resulted with a more focused research for 'renewables'. Renewables have gained particular importance for military to provide continuity and security of operations by using diverse sources of energy, which would be harvested from the ambient environment without long, costly and insecure supply chains. Therefore, it is useful take a closer look at the renewables as an emerging area of research.

Fig. 5 illustrates the most frequently studied areas in the field of renewable energy generation in military with the breakdown of technologies.

Solar, thermal and wind energies are the most referred technologies in patents. While solar and thermal have been the most widely studied areas in earlier years, it is noted that wind as a source of energy has been increasingly covered in recent years.

However, it should be borne in mind that despite the increasing emphasis on renewables, these technologies are still far from powering equipment with high power demand. For instance, Macdonald (2012) asserted that powering an Abrams tank engine would require a solar array of 5 ha, and similarly powering an F4 fighter plane would require an array of 117 ha, which means to cover about a hundred football fields of solar panels, under which is suspended a cockpit. This means that today's technology is not yet applicable to use these resources to power conventional battle equipment. Technological advancements are expected to provide greater opportunities for the more efficient use of renewables in the coming decade or two.

4.2. Energy storage

Energy generated should be stored in a suitable way depending on the type of energy sources. Therefore, in parallel to energy generation

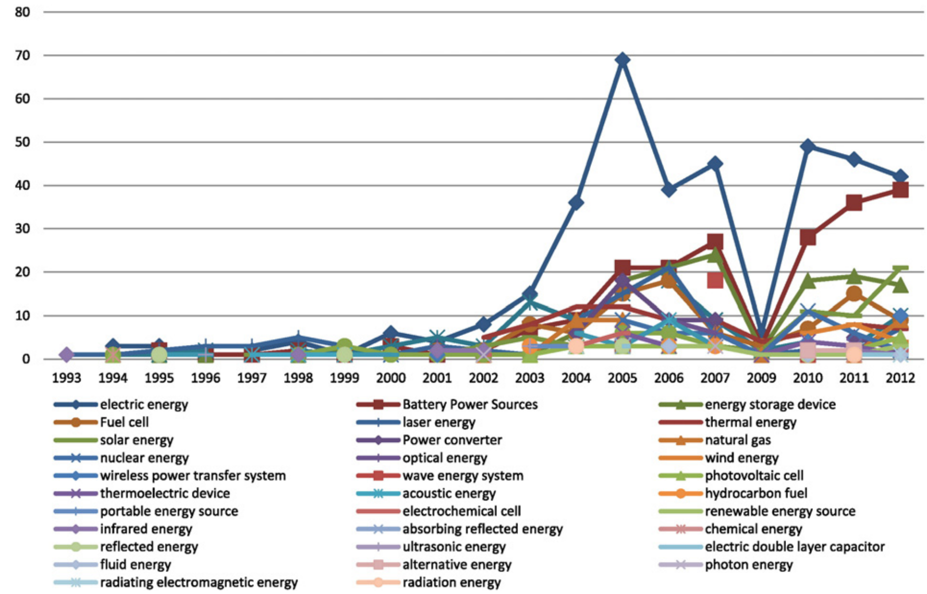

Fig. 3. Trends for military energy patents.

technologies, the scope and sophistication of research on energy storage technologies in military are increasing (Fig. 6).

The increasing diversity of energy generation technologies brings a wider range of energy storage technologies on the research agenda. As Fig. 6 illustrates, battery technologies are the most widely covered area in energy storage. Hence, energy storage devices can also be considered largely in association with the battery technologies. A wide variety of battery technologies are currently used to power devices through a chemical reaction with the use of lithium, zinc or manganese. Although research on battery technologies continue as a means of energy storage, starting from the 2000s considerable research activity is dedicated for fuel cells. This is because of the need for continuous replacement and recharging of batteries, and limitations for the use of renewable energies. Fuel cells are devices that convert the chemical energy of a fuel (such as hydrogen, natural gas, methanol, or gasoline) and an oxidant (such as air oxygen) into electricity; these cells can be accepted as batteries either. However, unlike batteries, fuel cells are designed for continuous replenishment of the reactants consumed. This may be a limitation for the use of fuel cells in certain military operations. For instance, batteries might still be needed to power lightweight devices for the use of individual soldier and can be recharged using ambient sources, such as with the use of solar panels. However, fuel cells might have wider use in forward operation bases and main bases. According to Aliberti and Bruen (2007) using hydrogen in fuel cells will change this situation and fuel cells will enable information systems to function reliably and efficiently during lengthy battlefields.

The next important concern in the military energy domain is energy transfer.

4.3. Energy transfer

Energy transfer is concerned with the transportation of energy to the final user or to another energy storage facility. Technologies covered by the military energy patents related to energy transfer are indicated in Fig. 7.

Fig. 7 illustrates that the 'laser energy transfer systems' have been focused across a number of years. Laser technologies have been used in a wide variety of areas ranging from biotechnologies to weapon systems. The figure also shows that there are a number of innovative ideas emerging in energy transfer. For instance, a significant emphasis is observed on the 'wireless energy transfer systems', which was initially covered in the year 2001 with an increasing weight in 2012.

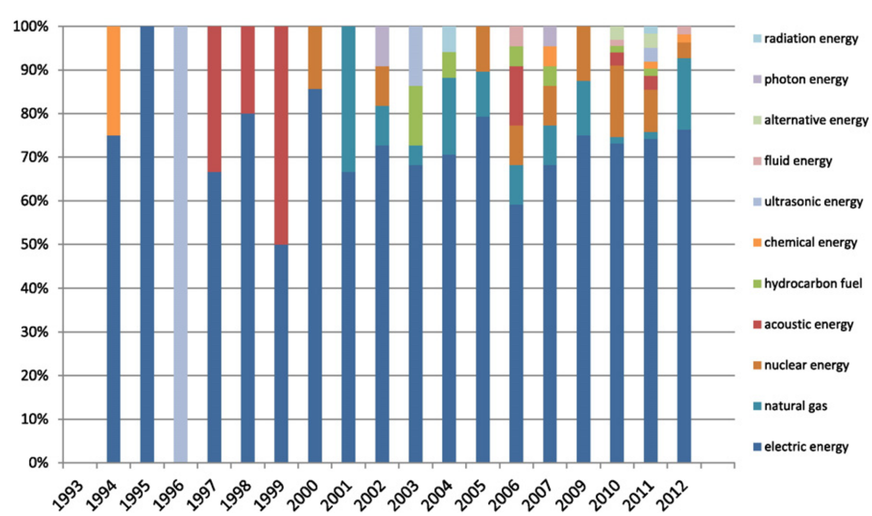

Fig. 4. Energy generation technologies.

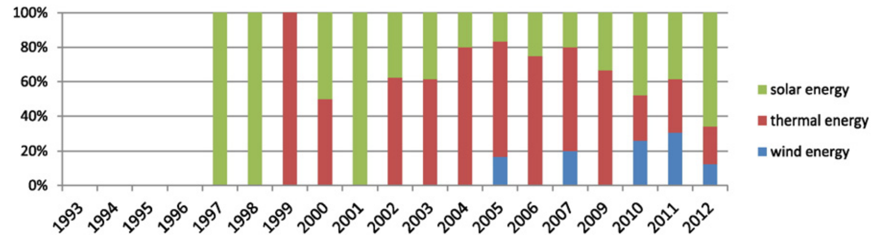

Fig. 5. Renewable energy technologies.

An important concern increasing in the energy transfer domain is to achieve an optimum supply at the right time, place and amount as required. Aforementioned research conducted by Soljajic (Kurs et al., 2007) is expected to have high impact to address these energy supply concerns.

In relation to energy use in military, 'energy transformation' is also considered to be crucial in parallel to the use of diverse energy generation, storage and transfer technologies. Therefore, 'power converter technologies' are expected to be focused more and more in the years to come.

Following the review of the changing characteristics of war and identification of the key trends and emerging technologies in the military energy domain through the patent analysis, the next section will discuss future energy uses in military by developing a set of scenarios.

5. Future scenarios

Scenarios are developed based on the trends and drivers of change identified through the work presented above. Among those two most important ones with high potentials of shaping the future of military landscape and energy use were selected through the consultations with the experts, including: the 'nature of military operations' and the 'intensity of energy use'.

The changing nature of war indicates that the context of war is diversifying and evolving. A greater number of conflicts are observed within states, which indicates a shift from 'inter-state wars' towards 'wars-in-state'. An increasing number of counter-insurgency operations are observed in the world. Two varieties of such operations can be mentioned. The first one is a counter-insurgency operation, where individual countries undertake operations within the country to provide stability by using their own capacity. The second type indicates a larger scale operation, which involves international governmental organizations like the UN, NATO or allied forces of individual states embarking upon a multi-national operation in individual states.

At the national level, the instances of insurgency are usually limited in frequency and scale. These operations involve smaller and more distributed forces to intervene into insurgency cases, in most cases instantly. This operation style is frequently applied to deal with smaller terrorist or rebellion groups within urban or rural areas. In these cases, typically one or more mission-oriented small-scale team of forces act to accomplish a task. These forces operate rather remotely and sometimes autonomously. They may not stay on the field continuously and can return to bases or smaller scale stations at certain frequencies and may be replaced by other teams. What is important in this type of counter-insurgency operation is to ensure the sustainability of the operation without interruption. Success criterion in this case is to be durable and to remain on the battlefield longer than the opponent. Continuous control and support of personnel and energy sources can be considered as a force multiplier.

On the contrary, the operations with the involvement of multi-national forces are much larger in scale with the mobilization of large amount of personnel and resources, and thus require more complex planning and organization. Not only these forces undertake the mission of peacekeeping, but also frequently conduct the task of reconstruction. Therefore, these operations involve larger number of military personnel, typically from different countries. Naturally, energy requirement of these forces will be fundamentally different by type and scale from the smaller-scale team-size operations.

Energy use in military will vary according to the operational demand arising. The variations may be high and low energy intensities in conjunction with the type of operation. The smaller scale and more flexible forces of counter-insurgency operations will require less but more distributed energy sources. On the contrary, large headquarters and higher number of units and personnel involved in multi-national operations will demand higher amount of energy in a fully-fledged and coordinated power structure. Besides undertaking operations, merely maintaining the daily life in such multi-national bases requires considerable amount of energy. Thus, the type and intensity of energy required in each type of operation may also vary depending on the size, location and time required.

Following these deliberations, a scenario matrix was produced based on the two key drivers of military energy R&D: 'nature of military operations' and 'intensity of energy use' (Fig. 8).

As the figure illustrates each driver axis has two dimensions. Counter-insurgency and multi-national operations represent the dimensions of 'nature of military operations'. Operations in real life may involve some combinations of these two types. Therefore, they may not completely contrast each other. For instance, multi-national operations may also involve smaller scale operations for reconnaissance

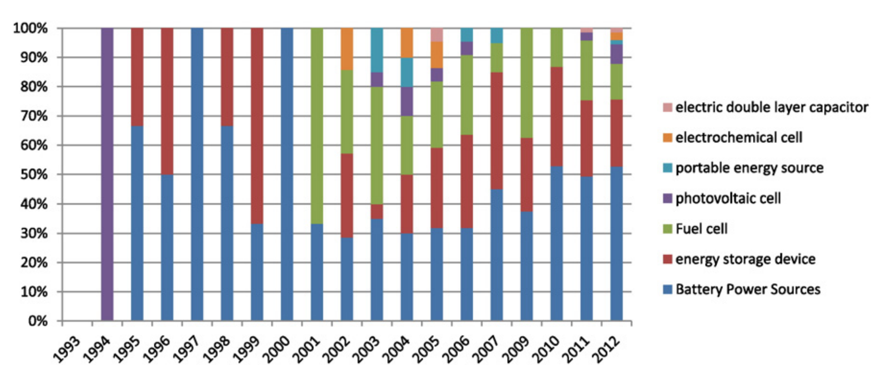

Fig. 6. Energy storage technologies.

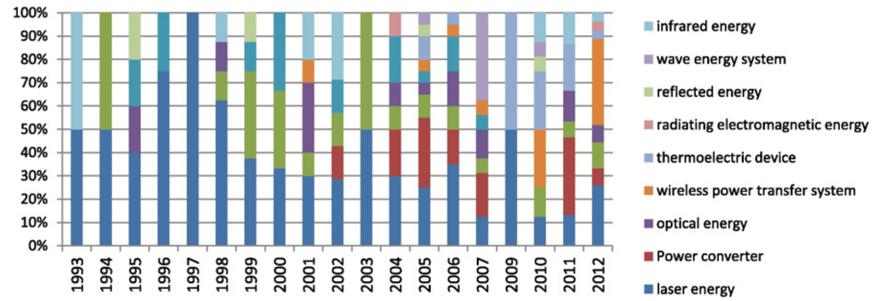

Fig. 7. Energy transfer technologies.

and control missions. However, there is usually a larger force behind, which remains stagnant until a stable state is achieved in the host country. Accordingly, the differentiation between counter-insurgency and multi-national operations reflects the aforementioned distinction between the small-scale distributed/networked operations and large-scale centralized ones.

As discussed earlier different types of operations will have different types and levels of energy demand. These are distinguished as high- and low-capacity operations. Four scenarios were generated with the cross-fertilization of the nature of military operations and energy use, including:

1. "Main operation bases": High-capacity — Multi-national operations scenario
2. "Forward operation bases": Low-capacity — Multi-national operations scenario
3. "Rural forces": Low-capacity — Counter-insurgency operations scenario
4. "Urban forces": High-capacity — Counter-insurgency operations scenario

Each scenario narrative describes a particular operation type drawing upon the literature review and discussion, combined with the sorts of emerging energy generation, storage and transfer technologies. Following the description of each scenario, these stages of technology development and deployment will be described in a in a strategic roadmap through a transformative process from the present towards desirable future visions with the examples of potential and emerging technologies.

5.1. "Main operation bases": high-capacity — multi-national operations scenario

Multi-national operations are the ones, where large-scale military forces assembled from different countries undertake operations typically in distant geographies and cultures with the challenges of communication, coordination and adaptation. A wide variety of technological equipment for the use of bases and operations make energy supply crucial for the sustainability and success of these operations.

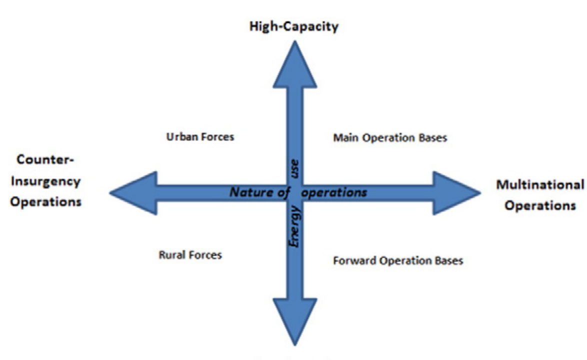

Fig. 8. Scenario matrix.

As in the aforementioned case of the Salala incident, even for the most modern military bases, currently, energy supply is provided through the convoys of fuel trucks in a very conventional way. Fuel is then used as it is or converted to electric energy through generators.

The main operation bases scenario suggests that moving towards the future, military bases should gain the capability of generating mass energy. Critical technologies for this scenario include: (1) solar, wind and waste energy generation technologies; (2) high-capacity and high-density energy storage technologies with limited space requirements; and (3) smart grids and wireless energy transfer technologies to transfer energy from remote sources and to longer distances.

Renewable energy sources are considered to be crucial for this purpose. Among those, waste, wind and solar energy appear to be the most promising ones. A suitable combination of them can be created for a sustainable energy system. For instance, high altitude autonomous wind power systems can be set up. Energy generated can be transferred to the base through wireless energy transfer systems, which can potentially play a critical role in this new energy ecosystem. Military units when undertaking exploration or civil operations may benefit from these technologies when they are on the field outside the base. Wireless systems can also be used to power remote preventive sensor systems. In addition, solar power systems and energy produced from waste can be used to meet the daily operational demand of the base. High capacity energy storage systems like NaS can be combined with smart grid technologies to provide 'energy supply on demand'.

With the possibility of using diverse and substitutional energy sources, the amount 'safety-stock', which is currently required due to vulnerabilities in energy supply, can be reduced. Energy-autonomous military bases will be more flexible regarding location, positioning and mobility. Moreover, cleaner, safer and sustainable energy sources will reduce negative environmental impacts of operations; reduce the number of security personnel responsible for the energy supply; minimize improvised explosive device threats to supply convoys; and will reinforce the humanitarian profile of the operations.

5.2. "Forward operation bases": low-capacity — multi-national operations scenario

Besides main operation bases, operations undertaken by multinational forces may involve forward operating bases (FOBs). Similar to the ones used for NATO and UN operations, FOBs are usually located far from the main operation base. They are expected to be self-sufficient during their operations to accomplish specific attack, control or security missions. Due to their smaller size with a limited number of personnel, FOBs are in a more vulnerable position. Hence an efficient use of UAV surveillance systems can be considered without locating FOBs geographically dispersed in the country. It is clear that UAV surveillance system will be more efficient and sustainable. However, psychological effect on target population should be considered too beside its efficiency. Critical energy technologies to provide the expectance of self-sufficiency for FOBs include: (1) energy generation technology from renewable sources for the operation of a small to medium scale FOB; (2) medium size energy storage technology with a capacity of storing surplus energy; and (3) wireless energy transfer technology to for the frontier forces. The self-sufficiency of FOBs will provide them flexibility and mobility when they need to be deployed in a short period of time at multiple locations. It is crucial to make these forces as independent of energy supply logistics as possible.

5.3. "Rural forces": low-capacity — counter-insurgency operations scenario

In this type of asymmetric operations, countries use their own conventional forces to undertake an intra-state operation. Different from the previous scenarios, in this scenario the source of conflict is frequently civilian and the opponents are rebels. Consequently, national security forces need to be alert continuously against the outbreak of frequently uncontrolled and unforeseen activities of civilian rebels. Such operations usually take place in rural areas, where rebels are usually based and have an opportunity to organize themselves by taking the advantage of being in far and remote areas. In the event of such a conflict, there is a need for rapid deployment of relatively smaller size of forces into the operation zones. As the rebels have the possibility of changing their places frequently, security forces have to be transferred from one geographical location to another swiftly. As these operations take place momentarily, it is difficult to establish a base with necessary energy infrastructure. Here, the challenge is rather to supply energy to individual soldiers and to make each of them self-sufficient for the sustainability and success of the military operations. Thus, the key technologies for rural forces are considered to be: (1) energy harvesting technologies to supply energy from ambient sources; (2) smaller-size, lightweight and re-chargeable battery technologies; and (3) small scale wireless energy transfer technologies for soldiers to use their weapons and equipment.

Energy harvesting technologies will allow smaller forces to generate their energy in rural and natural environments whenever required. Higher speed of energy extraction from ambient sources will reduce the dependence on larger batteries for energy storage and increase the mobility of forces with less weight. Energy absorbing paints, wearable camouflages, and piezo-electric systems can be mentioned among the energy harvesting technologies. Energy generated should be converted and stored. Wireless energy transfer will also be important at this level. Technologies to enable soldiers in a close-contact operation to receive energy from their detached backpacks wirelessly at the field will provide them a great operational efficiency without carrying an additional load.

5.4. "Urban forces": high-capacity — counter-insurgency operations scenario

In the urban forces scenario, operations take place in urban and residential areas. Likewise in the previous scenario, urban operations are also asymmetric in nature. However, in this scenario, the opponents are less organized members of the society with light or no weapons, but usually come together as large crowds. Due to the location of the operation and nature of the opponents, operations undertaken by urban forces will have different concerns regarding energy generation, storage and transfer: (1) because the operations take place in urban areas, access to energy sources is considered to be relatively easier. Therefore, the dependency on energy generation technologies in this scenario is relatively lower; and (2) similarly, because of the availability of energy in a closer proximity; there is a lesser need for energy storage systems. Storage can be provided by using simpler battery technologies than the other scenarios; and (3) on-demand energy supply can be provided through smart grid systems and smaller scale wireless energy transfer systems. Similar to mobile communication technologies, base stations can be set up in urban areas to transfer energy to the forces scattered around urban and residential areas.

6. Stages of military energy transformation: a roadmap

Due to the nature and speed of technological R&D and the availability of resources, it is expected that the scenarios described above will come into reality in an evolutionary process. Therefore, it is considered to be useful to outline a roadmap to indicate the stages of technological development and application from the present state towards desirable future visions. A matrix structure is proposed to describe the levels of energy use in military and stages of technological development at each level. Scenarios described above suggest that energy use in military will be mainly taking place at three levels:

1. Main-base level
2. Forward operating base level
3. Individual level.

Considering the immediate-term, medium-term and long-term transformations, three stages of development can be mentioned at these three levels as illustrated in Fig. 9.

6.1. Individual level

When an individual soldier level is considered, it can be seen that Stage 1 refers to the present state, where the soldier is using batteries which should be supplied to him/her. In the second stage, the soldier is expected to harvest energy from renewables and other ambient sources and store it in advanced battery systems for daily use. This approach has recently attracted a great deal of interest within both the academic community and industry as a potential way of providing inexhaustible source of energy for low-power devices (Mitcheson et al., 2008). Moreover, developments in mobile and autonomous technologies have increased the attractiveness of harvesting techniques. According to Harb (2011) energy harvesting is an emerging technique for a wide variety of self-powered micro-systems. He identifies several micro-energy harvesting sources as: Motion-vibration or mechanical energy, electromagnetic (RF), thermal, momentum generated by radioactive reactions into electrical energy, pressure gradients, micro-water flow, solar and light, and biological. This classification can also be made at the level of energy sources. From the source point of view, it can be asserted that one source is activities of humans or animals and the other is environment. Harb (2011) asserts that it is hard to make a fair comparison because of the high number of parameters that affect the performance of the generators. However, he notes that vibrations are the most available and the highest power provider sources. There are some special studies for individual harvesting systems. These are;

- Massachusetts Institute of Technology (MIT) has made the electrodes of a lithium ion battery from two common viruses that are benign to humans (Tobacco Mosaic Virus: a common pathogen of tobacco plants; and M13 bacteriophage: a virus which infects bacteria). By spraying these environmentally friendly batteries onto military uniforms, they become wearable power sources and minimize the need to carry cumbersome battery packs.
- In a similar vein, nanotechnology researchers in the Georgia Institute of Technology are developing an energy harvesting shirt that converts the wearer's physical movement into electricity. Known as the 'piezo-electric effect' energy is harvested through mechanical loading and agitations produced by everyday activities such as heartbeats, footsteps, and light wind.
- The UK's "Solar Soldier Project" may be considered as a mixture of this. According to Coxworth (2011) The University of Glasgow is studying on this project and the idea is that during daylight hours, robust solar photovoltaic cells would generate electricity, while at night, thermo-electric devices would do so by harnessing the temperature difference between the soldiers' bodies and the cool outside air.

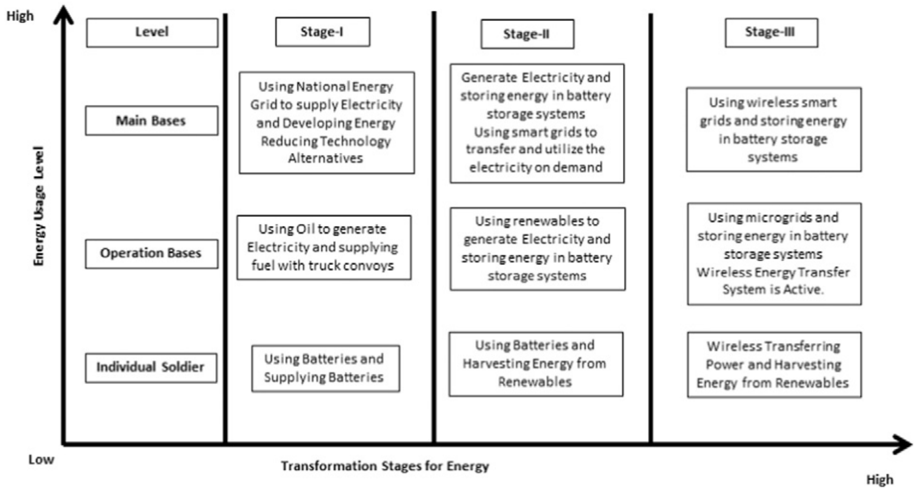

Fig. 9. Stages of military energy transformation.

With examining these cases it can easily be seen that technological R&D is oriented to create self-sufficient soldiers. For an individual soldier, the last step in Stage 3 is considered to be a mixture of harvesting and wireless energy transfer systems to establish an unlimited and uninterrupted energy supply system.

6.2. Operation base level

Following the individual level, next, energy demand is considered at the operation base level. The aforementioned case of Afghanistan can be considered as an example of this level. Supplying oil with trucks can be considered as the first and present stage at this level. However, due to the vulnerability of such energy supply system, operational forces seek ways to reduce the amount of supplies requiring convoys and hence the exposure of the personnel escorting them (Aliberti and Bruen, 2007; Lyons et al., 2011). The second stage of development and the operation base level suggests that these bases generate their own energy according to their operational demand. Portable solar or wind energy systems may be useful technologies for this purpose. According to Seah and Tang (2011), wind energy is one solution to harvest the energy at high altitude with unmanned vehicles and send power back to Earth via nanotube cables. This concept is currently experimented by balloons with future plans to build space-based solar panels.

It is important for operational bases to be portable because the mesh of grid of lines creates frequent failures (Garg and Meena, 2013) in the system and limits the operational flexibility. In addition, it is hard to sustain logistics support for long-range outposts/smaller units in operational environment (Narula, 2013). Even if energy is generated at the base, the lack of affordable and efficient energy storage systems prevent military bases to take full advantage of these renewable systems (Umstattd, 2009).

For operation bases energy storage can be considered with two points of views. One of them is more flexible for the purpose of individual energy needs. It is very important for these systems to be portable and can be carried individually. Moreover, these systems can provide daily energy need in short charging time and have long duration for uninterrupted operations.

The second point of view is concerned mainly with the operation bases. The main important aspect of these systems is capacity. In addition, it is very important for these systems to store alternative energy resources by converting them to appropriate type of energy and for flexibility to be modular. So, the first point of view can be considered for tactical vehicles and individual war fighters, correspondingly, and the second point of view can be considered for high energy consuming military bases. Military bases can be independent by using these kinds of battery systems. This independency provides military bases eliminating the exposure of the soldiers operating the convoys; reducing the logistics burden in the combat support command in terms of manpower and costs; and enhancing the mobility of the bases by reducing their day-by-day dependence on the fixed installations that supply them. According to Lyons et al. (2011) for achieving necessary flexibility and independency military R&D units should concentrate on areas such as bio-inspired large polymeric solar cells, multi-layered nanostructures for new batteries, new membranes with controlled permeability for ions, electrons, or reactant molecules; raising the thermal stability of celluloses for application in biomass conversions, solar photovoltaic technologies, converting solid carbon via pyrolysis to charcoal followed by oxidation by electrolysis in a molten salt.

The third stage for the operation bases should be considered as the mixture of renewables and wireless energy transfer systems under the idea of microgrids. Wireless transmission concept is an important issue and by using wireless energy transfer, operational flexibility can be enhanced; weight of individual soldier can be decreased; uninterrupted energy can be provided for sensors, on which failure might be fatal (Watfa et al., 2008); and the energy can be transmitted to wherever the energy is demanded. Although today's wireless energy transfer technology is not advanced enough, future potentials exist for incorporating energy technologies into military equipment to exploit these technological opportunities for operational forces. This can be considered as an opportunity for dual use of technologies.

6.3. Main bases

Finally, the main bases level implies national bases and is concerned with the national military energy policy. The first stage of development at this level refers to the present situation and it is assumed that military forces try to develop new technologies and applications to reduce energy demand especially in peace time. With the second stage, these bases become more autonomous by using renewable energy sources, high capacity storage systems and smart grids to effective distribution. The third stage explains a mixture of wireless energy transfer systems and intense renewable usage for energy generation.

Consequently, it can be asserted that, fundamental changes are observed in the external contexts of warfare including Societies, Technologies, Economy, Environment, Politics and Values/Cultures (STEEPV). The emergence of learning societies enriched the diversity of lifestyles and levels of development in the world, and as a result increasing 'asymmetry' in the balance of powers. The use of increasing Information and Communication Technologies with an increasing information intensity of daily lives generated various new opportunities. In parallel, the historical review and patent analysis have already given the 'weak signals' of change in the meaning of military power, which is clearly shifting from the use of forces towards the use of information. This creates more distributed and multi-source energy providing systems to be successful against a wider variety of opponents ranging from individuals to armies.

7. Discussion and conclusion

Scenarios developed based on the trends in military concepts and technologies, and changing energy landscape indicate that renewable energy generation, advanced large/medium/small-scale storage technologies and wireless energy transfer are among the most prominent technologies to be developed. Research in these areas will certainly increase the efficiency of military operations and will reduce human and environmental loses dramatically. However, there is a need for positioning this discussion within a wider framework. Besides the technological advancements, the transformations in the characteristics of war and broader changes in society, economy, politics and environment suggest that there is an increasing need to re-consider the "military power" concept. Currently, the key measures of military power are lethality and impact, which are far from reflecting the efficiency, sustainability, and greater responsibility for human life and environment. The shift from 'inter-state' to 'intra-state' wars means that destroying the human capital in a country is not acceptable humanistically and not rationale economically. Therefore, increased capacity such as on heavily armed jet fighters and tanks will not make countries stronger from the operational point of view, but will make them more vulnerable due to the high destruction power of these systems and increased dependency on conventional energy supply. Considering the nature of military operations towards more frequent intra-state cases; closer proximity of operations to society; and increasing expectations for more human- and environment-centric concepts, it may be concluded that there is a need for re-considering the meaning of the 'military power.' Without doubt, the development of more advanced technologies for sustainable and efficient operations will be one of the key enablers of this new military power concept. The expectation for more flexible and mobile forces will be achieved with less energy dependency, which can be achieved by:

1. developing and field new primary energy sources that do not rely on petroleum and are preferably renewable
2. reducing consumption through conservation, and
3. improving the efficiency of energy use so that more mission is accomplished per unit of energy input (Umstattd, 2009).

Renewables including waste, wind and solar technologies are gaining importance for military operations. Besides undertaking R&D activities in these areas, the present study proposes that it is first important to consider these technologies in an integrated way to create an energy system with the possibility of quick and efficient substitution of energy sources. Second, there is a need to consider energy generation along with storage and transfer technologies from a triangular perspective. Generated energy should be stored in an appropriate way depending on the operational needs and should be transferred on demand by using smart grid and wireless systems. Besides the base level, the scenarios developed indicate that individual soldiers will play a greater role particularly in urban and rural counter-insurgency operations. A similar triangulation of energy generation, storage and transfer solutions will be needed at this level. Meanwhile, complementary R&D activities should be undertaken to increase the energy efficiency of the buildings, operational infrastructure and equipment and to adapt them to the new sources of energy.

Changing characteristics of warfare suggest that in the new global context operations by multi-national forces will be performed both in main and forward operating bases with an increasing likelihood of performing operations both in urban and rural areas. Hence, it can be concluded that the aforementioned scenarios are not mutually-exclusive. Military R&D policies would be expected to address all the stages of transformation at three levels. One final important point in the military energy R&D domain is that most of the technological developments and advancements presented above would also create vast opportunities for civilian use due to increasing expectations for sustainability and renewable energy use. This possibility for the dual-use of technologies at the military and civilian domains will provide a greater motivation for research institutions and firms to be involved in the energy R&D.

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