REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
07-02-2017

2. REPORT TYPE
Master's Thesis

3. DATES COVERED *(From - To)*
SEP 2016 - JUN 2017

4. TITLE AND SUBTITLE
Renewable Energy and the DoD's Quest for Operational Resilience

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Bohanan, Travis, R., Major, USAF

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USMC Command and Staff College
Marine Corps University
2076 South Street

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This paper argues for the DoD to embark on a strategy to convert its facilities to run on off-grid, renewable energy, increasing the operational resiliency of its installations. The paper examines the costs and power production potential of wind and solar PV systems and studies their suitability for DoD installations.

15. SUBJECT TERMS
Renewable Energy; Solar PV; Wind; Facility Energy

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclass	Unclass	Unclass	UU		USMC Command and Staff College

19b. TELEPHONE NUMBER *(Include area code)*
(703) 784-3330 (Admin Office)

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

United States Marine Corps
Command and Staff College
Marine Corps University
2076 South Street
Marine Corps Combat Development Command
Quantico, Virginia 22134-5068

MASTER OF MILITARY STUDIES

RENEWABLE ENERGY AND THE DOD'S QUEST FOR OPERATIONAL RESILIENCE

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF MILITARY STUDIES

Major Travis R. Bohanan, USAF

AY 16-17

Mentor and Oral Defense Committee Member: Edward Erickson, Ph D.
Approved: ______________________
Date: 6 Feb 2017

Oral Defense Committee Member: Matthew Slater, Ph D.
Approved: ______________________
Date: Feb 6 2017

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EXECUTIVE SUMMARY

RENEWABLE ENERGY AND THE DOD'S QUEST FOR OPERATIONAL RESILIENCE, by MAJ Travis R. Bohanan, USAF, 20 Pages

Conventional power grids employ a hub and spoke architecture that makes them vulnerable to malicious hacking, natural disasters, software errors and simple accidents. A failure at the hub affects all of the spokes. Several recent examples have illustrated that these types of risks can also adversely cut off power to Department of Defense installations, making installation energy security a National Security issue. As the development of renewable energy technology has matured, the cost of these commodities has decreased, making some renewable energy sources price competitive with conventional, fossil-fuel sources. Renewable technologies, especially wind and solar photo-voltaic cells, can be employed in a more distributed manner, more akin to a network or web than a hub and spoke. This type of architecture is more resilient in the face of attacks, natural disasters or other interruptions of service. The Department of Defense should therefore embark upon a conversion strategy for its installations, ideally providing all of its 300,000 facilities with energy derived from renewable sources that are not dependent on vulnerable hub and spoke, fossil fuel-based power plants.

Prologue

On December 23, 2015, Russian computer hackers accessed the Kyivoblenergo energy control center in western Ukraine, in what some analysts believed to have been a state-sponsored cyber-attack.[1] The worker on duty watched as his computer began going through the steps required to shut down one sub-station after another, helpless to stop it. In the end, the hackers took approximately 30 sub-stations offline, denying electricity to over 225,000 Ukrainian citizens for three hours before the grid could be brought back online.[2]

On June 6, 2013, a small fire at a commercial power sub-station in the village of Dededo on Guam took out power to the island's 160,000-plus residents for six hours.[3] A faulty electrical cable was to blame. This incident caused loss of power at three American military installation, including Andersen Air Force Base, home of the United States' Continuous Bomber Program, a key strategic defense initiative designed to safeguard the nation and its allies in the Pacific.

On August 14, 2003, a software code glitch caused a series of cascading power oscillations that knocked out power to much of the United States' eastern seaboard and parts of Canada, affecting the power supply to an estimated 55 million people.[4] At least 12 people were confirmed to have died as a direct result. Additionally, 3,000 fires were reported and over 40,000 emergency calls were caused in approximately 24 hours. It was a catastrophic event; one that prompted massive changes to the US and Canadian energy policies.

Introduction

These three events had very different causes. Malicious hacking, faulty equipment and a software coding error are, unfortunately, all very real and very likely contributors to real world power grid emergencies. One common thread is evident in all three incidents: a conventional, hub and spoke-style energy grid, powered largely by fossil fuels, poses a strategic vulnerability to those who are dependent on it. Such a vulnerability is significant to civil society however, the fact that US military bases are reliant on the same grids makes it potentially catastrophic to national security. Under such a scenario, military vehicles could continue to survive and operate however, key critical facilities would be totally dependent on generators, which would be competing with those same vehicles for limited fossil fuel reserves. Communications and command and control systems would quickly be reduced to a fraction of their normal capability, forcing military personnel into degraded operations until the grid power could be restored.

This paper will examine the following: 1) The weaknesses and vulnerabilities of the existing power grid architecture the DoD utilizes; 2) The cost feasibility of the recommended conversion strategy; 3) The power generation feasibility for DoD facilities; and, 4) Which form of renewable energy is the most suitable for this proposal. This paper seeks to answer the question, "should the DoD develop a strategy to covert its facilities to an off-grid, renewable energy-based architecture?"

A change is needed. Therefore, the Department of Defense should embark upon an aggressive conversion strategy for its facility energy architecture in order to maintain a high level of operational capability in an energy insecure environment; one that utilized dependable, renewable energy, independent of vulnerable commercial or centralized grids.

Weaknesses in the conventional grid architecture

This section examines the weaknesses inherent to conventional grids, including key vulnerable nodes and how enemies can exploit them. The obvious weakness of a conventional, hub and spoke-style grid, is the hub itself. A failure at a key node in the grid, like the power plant or key sub-stations, has the potential to deny electricity to many thousands of users, including any DoD installations that may be dependent on that particular grid. This model of energy architecture presents a great risk to American national security. Terrorist organizations tend to favor dramatic, unexpected attacks that are likely to inflict fear in the hearts of the enemy population. In addition, they tend to favor tactics that have a high return on investment; something that can be carried out relatively independently by a small number of actors with minimal resources. An undefended power plant or remote sub-station would be a ripe target for a simple sabotage or bomb attack.

Further, and perhaps more timely given the recent spate of state-sponsored cyber-attacks on American infrastructure, the threat of cyber-attacks continues to stay at the forefront of the national consciousness. In the case of the Russian cyber-attack mentioned in the prologue, a private security firm assessed that in many ways, the Ukranian grid was more resiliently designed than many of those in the United States.[5] Sophisticated firewalls were placed in critical network locations and a manual back-up system had been designed into the system; two key protections many American power plants do not possess.[6]

This is something early air power theorists envisioned when they created the Industrial Web Theory of strategic bombing.[7] The idea was, by targeting key centers of production, bombers could inflict disproportionally severe damage upon an enemy by depriving him of his ability to fight, without having to engage his forces directly.[8] This strategy did not force Germany or Japan to capitulate, as some American airmen had promised, however; after the war, the United States Strategic Bombing Survey team assessed that the German power grid was a far more critical vulnerability than industrial production centers.[9] They then assessed that 95 power plants provided more than half of the entire country's electrical power and that the German government recognized the loss of even a few of those stations could be critical to their war effort.[10] From this analysis, American planners realized that the strategy itself had been a sound one, but they had applied it to the wrong target set.[11] German industry was far more resilient than their power production architecture. Applying the Industrial Web Theory to the German power grid potentially could have crippled the Nazi war machine and dramatically shortened the war. The American power grid of today, although utilizing far more advanced technology, still operates off the same type of architecture, a hub and spoke, that Germany did seventy-plus years ago. America's adversaries know this and can attack the grid to great effect.

Time has, unfortunately, not erased the vulnerability of a conventional power grid. In a 2014 report, the Center for the Study of the Presidency and Congress (CSPC) assessed that the network-centric "smart grids" of recent years are increasingly vulnerable to cyber-attacks due to a greater number of electronic access points designed into the architecture.[12] Recent examples of Russian cyber-attacks against conventional power grids, such as the Ukranian example and the 2016 malware deployment against a power provider in Vermont, show that America's adversaries have both the will and the skill to strike at our electrical grid.[13] One option the CSPC suggests is to defend against these attacks by strengthening the defenses in place. Upgrade the power grid's cyber-defenses, build in redundancies and other protections in the software code itself and strongly vet the personnel who work at the facilities.[14] These actions could offer some protection against cyber-attacks, but do nothing to protect against physical attacks.

While physical attacks on the American power grid are not necessarily highly publicized, several recent events have demonstrated the incredibly vulnerable nature of the power grid's physical infrastructure. In April 2013, several individuals attacked a sub-station in San Jose, California.[15] They cut fiber optic cables prior to firing over 100 rounds at key components located on the facility's exterior.[16] The facility was very remote and its only physical protection was a light chain-link fence.[17] The attack disrupted the power supply to the area for 27 days.[18]

In the same year, a series of three power grid attacks occurred in Arkansas.[19] The attackers used a variety of low-tech but innovative tactics. In the first, the attackers removed the bolts in an electrical line support tower, causing it to fall onto a nearby train track, which in turn caused the lines to be severed when the train passed by.[20] The second attack involved arson at a power plant and in the third, the attackers pulled down an electrical tower with a tractor.[21] These attacks took out power to over 10,000 people and were later determined to have been carried out by one man, an American citizen, meth addict, and self-employed pool maintenance technician, with no ties to any terrorist or other extremist organizations.[22] Similar attacks in the same year saw the use of Molotov cocktails and other crude explosive devices to damage or destroy power plants in Mexico and Arizona, denying electricity to more than 450,000 people total.[23]

Creating a more resilient energy architecture

Measures to simply harden the existing power grid would require a massive, expensive and time-consuming change to American national energy policy. Such actions pose tremendous costs, with little guarantee of success. Conversion to a different system architecture, however; that does not contain a central hub at all, removes the target from the enemy altogether, giving them nothing to strike at.

The United States government clearly recognizes the benefits of the DoD converting to a renewable energy architecture. Executive Order 13693 directed all executive agencies to seek out renewable solutions to the government's energy needs, however; often the focus of such initiatives is on cost or environmental concerns which, while compelling, are arguments that can be overly politicized and can hamper action.[24] One benefit arguably overlooked in this discussion is the effect energy independence can have on the military's ability to continue to survive and operate in an energy insecure environment.

Resilience is a major component of the United States defense strategy. The 2015 National Military Strategy lists resiliency in logistics, intelligence, communications and several other areas as primary emphasis items for the Department of Defense.[25] Every focus area mentioned in the document shares one core link; they all require energy to operate. All of these key capabilities, at some point, involve a computer or other device plugged into the power grid at a military base to operate. Those power grids are almost exclusively commercially-operated utilities, which most often do not have augmented security measures beyond normal industry standards. An energy infrastructure system utilizing renewable energy, deployed in a decentralized manner, locally at each DoD installation could provide that added measure of resilience required. This will reduce or eliminate the threat presented by attacks on conventional power production facilities, or damage to them by natural disasters. It will also reduce or eliminate the need to depend on costly logistics pipelines to deliver conventional fuels.

The potential benefits of converting to such a model are easy to see. Energy independent DoD installations would be essentially self-contained islands of military capability, remaining largely unaffected by scenarios such as the examples above. Military base facilities could count on a steady, resilient power supply to ensure vital command and control systems remained intact and operational despite interruption of service to the conventional grids they once relied on. The burden on bases to maintain additional fossil fuel reserves to run facility emergency generators could potentially be lessened and instead be dedicated for use by operational vehicles, further stretching the amount of time bases could remain active and independent of outside assistance, in the event of a significant power loss event.

Such a program would not be fix-all by any stretch. Bases would still depend on fuel pipelines and logistical deliveries to keep vehicles running and people fed, however; possessing a dependable, logistically unburdened supply of energy would be a massive increase in operational resilience and a dramatic decrease in logistical requirements to keep a base running, in the event of significant, sustained power loss. In addition, incorporating such technology into military facilities could provide added benefits, such as reducing individual unit costs, spurring development of more efficient and effective technologies and incorporation into more platforms such as vehicles and deployable assets.

Background on the US and DoD energy situations

This section will examine the overall energy demands of the United States and the DoD, as well as the associated costs. The United States is the world's largest per capita energy consumer.[26] Over the last five years, the nation's total annual energy usage averaged approximately 28,000 Terawatt Hours (TWh), with per capita usage during the same period at just over 87,000 Kilowatt Hours (kWh) per year.[27] [28] The DoD is the largest single energy consuming entity in the country, accounting for nearly one percent of the total US annual consumption rate.[29] The Department alone consumes more energy than nearly half the states of the union and its annual energy consumption rate accounts for nearly 80 percent of the total annual US federal consumption rate.[30] No other federal agency comes close to the DoD's energy consumption. The second-highest consumer is the United States Postal Service, which consumes approximately one-quarter the amount the DoD does each year.[31]

One important detail to note is the different categories of energy consumed by the DoD. For the purposes of this paper, two major categories of energy will be used will be used: *facility energy* and *operational energy*. The Office of the Secretary of Defense defines *facility energy* as energy consumed in order to power fixed structures, provide climate control and run associated equipment for those facilities.[32] *Operational energy* is defined as energy consumed to power vehicles, standalone equipment and other assets not tied directly to buildings.[33]

According to the DoD's 2015 Annual Energy Management Report, the Department is responsible for over 500 installations worldwide, containing approximately 300,000 separate buildings.[34] In Fiscal Year 2014, the Department consumed nearly 65 TWh of energy to power its facilities, at a cost of over $4 billion.[35] This was approximately 23 percent of the Department's total energy cost of $18.2 billion.[36] Each of the three military service departments (Army, Air Force and Navy, which includes the Marine Corps) accounted for approximately 30 percent of the total DoD facility consumption rate, with roughly five percent consumed by the remaining Defense Agencies.[37]

Background on alternative energy technologies

This section will briefly examine the pros and cons of off-grid renewable energy systems, including power production and costs. Renewable energy architectures, such as off-grid solar PV systems, offer the DoD greater energy security because individual facilities could potentially produce most of, if not all, their energy on their own. With conventional electrical grids, individual facilities are usually powered from a central plant, regardless of the energy source. A debilitating event, such as malicious hacking, a terrorist attack or even a simple accident could deprive an entire installation from a secure source of power for hours, if not longer. These types of events are not unthinkable or uncommon. For the DoD to have a high degree of energy security, and therefore operational resilience, an off-grid, decentralized solar PV architecture could provide an effective alternative to the current models employed. Off-grid systems have a significant advantage in being completely independent of commercially produced energy and are immune to the effects that disruptions at the central hub would cause.

These systems are not without their disadvantages, however. For instance, solar PV systems require batteries to store the excess energy generated during periods of high sunlight, in order to continue to run during hours of darkness or inclement weather.[38] Such batteries can be quite expensive and are in the relatively new stages of production. Whereas in many cases, solar energy can be price-competitive with fossil fuel-based energy, when incorporating the costs of batteries in an off-grid architecture, the costs can nearly double.[39] History has shown, however; that the cost of solar PV energy is trending downward. The Tesla corporation, whose Powerwall lithium-ion batteries could be one suitable model for DoD facilities, projects a 30 percent drop in its per hour energy cost later this year.[40] One of the key drivers of the momentarily higher costs of the energy is the relatively small market. As the market increases, the cost per unit and ultimately the cost per kWh drops.

Currently, the US solar market has the capacity to support approximately 5.7 million average American homes.[41] If the DoD were to embark on an aggressive conversion campaign for its 300,000-plus facilities, it would be roughly equivalent to a 30 percent growth in the US solar market. The generally accepted principle of economy of scale postulates that as the size and scope of an industry grow, the costs of production shrink relative to the cost of each unit.[42]

Disarming the counterarguments

Converting the DoD's facility energy strategy to a renewable energy-based model will not be without significant challenges. Critics of renewable energy often employ one or both of two primary arguments. First, that the technology is not currently able to produce power at the same cost as conventional systems. Second, that renewable energy sources cannot yet produce power levels at the same yield as most conventional sources. These arguments have merit and must be fully analyzed and addressed before attempting to shift DoD facilities to a renewable energy-based architecture.

Cost analysis

In today's fiscal environment, many senior military leaders have claimed that the number one threat to national security is the United States national debt.[43] Such comments are not hyperbole. Budget restrictions, coupled with the need to recapitalize on aging weapon systems, have driven significant, potentially critical, reductions in personnel strength is all branches of the military.[44] One of the primary areas in which the DoD is seeking to reduce costs is its energy usage. The Department of the Navy has arguably led the charge in changing the DoD's energy usage paradigm by incorporating a number of varied energy initiatives including seeking efficiencies in the use of fossil fuels and seeking alternative methods to provide its installations with energy, including many renewable sources like wind and solar.[45]

A 2011 study by the Department of the Navy reviewed 87 CONUS Navy and Marine Corps bases for potential costs of shifting to solar and/or wind power.[46] It found that only five of the assessed bases were likely to have to pay less than current market prices for their energy needs under such a change.[47] Of the 82 bases expected to have equal or higher than current facility energy costs, 73 of those bases were predicted to have cost increases greater than 25 percent.[48] Such costs are often used to justify continued reliance on legacy energy systems, however; the same report also found that 17 of the reviewed bases could expect to pay similar, if not equal, facility energy costs by switching to renewable energy sources. Framed in that light, it was found that 23 of the 87 CONUS bases reviewed could be expected to pay equal or lesser costs for their energy by switching energy sources.[49] As interest and investment in renewable energy technologies have increased, and coupled with increased regulatory costs placed on fossil fuel systems, the costs of renewable energy have become more competitive.

The US Energy Information Administration's 2016 Annual Energy Outlook report found that the Levelized Costs of Electricity (LCOE) per mega-watt hour (MWh) produced from renewable energy sources have, in some cases, become competitive with some fossil fuel sources.[50] Dollar cost per MWh for conventional energy sources varied greatly between methods of generation, with certain types of natural gas costing around $57 per MWh on the low end, to advanced coal system generated power costing nearly $140 per MWh.[51] By comparison, the before tax credit costs of land-based wind and solar photovoltaic (PV) systems were found to be $66 and $84 per MWh, respectively.[52] These costs reflect a sustained trend of falling prices for land-based and solar PV energy. The same reports show significant reductions in costs over the last six years and project additional savings going into the year 2020.[53] There is a clear trend showing falling costs for the two renewable sources most likely to be used to provide energy to US military bases. This data helps argue against perhaps the most significant case against making the switch from using fossil fuel based energy sources to power the DoD's facilities.

While the data shows that the costs of energy alone are no longer the same disincentive to convert to a renewable energy-based model, the DoD would need to carefully evaluate the cost of the hardware and its installation. The previously-mentioned LCOE figures do incorporate the average total cost of the energy production method, meaning the cost per MWh includes the cost to build, operate and maintain the means of production over the lifetime of the power plant, wind farm or solar PV array.[54] This bit of information is important although not entirely sufficient on its own. LCOE figures assess the costs of centralized energy production facilities whereas the proposed DoD facility energy model argues in favor of a decentralized model closer akin to a residential community where each housing unit has its own, independent solar PV array. Such a model is required to provide the level of operational resiliency the DoD would need to remain truly energy secure.

<u>Power production analysis</u>

Since the data suggests the costs of renewable energy are not prohibitive to the conversion strategy this paper argues, the next question is, can DoD installations draw sufficient power from the renewable systems to meet their needs? The answer to this question depends greatly on the type of renewable energy considered and the location in which it is to be utilized. Since this paper is arguing for the adoption of systems that the DoD can best utilize worldwide, both land-based wind and solar PV systems will be assessed. Other renewable sources, including hydroelectric, solar concentrating photovoltaic (CSP) and geothermal, were evaluated but not included in this paper due to obvious unsuitability for installation at every DoD installation. Hydroelectric and geothermal plants require fixed facilities and access to natural water sources that most DoD installations will not have. Solar CSP energy production would require the construction and operation of massive, specialized power plants at every installation. This would require dedicated personnel trained to operate the facility as well as creating another hub and spoke style system, which would not provide the operational resiliency this paper is arguing for.[55]

Since electricity generation by type of renewable energy source is location dependent, when evaluating the energy source for suitability world-wide, as is necessary if considering it for the DoD, a proper first step would be to evaluate the energy source's potential capacity against the DoD's energy need. As was previously mentioned, the total annual DoD facility energy demand is approximately 65 TWh. This total is then spread across more than 300,000 facilities, a very rough approximate demand of 0.0002 TWh (217,000 KWh) per facility, per year, can be extrapolated.[56] With this as a baseline planning factor, one can gauge wind and solar PV's suitability to the need.

Some industrial wind turbines have been shown to have electrical capacities up to 500 kW. This would translate to 4.56 million kWh per year, or enough to power 21 facilities per turbine, per year. Since it is not uncommon for a military base to have well over a hundred facilities on it, most installations would likely require at least five, and likely more, industrial-sized turbines for full energy independence.[57] Smaller turbines, like what an individual home might use, have been rated as having energy capacities under 100 kW, making the minimum number of turbines per base at over 20. These turbines are generally placed on open ground, requiring unobstructed real estate for installation. In addition, the height of the turbines would create airspace restrictions for aircraft departing and arriving at any DoD facilities equipped with them.

Solar PV arrays can vary wildly in size, so a comparison of one array's capacity against another must include the square footage of both to ensure the data is being analyzed appropriately. The Nellis Air Force Base solar array has a capacity of 14.2 MW and is a good approximation of the type of technology, if not the size, that DoD installations might adopt under the program proposed in this paper. The array is quite large, at 70,000 panels, spread over 140 acres. Since going into operation in December 2007, it has generated approximately 32 million kWh each year.[58] Scaling this down, it can be assessed that each acre of solar panels has the potential to generate over 12.3 million kWh annually, or enough to power 57 facilities. For a base with 100 facilities, roughly 2 acres, or approximately 87,000 square feet of panels would be needed. An advantage of solar PV panels is that additional real estate is not necessarily needed.

Though the Nellis array was installed on open ground, many solar technologies are designed for rooftop installation, freeing up base real estate for other uses.

Both of these calculations were made assuming relatively ideal conditions. Local wind speed and hours of sunlight analyses would need to be conducted to get a better estimation of a location's true wind energy potential. The following sample study will attempt to provide that estimation.

Renewable energy feasibility sample study

DoD installations are spread quite literally all around the globe, so for the purposes of the paper, an indicative sample of regions with a dense DoD installation presence will be assessed. Average days of sunshine will be assessed as a measure for how feasible solar PVs would be, by location, and average wind speed and duration will be assessed for the feasibility of wind power. The below table displays seven locations where the DoD has a significant installation presence. Locations were chosen based on the population density of US forces in the region and geographic and climate diversity. The data set will then be used to determine which of the two renewable energy strategies is more likely to be feasible for the conversion strategy this paper argues.

Table 1.[59] [60] [61] [62] [63] [64]

Location	Avg Hours of Sunshine/Year	Wind class at 80m (meters per second)
Kabul, Afghanistan	3,085	1 (< 5.9 m/s)
Doha, Qatar	4,380	1 (< 5.9 m/s)
Joint Region Marianas, Guam	2,422	2-4 (5.9-8.1 m/s)
Okinawa, Japan	1,746	2-4 (5.9-8.1 m/s)

Stuttgart, Germany	1,692	2-4 (5.9-8.1 m/s)
Las Vegas, Nevada	3,825	1 (< 5.9 m/s)
Joint Base Lewis-McChord, Washington	2,170	2 (5.9-6.0 m/s)

Feasibility of wind power

According to the United States Department of Energy (DoE), regions with an average annual wind speeds greater than 6.5 meters per second, at 80 meters of altitude, are considered suitable for wind power development.[65] An 80 meter altitude is generally used as a planning factor based on current average heights of utility-scale windmills, however; technological advances are pushing newer windmills to heights up to 140 meters, meaning more areas will soon be considered suitable for wind development.

Based on the current standards, three of the four sample locations would be considered suitable for wind power development, with locations in the Pacific region showing the most potential. The US bases in the Pacific region are also some of the most logistically challenging to sustain from an energy perspective, making them good potential candidates for a renewable energy architecture.

On the contrary, the Pacific region experiences approximately 40% of the world's total natural disasters, many of them typhoons, which wreak havoc on windmills.[66] A 2012 study found that a single category 3 storm would buckle the towers of 46% of existing turbines.[67] This is considered catastrophic damage that would require massive repair, if not replacement of the turbine(s), altogether. To be fair, this is not dissimilar from the risk posed to offshore oil rigs, which experience similar threats from hurricanes and typhoons, however; this paper is arguing for both a renewable and resilient energy architecture for DoD installations. Based on the existing data, wind energy may be a potential augmentation to legacy power grids, or a technology that could work in tandem with a more universally suitable renewable energy source, but it does not appear that wind power alone is suitable for the purposes this paper is arguing.

The same DoE database shows that with the exception of a wide vertical band stretching north to south from North Dakota to central Texas and from Colorado to Missouri, most of the continental United States is not considered suitable for large-scale wind power development.[68] In this case, wind energy could be a possibility for the so-called northern tier bases, many of which are charged with maintaining the nation's nuclear arsenal and have a vested interest in maintaining energy security.

Feasibility of solar photovoltaic power

Solar PV systems offer another, potentially more suitable option for most DoD bases. Assessing each location's solar potential based on historical average hours of sunshine per year, it is shown that a location like Joint Base Lewis-McChord (JBLM), located adjacent to Seattle, Washington, has the potential to generate 0.013 TWh of energy per year for every 100,000 square feet of solar PV panels installed.[69] This means that every 100,000 square feet of solar panels can roughly sustain more than 60 base facilities, based on the demand estimate of 0.0002 TWh per facility, per year. To put the 100,000 square feet into perspective, just one of JBLM's C-17 aircraft hangars has over 50,000 square feet of usable space on the roof for solar PV panel installation.[70]

Seattle is, of course, quite infamous for being dreary and not the first location that comes to mind when thinking of solar power. The Las Vegas, Nevada region hosts both Nellis and Creech Air Force Bases and boasts a solar potential nearly double that of Seattle, with 0.022 TWh per year for every 100,000 square feet of solar PV panels. This would mean that each 100,000 square feet of PV panels could support over 100 base facilities. For some context, this equates to the amount of energy required to power over 1,500 American homes each year.[71] Nellis' aircraft hangars and flight line support facilities alone could easily accommodate half a million square feet of solar PV panels, providing approximately 0.11 TWh of energy per year.[72]

For the overseas bases considered in this sample, the results are similarly promising. For instance, the three US military bases located on island of Guam are serviced by a commercial power grid more prone to failure than most American regions. Outfitting just a few of the larger flight line support facilities on Andersen Air Force Base could provide well over 200,000 square feet of solar PV panels, potentially generating more than 0.03 TWh per year. One single industrial facility on Naval Base Guam boasts over 300,000 square feet of roof space suitable for PV panels.[73] It is certainly possible that outfitting relatively few facilities on Guam with PV panels could produce more than enough energy to power the three bases there, making this strategically important military site's facilities virtually energy independent.

Such a change would also negate the need for costly logistics support, as commercial ships are currently needed to deliver massive amounts of fossil fuels to power generators during the island's frequent power losses, further making the economic case for the conversion. In addition, considering the island's small size and population, with some additional infrastructure work, the solar PV arrays could serve as a backup power source to the civilian population in the event of a major catastrophe.

The locations sampled in Japan and Germany both have approximately 77% of Seattle's solar potential, making them the suitable for conversion in the sample, however; both locations still possess enough potential to make the change worthwhile. Each area has roughly 0.017 TWh of annual solar energy potential per 100,000 square feet of solar PV panels installed. This lower potential per square foot would require more panels to generate the same yield, but as the previous examples have shown, most military bases would need to outfit very little of their existing roof space to generate sufficient solar power.

Kabul, Afghanistan, at first glance, seems like a suitable candidate for conversion to solar power. Its solar potential is approximately 20% higher than that of Guam's and there is a definite need to reduce the reliance on fossil fuels in Afghanistan. The cost of delivering fuel for generators is extremely high, both in dollars and the risk to people's lives, with convoys and aerial delivery being dangerous operations. Fuel deliveries for some of the larger expeditionary bases cost over $6.00 per gallon and generator fuel accounts for 20-30% of all fuel consumption in Afghanistan.[74] Places like Afghanistan do possess some challenges that more stable locations do not. For instance, the expeditionary nature of the bases tends to mean there is near constant construction. Facilities are overhauled, relocated, damaged or abandoned at a far faster pace than most conventional facilities. In addition, previous DoD studies have concluded that essentially 100% of the current diesel generator backup systems would have to be maintained since a commercially viable conventional power grid cannot always be counted on.[75] Such challenges, for now, indicate that more expeditionary bases may not be ideal candidates for solar PV energy.

On the contrary, a base such as Al Udeid in Qatar might be the best candidate for conversion to solar PV-generated power. Coming in as having the most solar potential in the sample, every 100,000 square feet of solar PV panels could generate 0.02 TWh of electricity per year, enough energy to power nearly 100 base facilities. Six of the largest aircraft hangars on the base offer close to 500,000 square feet of usable roof space, offering the potential to power 500 facilities.[76]

Since Al Udeid has a viable commercial grid currently powering it, the requirement for generator backup would not be as stringent. Additionally, most of the larger buildings are relatively permanent in nature, meaning once solar PV panels are installed, they can be reasonably expected to remain in place and operating for the foreseeable future.

Recommendation based on analysis

While this sample is by no means a complete assessment of the entire DoD enterprise's suitability for conversion to solar power, it does provide a good, rough approximation of the main geographic regions in which steady-state US military facilities are located. In all cases, with current technology, every geographic region is reasonably suitable for installation of solar technology. In all the locations where the military facilities are relatively fixed, static structures, solar PV panels are assessed to be a viable alternative to the legacy systems. Only in a relatively forward, expeditionary environment is solar not assessed to be a viable alternative to the conventional architecture. This means that the potential energy exists generally everywhere the DoD has a significant presence. Coupled with the falling costs of solar PV energy, it appears that conversion to this architecture is now a feasible option.

Additional benefits of solar PV for the DoD

An additional benefit of using rooftop solar PV panels for this purpose is the associated reduction in electricity required for facility air conditioning. Solar panels on a facility's roof absorb much of the heat that would otherwise be transferred to the facility itself. A 2011 study found that rooftop solar panels act as an additional form of facility insulation, keeping interiors cooler during warmer weather and retaining heat during colder weather. The data suggests that as much as 5 percent of a facility's energy costs are offset simply by having the panels installed on the roof.[77] Taken as a whole across the entire DoD, this could amount to an annual savings of over $200 million, providing further incentive for conversion to such a renewable energy architecture.

Conclusion

As the world's energy demands continue to increase, it is inevitable that one-day fossil fuels will stop becoming as suitable to filling those needs as they are today. The resources are finite and eventually competition for them will likely cause conflict. In addition, the threat of attacks, both cyber and conventional, as well as natural disasters to legacy hub-style power grids presents a risk the United States need not operate under. A necessary, proactive approach would be to remove these risks by weaning the United States off of fossil fuels altogether, removing the vulnerability of central hubs in the power grids. Since that is a massive, likely generations-long undertaking, a feasible initial step would be to first convert the DoD's facilities to a renewable, resilient energy architecture. Energy independence and security for the nation's military infrastructure would provide a greater guarantee of the DoD's ability to operate in the energy insecure world of the future. Since renewable energy costs are now becoming more competitive with legacy energy costs, now is the time to begin such a conversion. Converting nearly 300,000 facilities worldwide will likely a decades-long program that should be initiated before the need is urgent, not after.

When going camping, it is always wise to set up your campsite before it gets dark. You make sure you take your time to assess your situation, scout an ideal spot and properly build up your camp while you still enjoy the luxury of sunlight. This is the situation the nation currently finds itself in. The US is currently enjoying high domestic fossil fuel energy production and relatively affordable energy costs, making it the perfect time to begin the switch to renewable energy.

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