MICROGRIDS ON DEPARTMENT OF DEFENSE INSTALLATIONS: ENERGY POLICY'S IMPACT ON NATIONAL SECURITY

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Executive Summary

Energy policy serves as a key component to national security. How the United States protects its military's access to dependable electricity is important to ensure that servicemembers are trained, equipment functions, and operations can occur around the world. Despite energy policy's importance, the United States does a poor job of promoting sound, defensive energy policy. On American military installations around the world, facilities are dependent upon civilian power plants that are vulnerable to physical intrusion or cyber-attacks. These installations rely on outdated fossil fuel generators to provide backup power, which comes with their own weaknesses.

Microgrids can serve as a key component of enhancing energy resiliency on military installations, thus improving our national security posture. They do this by providing a source of power and reducing dependence on external variables to increase the assured power to key facilities on an installation. The research in this capstone consisted of interviews with key stakeholders who have experience with providing power to their military installations. From these interviews, the key factors impacting the feasibility of microgrids to increase energy resiliency revealed themselves. Decision makers must consider the energy production, sustainability, and energy storage of their potential system, as well as their installation's weather, purpose, size, and distance from utility provider. Understanding these factors provides decision makers a better understanding of the impact that a microgrid will have on their energy resiliency, and thus, are important to understand fully before determining the feasibility of a microgrid.

Ultimately, microgrids may serve to have a large impact on energy resiliency on an installation, thereby increasing the United States' national security. Future research is needed to quantify these factors and expand the research to more military installations to determine if other factors may affect the different military services and their missions.

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2. Introduction

In 2016, I was a 22-year old Second Lieutenant deployed to Kandahar, Afghanistan. I was an intelligence officer with an army aviation unit from Fort Carson, Colorado. My unit was responsible for flying coalition and Afghan special operations forces deep into provincial Afghanistan to destroy Taliban strongholds. At this period in the war, political leaders had reduced the number of troops to just a few thousand Americans around the country. This meant that aircrews and helicopters would move to support whichever commander most needed them. There were neither helicopters, nor crews, to spare.

That summer, the Taliban started conducting attacks with improvised explosive devices and small arms weapons on a road running through Helmand Province. The attacks stopped the supply of fuel to one of our bases in Helmand. Without a steady supply of fuel, the base had to ration its energy consumption. Some buildings had to shut off air conditioning; others had to monitor closely their power usage. Military leaders were concerned. They came up with the most expedient solution: use Chinook cargo helicopters from my unit to fly fuel from Kandahar Airfield to this base in Helmand.

To do this, our crews had to adjust their flight schedules, aircraft maintenance, and their required crew rest. Crews had to fly from Bagram to Kandahar to compensate. In the end, it became more difficult to do what our unit was there to do: deliver special operations forces to the battlefield. A fuel issue on one road leading to one base reduced our operational abilities in Helmand, Kandahar, Uruzgan, and Zabul provinces. The most powerful military in the world had to change the way it operated because of a few homemade bombs and a dozen armed men.

In order to maintain military dominance, the United States must retain unfettered access to energy. Military decision makers, therefore, must be concerned with energy resiliency on their installations. Energy resiliency, which this paper will describe in more depth in proceeding chapters, is the act of ensuring access to energy to meet mission needs. There are several ways to change energy policy to improve energy resiliency. One change to energy policy that could increase energy resiliency and thus improve national security is to operate microgrids on military installations.

Microgrids, defined in greater depth later in this paper, serve to provide backup power to predetermined key facilities in the case of a power blackout. Current research addresses how microgrids may have an impact on energy resiliency, but fail to address how to determine whether it is appropriate or feasible for a military installation to employ a microgrid (Castillo, 2019) (Delboni, et al., 2019) (Marqusee, Schultz and Robyn, 2017) (Romankiewicz and Marnay, 2014). This is a critical gap in current knowledge and this lack of fundamental knowledge concerning feasibility reduces decision makers' efficacy.

This paper seeks to answer the question of what challenges must be overcome and what requirements must be met to make a microgrid feasible? This researched consisted of interviews with key stakeholders in an official capacity at different military installations to provide context and greater understanding of the energy needs on military installations and shed light on the factors that impact microgrid feasibility. By understanding these factors, decision makers will be better able to evaluate how a microgrid can improve their energy resiliency and will be better able to support the national security mission.

This paper will begin by discussing the background of the problem, to include defining microgrids, explaining the current backup power system and its flaws, the potential military use for microgrids, how to asses for microgrids, and how to pay for them. Next, this paper will examine the methods employed in the research, including the coding and analysis of stakeholder interviews to determine emergent themes. The methodology will also address the case study of Fort Carson, Colorado and Fort Huachuca, Arizona. Next, the paper will examine the results from the interview coding and analysis to determine key factors that influence microgrids on military installations.

Lastly, the paper will conclude with a discussion of why this is important, what use this may be to stakeholders, and the potential for future research.

3. Background

3.1 What is a microgrid?

First, it is necessary to understand what a microgrid is and how it relates to the concept of energy security. Numerous researchers have defined microgrids in various ways, but this paper will rely on the definition provided by Marqusee, Schultz, and Robyn (2017). They define a microgrid as a local system of distributing energy resources, i.e. electricity, which can operate in parallel to the commercial power grid or independently from the commercial grid as an "island" (Marqusee, Schultz and Robyn, 2017, page 13). Microgrids provide some sort of power generation capability, whether that is a natural gas plant, a photovoltaic solar array, or an interconnected system of diesel generators. What makes a microgrid different from a backup generator, however, is that microgrids are not exclusively isolated systems or mini-sources of energy, but rather operate in conjunction with the existing energy grid (Schwaegerl and Tao, 2014). As such, an installation can use its normal power utility and can alternate between that and its microgrid for its power.

In addition, microgrids have three major components that make them essential to energy security. These three components are that microgrids focus on supply-side energy, they can flux between normal state and emergency state operations, and they can handle conflicting interests to operate at an optimal energy level (Schwaegerl and Tao, 2014). These three components give microgrids a unique level of control over their installation's energy use by allowing them to direct power to specific facilities on an installation and adjust the amount of energy received at each installation as needs change, something that disconnected facility generators cannot do. In many instances, this will be facilities like hospitals, police stations, or centers of disaster relief. This greater control reduces risk to power and provides installation leaders with assurance that they will have the resources to complete their mission. The diagram (*Figure 1*) below details an example of a microgrid (the acronyms are "MC" for "microcontroller", "LC" for "load controller", "MGCC" for "microgrid central controller", "MV" for "medium voltage", and "CB" for "circuit breakers").

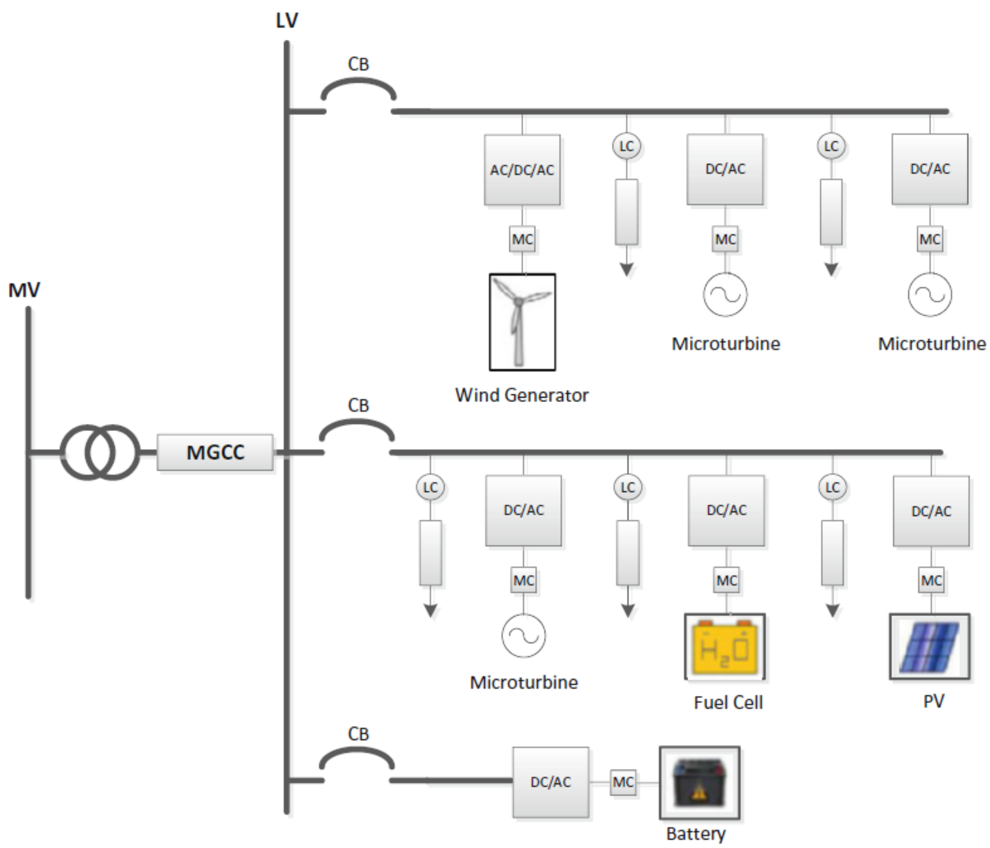

Figure 1. A diagram of a microgrid (Delboni et al., 2019)

3.2 Energy resiliency

Energy resiliency, for the purpose of this paper, is defined as "ensuring adequate energy resources to meet demands…in the face of uncertain and changing energy resource availability." (Thomas and Kerner, 2010, page 7) By allowing for some portion of a military installation to be in control of its own flow of energy, a microgrid can increase the assurance that it will have constant power. Additionally, microgrids allow for installations to be responsible for their own source of energy, something that increases their defensive posture in case of a terrorist attack or other disaster on the homeland. Examining microgrids through the lens of energy resiliency enables one to consider microgrids as a component of national security.

3.3 What is wrong with the current system of backup power?

Military installations are essential components of national security and readiness that rely on key systems to maintain their combat and operational capabilities, such as sensitive compartmentalized information facilities (SCIFs), radar, antennas, communication equipment, and even facilities like installation housing or hospitals (Marqusee, Schultz and Robyn, 2017). The current system for backup power in the event of a blackout is gasoline-powered or diesel-powered generators. Each facility on an installation will typically have its own backup generator that will activate in the event of an emergency. Not every facility has a backup generator, nor does every facility need one. There are several flaws with this system.

First, during an attempted coup in Turkey in 2016, the U.S. Air Force's Incirlik Air Base lost power, resulting in a reduced number of combat missions flown out of the base to Iraq and Syria (Marqusee, Schultz and Robyn, 2017). Without control over its own power generation, Incirlik Air Base had to reduce its combat operations. Because the installation received its power from the local community without a microgrid as backup, weak energy resiliency threatened broader American strategy in the region and had impacts beyond just one installation. Without on-site ways to maintain consistent energy, military installations are at the mercy of their community's power source, which may or may not be consistent depending on factors like weather, resources, and, in the case of some countries, political stability. A microgrid that provides consistent power to these key facilities could have reduced or eliminated this risk at Incirlik Air Base.

Additionally, using generators as backup power poses a problem because they require regular maintenance and fuel to operate, without which they become less likely to work (Ericson and Olis, 2019). Another problem for diesel generators is training or hiring generator mechanics and maintaining a consistent maintenance schedule. Many generators currently in use, as reported by stakeholders in interviews, have exceeded their shelf life and are overdue for replacement, increasing the likelihood that they will need repairs or will have a catastrophic breakdown. Additionally, each generator typically only provides power to one building and cannot disperse its energy to another. Thus, if a key facility's generator stops working, that facility will be unable to power its systems even if other less important facilities have functioning power sources. These generators also rely on fuel that comes from somewhere outside the military installation. If, as was the case after 9/11, installations go into lockdown and nobody may enter through the gates, then fuel trucks will not be able to resupply these generators during operations.

Lastly, the current system does not offer a way to generate or store energy. Without the ability to provide some continuity of power, whether from some form of power generation or from stored energy, the current system is unable to respond to blackouts and maintain energy during emergencies. In the current system, installations do not use energy storage methods to maintain access to power during inopportune times, nor do they generate energy to meet their energy needs. Any blackout or disruption in power is an immediate switch to fossil fuel backup generators, which, as discussed above, are prone to breaking or running out of fuel. This system is too dependent on external resources or power generation capabilities. Because of its dependency, energy is a key vulnerability to the military and the United States' national security.

3.4 Why the military could use microgrids

The military should consider changing the way it consumes energy for three reasons. First, energy supply and distribution are at risk as the system ages and becomes vulnerable to new kinds of cyber-attacks and physical attacks (Fritz, 2019). Second, our bases, equipment, and operations are increasingly dependent on energy to fight effectively, which means establishing energy independence increases the capabilities of our warfighters (Fritz, 2019). Third, new technologies and policies mean that there is a potential capability at present time to reduce our need for energy and our need for re-supply (Fritz, 2019).

The Department of Defense has already published policy informing the military's decision makers that energy must be considered a planning factor. Specifically, "DoDI 4170.11 requires alignment to critical energy requirements to prioritize and inform mission-based metrics development." (Castillo 2019, slide 4) When it comes to energy in the military, there are four applications to consider: contingency bases (small, combat outposts, such as in Iraq or Syria), platforms like aircraft carriers, the dismounted warfighter, and permanent bases (Fritz, 2019).

Microgrids are uniquely useful for military installations because they can help reduce the threat posed by this vulnerability and help meet the three critical energy resiliency metrics of critical loads, availability, and duration (Castillo, 2019, slide 5). By incorporating energy storage and on-site microgeneration, a microgrid can "act as a hedging tool against potential risks of …outage." (Schwaergerl and Tao, 2014, page 276) The military has already begun operating these types of microgrids. Military installations with microgrids include Naval Base Guam Telecommunications Site Finegayan in Guam and the Marine Corps Air and Ground Combat Center Twentynine Palms in California, which have increased energy resiliency because of these microgrids and a greater access to assured power (Office of the Assistant Secretary of Defense for Sustainment, 2018). These mimic civilian microgrids such as in Borrega Springs, California, a town which operates a microgrid with battery storage, diesel generators, and rooftop solar to help protect the community from power outages (Romankiewicz and Marnay, 2014). The military would gain an advantage not offered by the current system of backup generators to maintain power continuity.

3.5 How to assess for a microgrid

To assess for a microgrid, it is necessary to start by examining what sources of energy will power the microgrid, whether from a fossil fuel source like coal or a renewable source like solar and wind. Understanding this question is important because that leads to the modeling and simulation of the microgrid to determine sizing, implementation, local control, and energy management in the microgrid (Solano et al., 2019).

Next, it is important to be able to estimate the load on the microgrid, which involves identifying the main loads and then characterizing these loads (Solano et al., 2019). For a military installation, this would entail determining the necessary facilities and resources that must maintain power for national security reasons. The installation must know its key operational facilities and prioritize its power demand accordingly. It also means characterizing how much power the facilities will require and whether that power will need to be consistent or intermittent. By understanding power needs at these key facilities, microgrids can adjust to meet these needs.

Lastly, it is necessary to forecast future loads to determine how the microgrid must scale for future energy demands (Solano et al., 2019). It would make no sense to build a microgrid that would be insufficient for the next year's energy demands. The "forecasting problem can be solved based on different approaches such as artificial intelligence techniques (neural networks or fuzzy logic), statistical techniques (linear regressions), and visualization techniques (histograms or scatter plots), among others" (Solano et al., 2019, page 345). Of note, energy needs often go down after building a microgrid, as decreased energy costs tie into the payment methods for the microgrid, as discussed in the next paragraph.

3.6 Methods to pay for a microgrid

There are many ways to pay for a microgrid. This includes three types of government appropriations and four types of third-party investments. To start, this research will examine the three types of congressional appropriations.

Like other endeavors in the Department of Defense, Congress can appropriate money to fund these projects. The first type of funding is the military construction (MILCON) project. These projects have no statutory cap on how much can be appropriated to them, meaning they can be used to fund very large projects (Miller, 2016). They are also useful because the money allocated towards a MILCON project is guaranteed explicitly to that project; once determined, no further politicking is required. However, MILCON projects can be difficult to fund. Due to the political nature of funding projects, it can be difficult to convince Members of Congress to appropriate money into microgrids. As such, MILCON projects are not often the financial vehicle used to construct microgrids.

The second type of appropriation is the operations and maintenance fund. This fund also can allocate money to specific projects, and, like a MILCON project, is useful because once the money is allocated it must be spent on that project. The operations and maintenance fund exists outside Congressional purview, meaning these projects can avoid the politics of Capitol Hill. The weakness of the operations and maintenance fund is that it can only finance projects up to $1 million, which makes it infeasible for most microgrid projects, although this funding may be used for complementary efforts, such as making buildings more energy efficient, installing timers on lights to reduce demand, or upgrading heating and cooling systems (Miller, 2016). Ultimately, operations and maintenance funds are not useful vehicle to support microgrid projects.

The third and final type of government funding is direct congressional appropriations. These tend to be large projects devoted to the whole of the Department of Defense. One such example is the American Recovery and Investment Act of 2009, an act that used part of its investment to fund approximately $200 million worth of renewable energy projects in the Department of Defense (Miller, 2016). While this amount of money can greatly influence microgrid projects, these types of congressional appropriations tend to focus on broader issues and do not usually fund specific projects on specific installations. They simply do not happen often enough to be a consistent tool for financing.

While each of these options can be useful in specific situations, none of them are particularly useful for developing a microgrid on military installations. For that, one must turn to one of the four types of third-party investments.

The first type of third-party investment is the Enhanced Use Lease. In this situation, excess property on a military installation that is not being used may be leased to a developer that will use the land to promote national defense goals in exchange for cash or other discretionary forms of "in-kind" payment (Miller, 2016, page 695). This can be challenging, however, as many military installations do not have surplus property that is not awaiting some potential future government use, as training space is always in demand and installations increase as tenants move to the installation. Guaranteeing the physical space for the project can be difficult, as other potential projects may prove more expedient than a microgrid or energy project.

The second type of third-party investment is the Federal Acquisition Regulation Part 41 contract. In this contract, the Department of Defense works directly with a utility provider to construct a source of renewable energy, like a wind farm or solar plant. The utility then owns and operates the electric plant on the installation and sells the energy that it generates back to the installation (Miller, 2016). This tool is useful because it allows the utility provider to carry out the project, leading to less work for Army installation project managers. From there, the installation can receive energy directly from its source on the installation. Unfortunately, some utility providers may not be able to offer the deals at a cost that is competitive for the installation. Additionally, energy costs may be cheaper offsite and could undercut the project.

The third type of third-party financial vehicle is the power purchase agreement, where the military installation or agency pays for the construction of a project by either purchasing the energy produced from the utility at a pre-agreed fixed rate or at a scaled rate (Miller, 2016). This is different than a Federal Acquisition Regulation Part 41 contract because it allows for prices to be known and agreed to before a project starts, giving the government a better understanding of its costs in the future. The detriment of this project is that once the contract expires, the utility must remove all equipment and return the project site to its previous condition. While the utility and the installation may choose to continue the contract, it may not leave the installation in a position of financial strength from which to negotiate prices.

The fourth and final type of third-party investment is the energy savings performance contract (ESPC). The ESPC is a contract where an energy service company designs, finances, and constructs a project to conserve energy on an installation (Miller, 2016). The onus is on the contractor to guarantee that the project will save enough money to pay for itself throughout the term of its life. Its strengths are that it is designed to save money, so the ancillary benefits of increased energy resiliency or reduced emissions have a financial incentive. Additionally, once the project pays for its costs, the project remains active, meaning that the installation continues to benefit from cheaper energy costs. Furthermore, the utility funds the project's initial expenses, instead of the installation, which makes this form of investment appealing in fiscally constrained environments. Ultimately, the ESPC allows outside entities to bear the brunt of the costs associated with the project and lets military installations pay back the expenses over the course of the project's life. With the expertise of outside entities, it is a much simpler process than trying to convince Congress to allocate funds to allow the installation to build the microgrid itself.

4. Methods

4.1 Interview of stakeholders

This research consisted of an open-ended qualitative interview of two stakeholders whose official positions offered a unique perspective on the problem. Their knowledge and experience, when synthesized, would help to assess the key factors affecting an installation's need for a microgrid. Research had to address both the variety of stakeholders and the installations they represented. As such, the research conducted interviews with a deputy Garrison Commander from Fort Carson, Colorado and an Energy Manager from Fort Huachuca, Arizona. These two individuals were able to offer unique perspectives because of their roles and the facilities they represented.

In the Army, a Garrison Commander (and, by proxy, the deputy Garrison Commander) is responsible for "day-to-day operation and management of installations and base support services. The [Garrison Commander] ensures that installation services and capabilities are provided in accordance with Headquarter, Department of the Army directed programs" (Department of the Army, 2014, page 8). An installation energy manager, however, "develops a strategy for achieving energy reduction goals, assigns tasks to various organizations, and monitors goals and task progress" (Department of Defense, 2005, page 25). These two individuals held different stakes in their installation's success, providing a richer understanding of the topic.

The two installations are visible in the image below (*Figure 2*) from Google Maps; both locations are indicated with green dots. Fort Carson is in Colorado, just south of Colorado Springs and Fort Huachuca is in Arizona, just west of Sierra Vista., Fort Carson is prone to much more snow and colder winters, while Fort Huachuca is much hotter during the summer. Additionally, Fort Carson is devoted to units that deploy while Fort Huachuca is focused on training. The hypothesis was that this would play a part in the facilities' need for a microgrid.

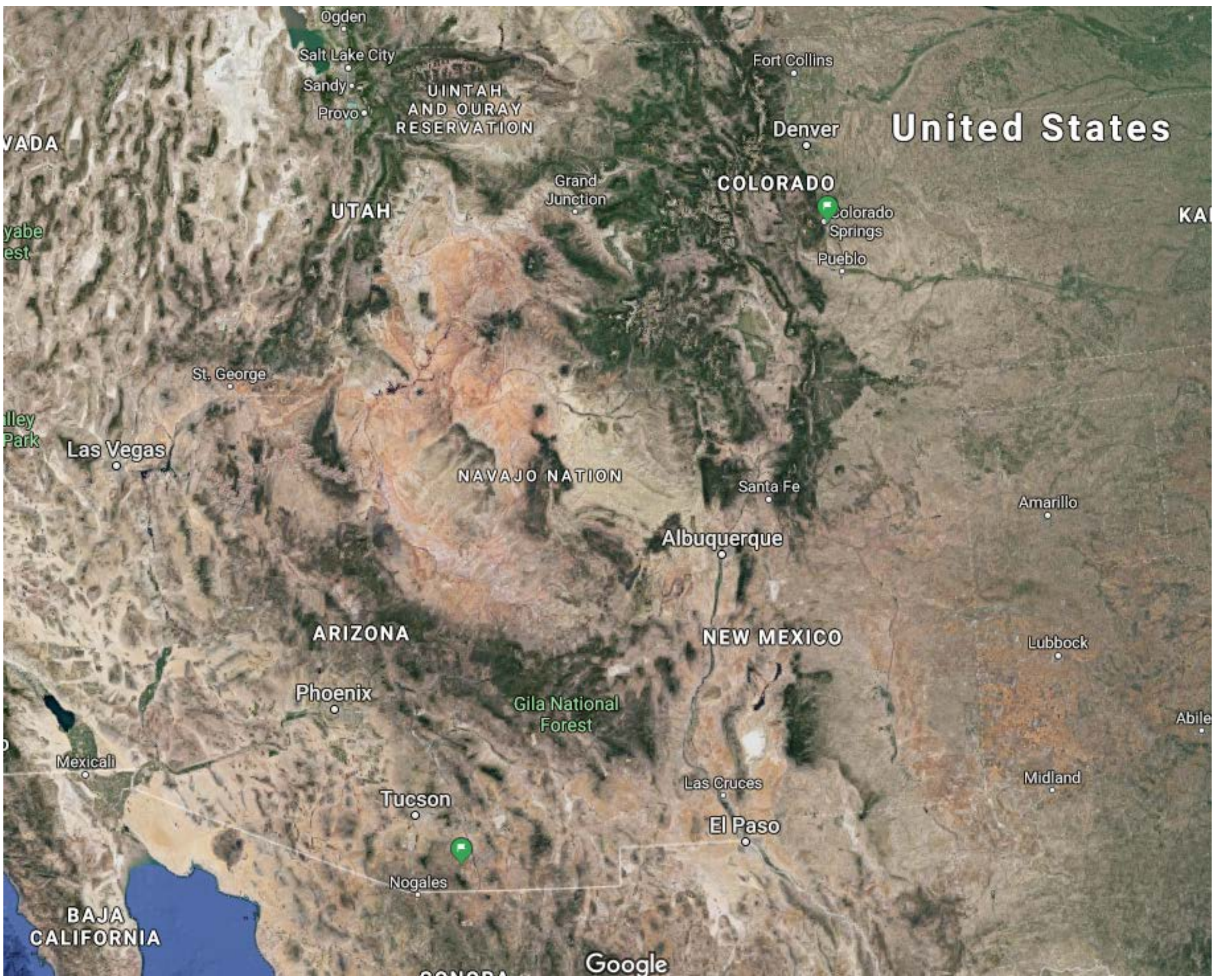

Figure 2. Map showing Fort Carson and Fort Huachuca (Google Maps, 2019)

4.2 How interview was conducted

The interview was conducted over the phone for the deputy Garrison Commander from Fort Carson, Colorado and in person for the Energy Manager from Fort Huachuca, Arizona. Both interviews were recorded with the interviewees' permission. The table below (*Figure 3*) shows the starting questions for the interviews:

1. How many facilities are on the installation?
2. How much electricity do these facilities use daily?
3. What are the installation's key systems or facilities?
4. What is the current backup power plan?
5. How long does backup power last?
6. Where does the installation get its energy?
7. How much energy does the installation produce?
8. Is there a plan or goal to produce more energy on the installation?
9. What energy savings techniques does the installation use?
10. Does the installation have a microgrid? Is there a goal to build one?
11. Will the microgrid operate on island mode?
12. What other ways to we ensure energy resiliency?
13. How do we pay for these systems?

Figure 3. Starting Interview Questions

Through these questions, the stakeholders offered a look into the factors that affected their energy resiliency and ways in which a microgrid could alleviate those concerns. These questions and the stakeholders' detailed responses led to a more natural conversation and allowed additional unscripted questions, furthering understanding.

4.3 How interview was coded and analyzed

The interview was coded at the sentence-level. This means that each sentence was examined to determine if it was addressing a specific factor that could influence a need for microgrids on installations. As different factors were discussed, they were annotated with a different color by highlighting the specific sentence or clause describing the factor. Both interview transcripts shared this same color system. By applying the same coloring format to both interviews, it was possible to compare how the stakeholders viewed the different factors influencing microgrids. For example, when both the Fort Huachuca stakeholder and the Fort Carson stakeholder talked about energy storage, the sentence was color-coded green. These green sentences were compared against one another to determine the impact that energy storage has on microgrid feasibility. Additionally, each sentence was analyzed to determine if they were stating a fact or an opinion. Both interviewees, however, spoke largely in facts. By focusing only on facts, the stakeholders made it even clearer to understand how different factors can support or discourage microgrids on military installations, and the coding process made it easier for each factor to present itself in the research.

5. Results

5.1 Preferred payment

The first result that became abundantly clear from stakeholder interviews was that the Energy Savings Performance Contract (ESPC) was the preferred way to pay for microgrid projects. This is for two reasons: the bureaucratic simplicity of receiving an ESPC and the financial structuring of the contract itself.

As stated earlier in the paper, the ESPC does not require the same kind of congressional oversight that other financing methods require. It is an agreement between a third-party energy provider, the installation, and the Department of Defense. Reducing the number of organizations involved in the decision helps to expedite the bureaucratic process. Stakeholders raved that the ESPC was the best choice because it was an established procedure. This meant that everyone within the professional community understood the ESPC, something unique to that form of funding. The Deputy Garrison Commander from Fort Carson, Colorado described them as the "main tool that the government is using right now that leverages private dollars through these contracts." (Chisholm, 2019, page 7)

Second, stakeholders elaborated that getting senior leaders to care about energy resiliency is difficult. When it comes to gaining the support of senior leaders, one stakeholder highlighted that describing energy resiliency in terms of money could garner the most support. The energy manager of Fort Huachuca described calculating the cost per hour of lost training due to a power outage and using that figure to help promote taking financial risks associated with building a microgrid to reduce the risk of a power outage. The microgrid built by the ESPC also cut the energy costs of the installation, which let the installation pay for the project over time and reduced their overall energy expenses.

Therefore, the ESPC is the preferred payment method of microgrids because of the bureaucratic simplicity and the financial benefits of the process.

5.2 Energy factors and installation factors

What was most noticeable after analyzing interviews with stakeholders was that the factors they described easily sorted themselves into two groups: energy factors and installation factors. The following paragraphs will describe the results of interviewing stakeholders and the two groups of factors that their statements revealed. The first group, energy factors, pertains to how energy influences the microgrid, including its production, sustainability, and storage. These three factors, which can vary by installation, influence how needed a microgrid is on an installation.

The second group of factors are installation factors. These are factors about the installation itself, which influence its need for a microgrid. These four factors are the weather, the purpose of the installation, the population size of the installation, and the distance from its utility provider.

In total, these seven factors, which revealed themselves after interviews with the stakeholders, all affect the need for a microgrid on a military installation. By analyzing these seven factors, it will become easier for decision makers to understand if their installation needs a microgrid, as well as how a microgrid can increase their energy resiliency.

5.3 Energy production

As defined earlier in this paper by other authors, one of the main components of a microgrid is that it must generate some of its own electricity (Schwaegerl and Tao, 2014). This gives the microgrid the ability to operate in an island mode when power from the main utility ceases. As such, it is important for decision makers to determine the best way to produce power on their microgrid. The stakeholders interviewed reiterated that figuring out how to power the microgrid was one of the most important steps. Fortunately, as the number of microgrids worldwide has increased, so too have the number of examples that researchers can use to guide decisions.

One such example is the Gaiduromantra microgrid on the island of Kynthos in Greece. This system generates about 10kW of solar energy from photovoltaic cells, which, in addition to a 52kWh battery bank and a 5kW diesel generator, lets every house in the microgrid live on 100% solar energy with the batteries for the nights and the diesel generator for backup power (Kariniotakis, Dimeas and Van Overbeeke, 2014). This microgrid is an example of one that operates completely in island mode, without any input from the outside energy grid, as evidence by their need for batteries. This is an important proof of concept for stakeholders that seek to operate independently from outside energy utilities.

A second example is the Bronsbergen holiday park near Zutphen in the Netherlands. In this microgrid, experimenters wanted to prove that the system could provide a minimum of 4 hours in island mode in case they had to wait for an interruption in the main utility's power supply (Kariniotakis, Dimeas and Van Overbeeke, 2014). The microgrid produces roughly 315 kW of photovoltaic solar during peak generating hours and consumed a peak load of 150 kW. After tests, the local network operator showed that switching to an island mode during daylight hours was feasible, and the use of batteries could extend the time the microgrid could provide power during a blackout (Kariniotakis, Dimeas and Van Overbeeke, 2014). What is key about this system, as opposed to the system in Gaiduromantra, Greece, is that the microgrid in Bronsbergen does not produce enough energy to provide a constant source of power to the microgrid. This is likely what will happen on military installations: the installation will be able to generate enough power for its key facilities or buildings over a short duration, rather than the entirety of the installation for an extended period. What it does prove is that energy generation, even at a small level, can provide enough certainty to increase the amount of time that an installation or community has power before having to repair the primary energy utility.

The two questions for decision makers, therefore, become how much energy do you produce for a microgrid and how do you produce that energy? After interviewing stakeholders, they determined the first step of the process is to determine the critical infrastructure. The Energy Manager at Fort Huachuca described it by saying, "start at the basics, find out what your load is, find out where your critical missions are." (Porter, 2019, page 7) For a military installation, this means determining what missions require power more than all the others. This can be a difficult challenge, as commanders throughout the installation will have a biased opinion of why their equipment merits power and is the highest priority, obfuscating unbiased analysis. For those designing a microgrid, the challenge comes in determining the true priorities that *must* receive power for the installation to remain effective. Once that can be determined, all that is left to do is determine how much power those facilities need, and for how long they require that power. When decision makers understand that, then the installation can determine the best power source to meet that need.

For determining a power source, it is necessary to understand how the microgrid will generate energy. Will it require off-site resources, such as coal or natural gas, or will it rely on on-site resources, such as wind and solar? For power generation, can the power be intermittent or must it be consistent? For how long? These types of questions are all necessary for decision makers to understand prior to trying to implement a microgrid. These questions lead into the next factor that decision makers must consider.

5.4 Sustainability

Microgrids should reduce the amount of money spent on energy annually on a military installation; this is usually required to fund the project. When installing a microgrid on an installation, the interviewed stakeholders said, the project should examine the totality of energy consumed on an installation and look for ways to reduce energy consumption and therefore reduce the amount of energy required of the microgrid. As such, energy-saving measures become resiliency-increasing measures, something that stakeholders said can influence decision maker buy-in.

When investing money towards a microgrid project, decision makers should therefore find ways to reduce the energy burden of the new microgrid before it is running and include these techniques in the cost of the microgrid. On military installations, numerous opportunities arise to reduce energy demands. Techniques such as motion-activated lights, tinted windows, and better insulation can reduce energy costs. A stakeholder from Fort Carson, Colorado, described switching to energy-efficient lightbulbs in homes, offices, and even traffic lights to conserve energy. Energy managers can employ these techniques throughout military installations. Additionally, he described how Fort Carson likely has the highest number of Leadership in Energy and Environmental Design, or LEED, certified buildings in one location of any government agency (U.S. Green Building Council, 2019). Designing and building LEED certified buildings could be an excellent way to reduce energy costs.

Engineers could construct LEED certified buildings in such a way to reduce energy costs, both in warm and in cold climates. For colder climates, buildings with southern facing windows (in the northern hemisphere) allow more sunlight to enter the building, passively heating the building and reducing the energy needed to heat the building (Prowler, 2016). In warmer climates, where building managers want to reduce excess heat inside buildings, building designers can implement landsape features such as trees to provide shade for the building, venetian blinds, vertical fins, or other types of horizontal sun control devices (Prowler, 2016). For maximum effectiveness, however, it is incumbent that designers build facilities to maximize the seasonal performance of shading devices, which allow sunlight into the building during cool winter months and block sunlight during hot summer months, as depicted below (*Figure 4*):

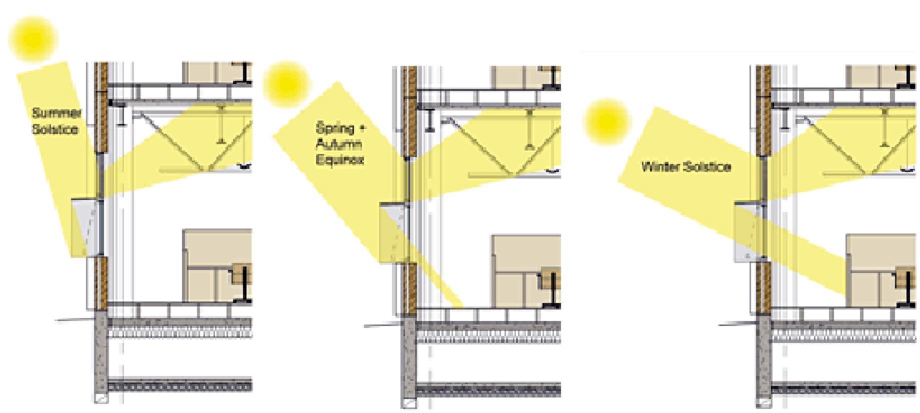

Figure 4. Seasonal Shading Devices (Ander, 2016)

Efforts such as these reduce the demand for energy from the microgrid, thereby making the project more likely to meet its goal of increasing energy resiliency. Additionally, by tying the funding of the microgrid project to enhanced enery savings investments, the installation can more easily pay back the cost of the microgrid, if paid for with an ESPC.

5.5 Energy storage

Decision makers must also decide if energy storage is a necessary component of a microgrid. Energy storage, for the purpose of this paper, refers to any way to contain and preserve electricity for future use. As such, determining the need for energy storage is highly dependent upon how much power the installation generates for a microgrid. In the case of consistent power generation, such as at a nuclear power plant or natural gas power plant, energy storage systems provide less of a benefit because there is little reason to think that the power plant will stop producing power. For other sources of energy that are less consistent, such as wind, solar, or even hydroelectric, battery storage may make sense because power is not always guaranteed. For this factor, the interviewed stakeholders disagreed with one another: Fort Carson's stakeholder described their large-scale batteries they have installed on the installation, while Fort Huachuca's stakeholder did not see a need for batteries with their combined heat and power plant, which provides consistent energy.

Battery storage for an intermittent source of energy, as described above, makes sense once one analyzes the energy needs of the installation and its energy loads. The next step is to determine if the installation generates enough energy only to meet its energy needs without excess energy. If, on the other hand, the installation generates substantially more energy during peak production than it consumes, then an energy storage system may be useful. The energy source can produce electricity for peak demand, with the leftover energy saved for a later period during the day. This is what the Deputy Garrison Commander at Fort Carson described, saying that they use the battery storage on the installation to "feed that back into the system during high peak times to shave those costs so that we are not paying what's called a high demand charge with our provider." (Chisholm, 2019, page 5) Next, it is necessary to determine the purpose of that saved energy.

Some systems, such as the one from Gaiduromantra, Greece, as mentioned earlier, use excess energy generated from solar panels during daylight hours to power the entirety of their gird at night, when solar panels do not generate energy. Based on their energy production and needs, the grid is able operate 24/7 on solar energy, with a small diesel generator as a backup in case of rare periods of extended darkness. Other installations, such as Fort Carson, Colorado use battery storage to cut energy costs. They generate excess energy from their solar plant during non-peak hours, when energy is not as expensive, then feed it into the grid during peak-hours, when energy from the local utility is more expensive, thereby saving money. For decision makers, determining energy storage needs is a necessary part of constructing a microgrid.

Once the energy storage needs of an installation are determined, the next step is to design an energy storage system. There are a few different types of energy storage systems, but this paper will put them into two categories, traditional batteries and physical energy storage. Traditional batteries use "an electrochemical oxidation-reduction reaction between the active materials that are packed in its cell chamber, separated by an ion-conducting electrolyte." (Wei et al., 2014, chapter 1) Examples include commercially available options such as the Tesla Powerwall. Physical energy storage relies on simple physics principles to store energy. One example of this is pumped hydro-storage. In this system, as demonstrated below (*Figure 5*) by the Tennessee Valley Authority, water from a lower reservoir is pumped into an upper reservoir using the excess energy generated in the microgrid (Parfomak, 2012). When the system needs energy, water flows from the upper reservoir to the lower reservoir, turning turbines and generating electricity. This system is more useful if there is already an existing lake or reservoir in place, and may be less feasible if an installation must first construct artificial hills and reservoirs.

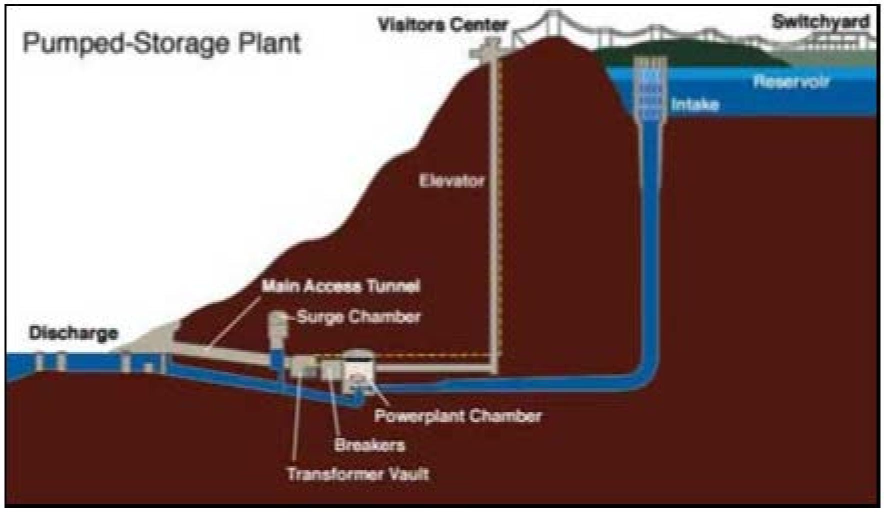

Figure 5. Pumped-Storage Plant (Parfomak, 2012)

Another similar system is a compressed air system, where air is compressed in vast containers with excess power, then released through turbines when energy needs to be generated (Kularatna, 2015). Most non-battery storage systems tend to rely on simple mechanical processes that can easily intake energy and store it for long periods without degradation, something with which larger battery systems still struggle.

Ultimately, an installation's energy generation and energy needs affect the need for energy storage. Decision makers must determine whether there is a need for stored energy, and, if so, how much energy must be stored at one time. At the end of the day, a simple cost comparison may be used to balance the need for energy with the expenses associated with the system- in many cases, diesel generators provide a similar access to emergency energy without the large costs associated with a newer system. Decision makers must decide how much risk they reduce by converting to an energy storage system or a combination with diesel generators. For most installations, some form of energy storage, in combination with traditional facility generators, may be the simplest option that provides a reasonable increase in energy resiliency.

5.6 Weather

Next, stakeholders discussed how weather impacted the feasibility of microgrids on their installations. To begin, both installations have vastly different types of weather. Fort Carson, Colorado, experiences colder temperatures throughout the year and higher amounts of snowfall, necessitating an installation that can maintain heat through long winter months. Fort Huachuca, Arizona, maintains consistently high temperatures throughout the year and rarely receives the cold necessary for snowfall, increasing demand for air conditioning during the summer. Stakeholders described these temperature extremes at both installations as increasing their energy use, mainly to maintain a temperate climate within buildings. Both installations receive heavy rains in the summer months, yet also risk wildfires due to dry air, putting Fort Huachuca's power supply in danger, because it must travel on power lines over 60 miles from Tucson. Large amounts of precipitation, whether from snow or rain, can make getting fuel onto the installation more difficult or dangerous, as well as make it harder to perform maintenance on outdoor backup generators. The charts for their average temperature (*Figure 6* and *Figure 7*), rainfall (*Figure 8* and *Figure 9*), and snowfall (*Figure 10* and *Figure 11*) can be seen below, providing context for the stakeholders' claims (Weather Atlas, 2019).

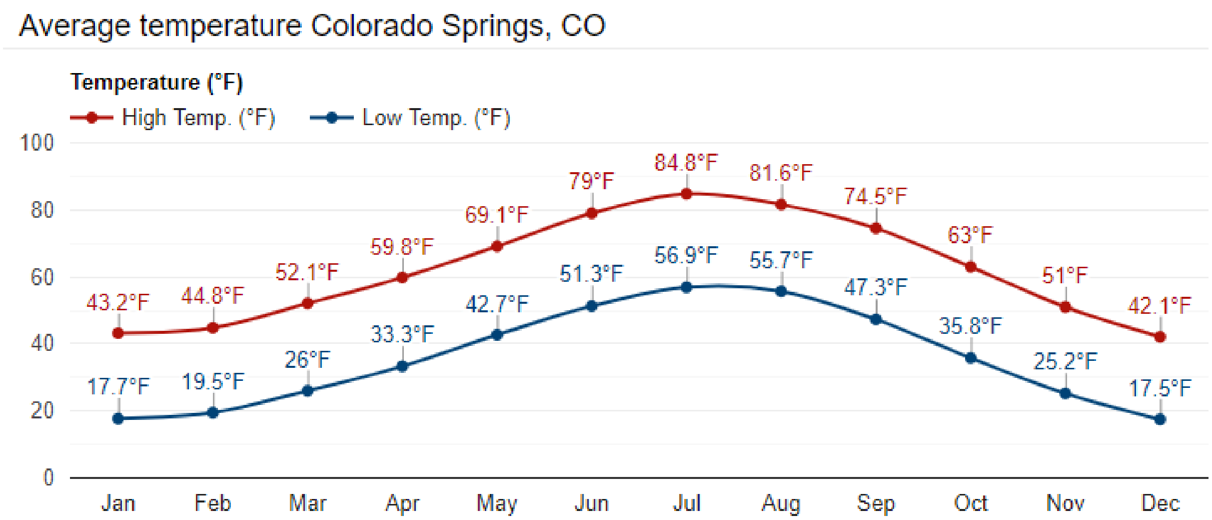

Figure 6. Average Temperature in Colorado Springs, CO (Weather Atlas, 2019)

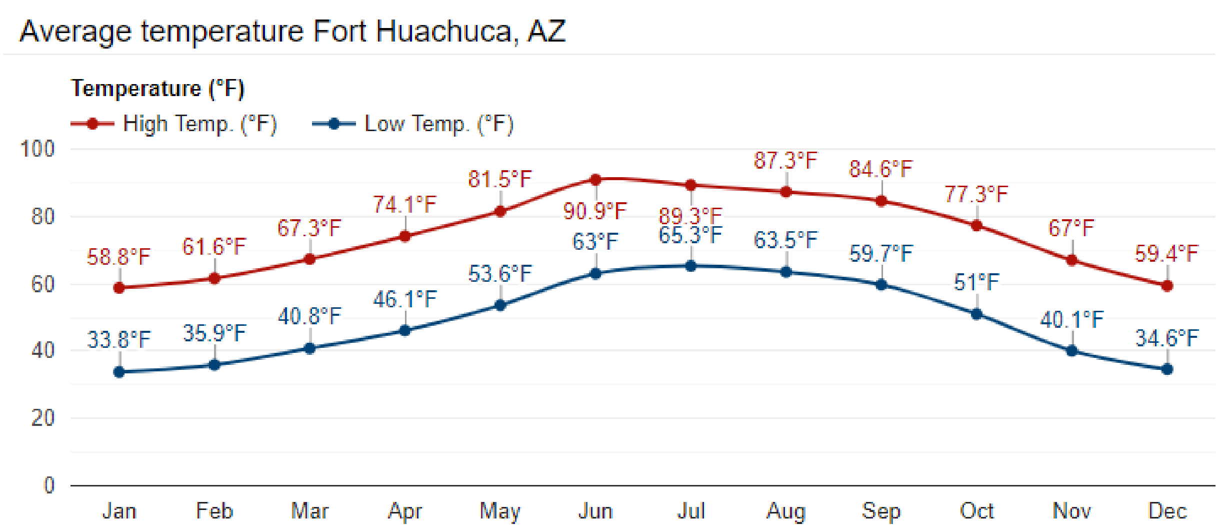

Figure 7. Average Temperature in Fort Huachuca, AZ (Weather Atlas, 2019)

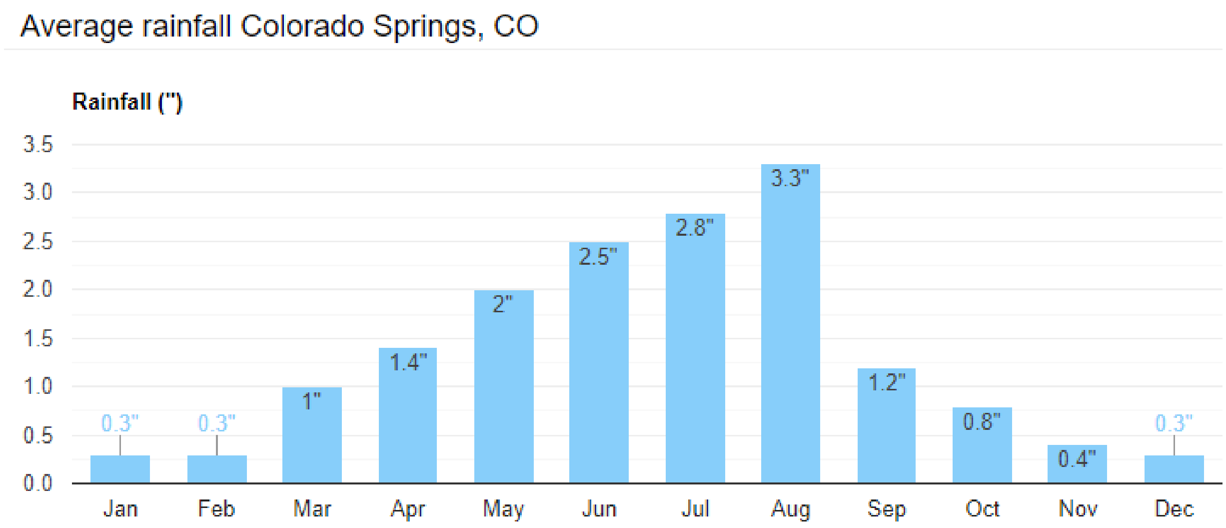

Figure 8. Average Rainfall in Colorado Springs, CO (Weather Atlas, 2019)

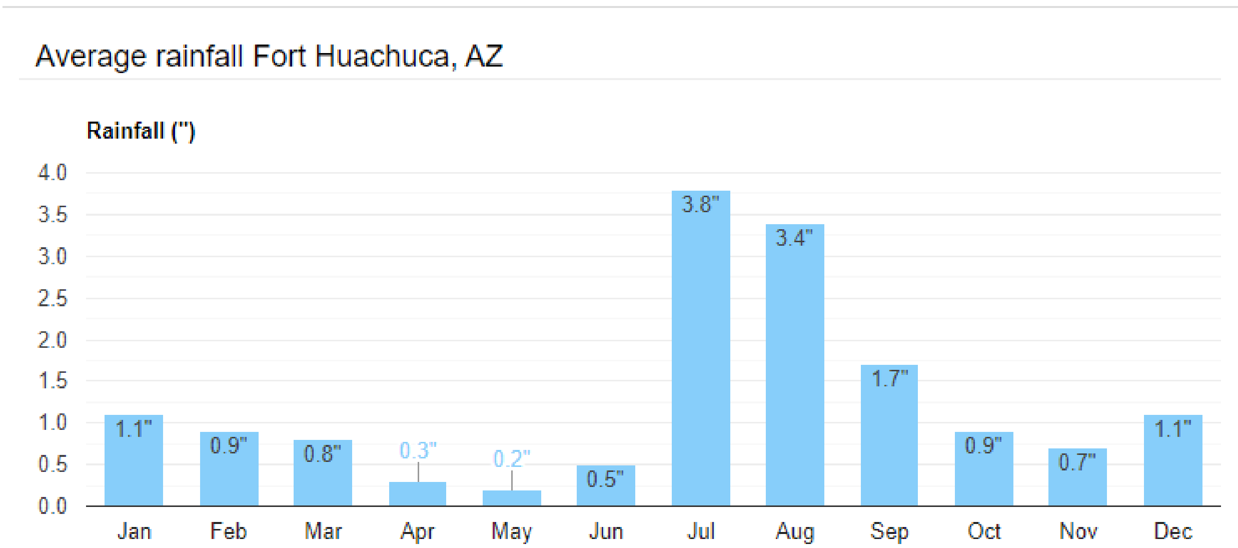

Figure 9. Average Rainfall in Fort Huachuca, AZ (Weather Atlas, 2019)

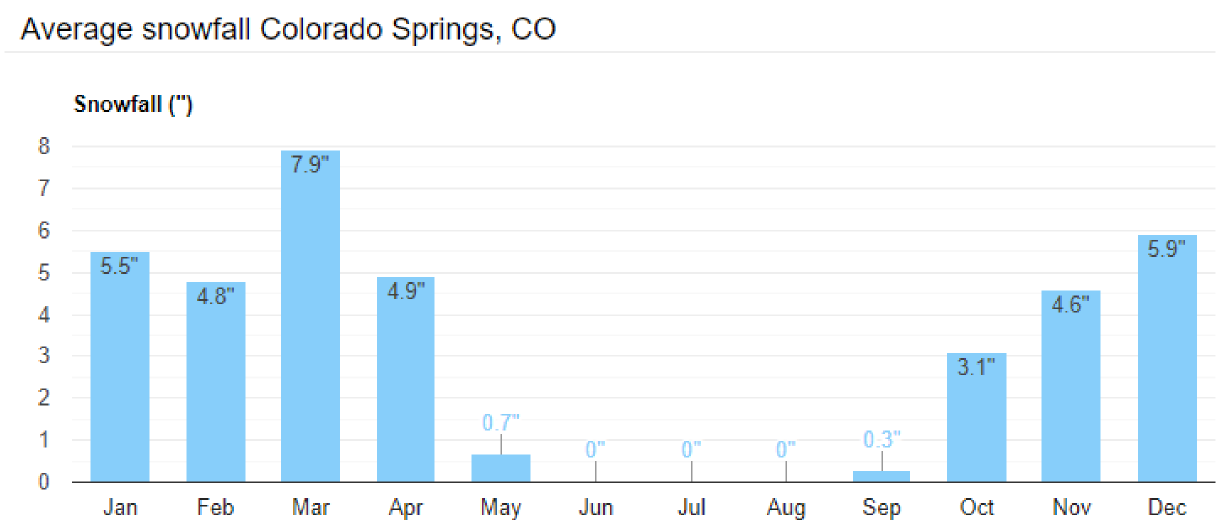

Figure 10. Average Snowfall in Colorado Springs, CO (Weather Atlas, 2019)

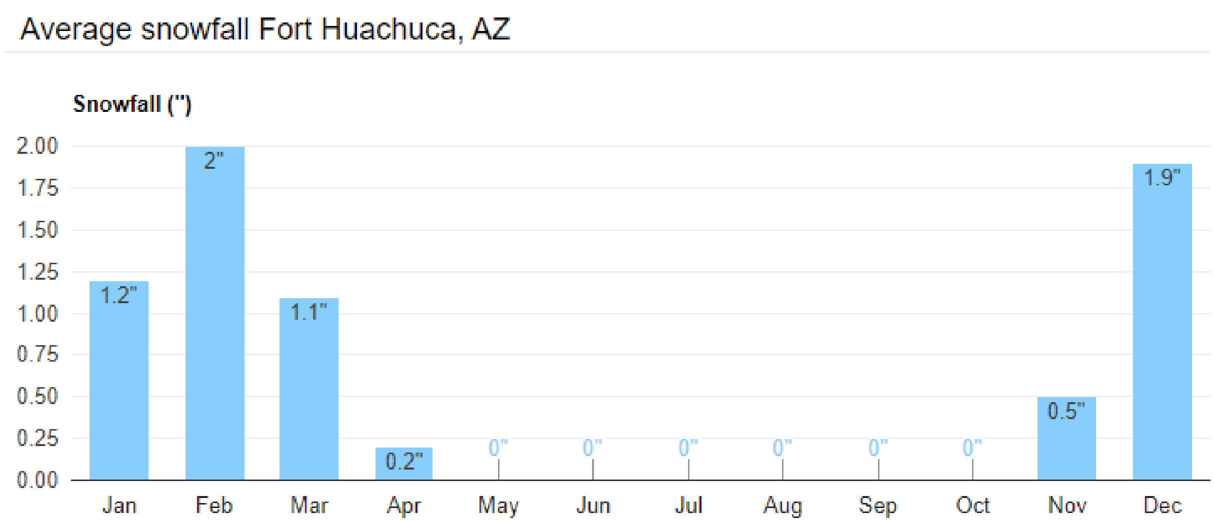

Figure 11. Average Snowfall in Fort Huachuca, AZ (Weather Atlas, 2019)

5.7 Installation purpose

Next, each installation serves a different purpose for the United States Army. Fort Carson, Colorado is home to over 24,000 Soldiers and over 30,000 family members (Fort Carson, 2019).

These 24,000 Soldiers are members of the 4th Infantry Division, 10th Special Forces Group, 4th Security Force Assistance Brigade, and 1st Space Brigade. These units primarily focus on operational deployments around the world. According to the stakeholder from Fort Carson, this means that the key facilities on the installation are the command and communication facilities, such as the Division Headquarters, which needs to maintain contact with higher elements in the chain of command to support deployed units. Fort Huachuca, Arizona, on the other hand, is home to roughly 6,500 active duty Soldiers and 7,400 family members, with a peak of 18,000 people on the installation at its busiest hours (Military Bases, n.d.). Fort Huachuca is home to the 111th Military Intelligence Brigade, the Intelligence Center of Excellence, the Army Network Enterprise Technology Command, and the Electronic Proving Ground. The installation is focused on developing intelligence Soldiers and intelligence systems, capabilities, and doctrine for the Army. It is, in short, a training institution and Soldiers from Fort Huachuca do not deploy; rather, they leave Fort Huachuca for operational units at other installations (such as Fort Carson). As the Energy Manager described, they have "a need to keep our missions going and our missions are critical. We train Soldiers; we have worldwide missions that cannot afford to lose power anytime." (Porter, 2019, page 7) For Fort Huachuca, as the stakeholder described, lost power equates to lost training time, which equates to lost money spent on contractors, food, and housing for the Soldiers on the installation. Each installation therefore has a different size, with Fort Carson the more populous of the two (by about 3 times as many Soldiers), and each is focused on different objectives, which therefore affect their energy needs for a microgrid. Additionally, the installations' purpose influences their size.

5.8 Size

Both installations also vary in size. Fort Carson includes an area known as the Pinon Canyon Maneuver Site, where Army units composed of armored vehicles and tanks can train. Including this area in Fort Carson's total size calculation, Fort Carson comes to about 373,000 acres, or roughly 583 square miles of land (Fort Carson, 2019). Fort Huachuca consists over 2,500 square miles of land, mainly in the western portions of the installation's protected electronic ranges (U.S. Army, 2019). The size of a facility does have an impact on the required power, determined mainly by the equipment on the installation and the number of facilities. Total acreage or size of an installation does not bear much weight on total energy needs. What is important about the size of the installation, however, is where key facilities are located on the installation. The stakeholder from Fort Huachuca, for example, described how the key facilities on the installation were all located geographically close to one another. Additionally, he said that they were all running along the same power line, which allowed the installation to construct the microgrid very easily around its key facilities. Fort Carson, on the other hand, has key facilities for each unit's headquarters scattered around the installation, which makes constructing a microgrid much more challenging. The key takeaway for this factor from the conversation with stakeholders is that larger installations can disrupt the ability to build a small, easily contained microgrid.

5.9 Distance from utility provider

Lastly, it is important to examine how far each installation is from its utility provider, as this has an impact on how resilient its energy supply is before installing a microgrid. Fort Carson, Colorado, is located adjacent to Colorado Springs and is roughly 6 miles direct from its utility provider in Colorado Springs. As its stakeholder explains, they have had consistent power from Colorado Springs Utilities without significant power outages. This can be attributed, in part, to the proximity and shorter power lines running between their facilities and energy provider, reducing the chances for disruption. Fort Huachuca, on the other hand, is over 50 miles direct from its power provider in Tucson, and over 60 miles when accounting for the mountainous terrain. Their energy manager described how every year, they must contend with wildfires in the mountains that fell power lines and disrupt their power supply. The increased distance is an impediment to their ability to provide power consistently, and they are constantly on guard in the summer to make sure their power stays uninterrupted. For this reason, the further the distance from an installation's utility provider, the greater need for a microgrid on the installation to increase energy resiliency and decrease the chance of power outages or mission failure. These distances are displayed in the maps below (*Figure 12* and *Figure 13*) (Google Maps, 2019).

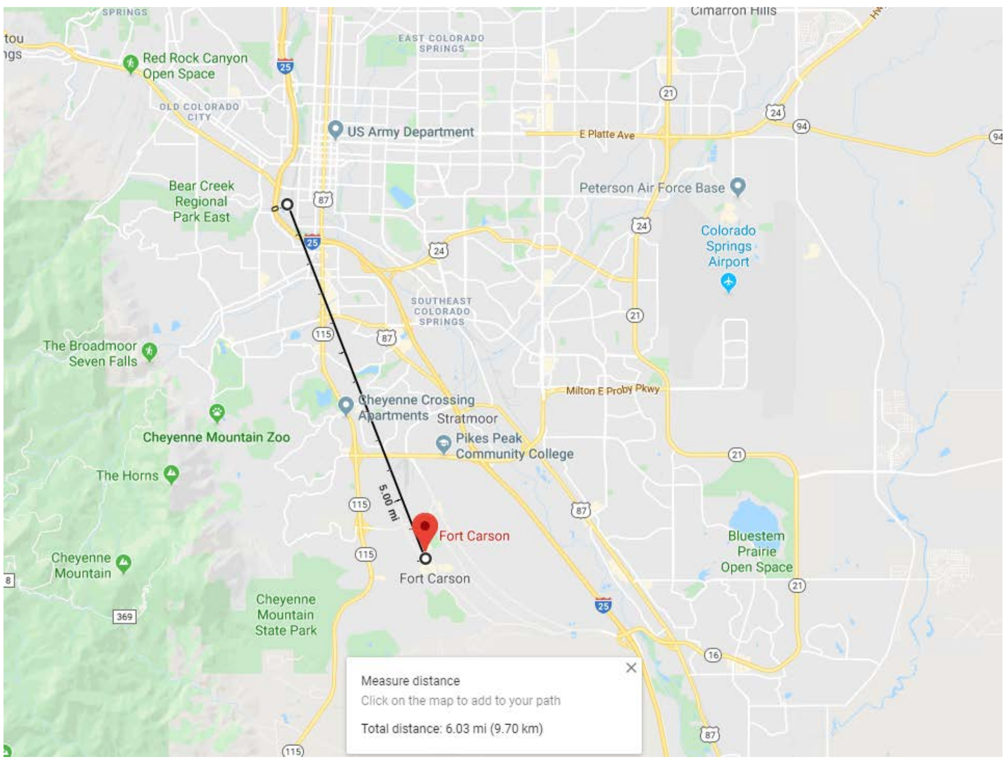

Figure 12. Distance Fort Carson to Colorado Springs Utility, Direct, 6.03 miles (Google Maps, 2019)

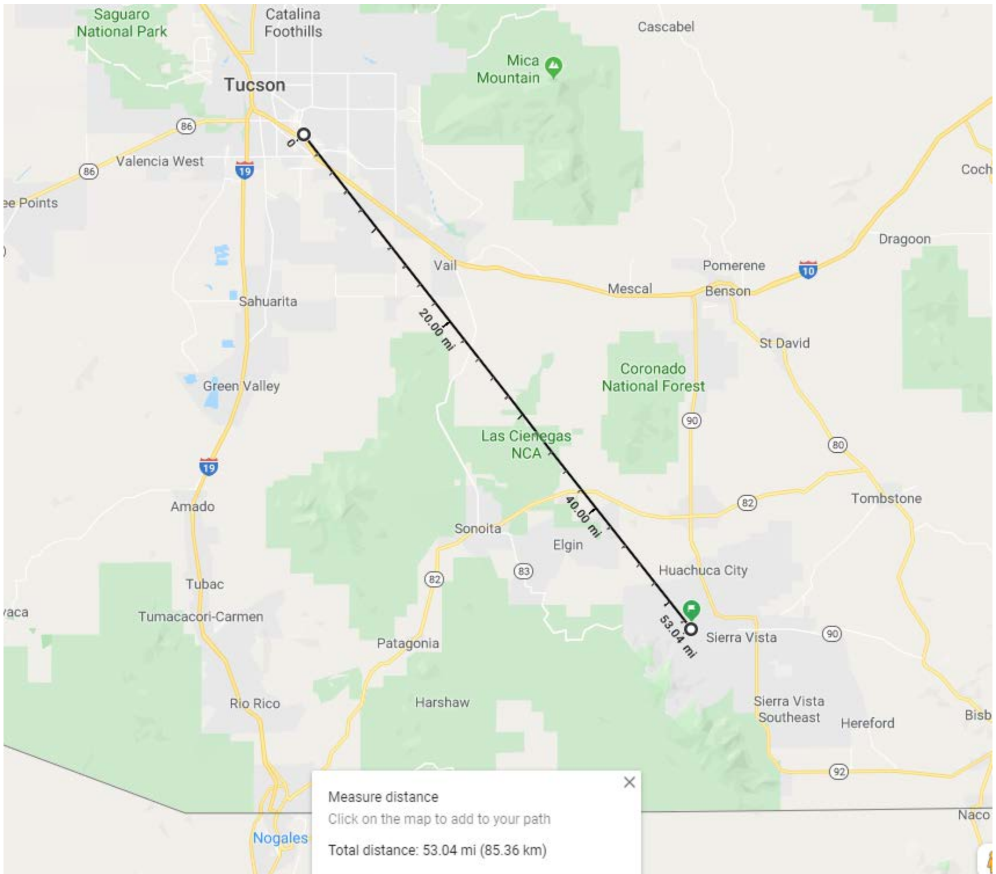

Figure 13. Distance Fort Huachuca to Tucson Electric Power, Direct, 53.04 miles (Google Maps, 2019)

6. Discussion

6.1 Knowledge gained

This paper set out to address the feasibility of microgrids to improve energy resiliency on military installations as a method of increasing national security. Specifically, this paper wanted to determine the factors that affect the feasibility of microgrids on military installations to achieve this end state. This paper determined, after interviews with key stakeholders, that there is one preferred payment method, 3 energy factors, and 4 installation factors that influence the feasibility of microgrids on military installations.

First, stakeholders strongly confirmed that the Energy Savings Performance Contract (ESPC) is the ideal payment method to construct a microgrid.

Next, they determined that the energy production, sustainability, and energy storage factors influence the feasibility of a microgrid on an installation; depending on the installation's pre-microgrid condition and post-microgrid goals, an installation will have a greater or lesser need for a microgrid.

Lastly, research from stakeholders shows that the installation's weather, purpose, size, and distance from its current utility provider all affect the need for a microgrid. These factors are unique to each military installation in the Department of Defense.

With the factors affecting the feasibility of a microgrid identified, stakeholders and decision makers in the military can use these factors to assess their own installation's need for a microgrid. Microgrids may at times pose a daunting risk-reward challenge. Whatever quantitative analysis or financial assessment must occur to assess for a microgrid, ultimately, the problem becomes a determination of how much value is put into increasing energy resiliency and how much resiliency does a microgrid project provide for your installation. By understanding these factors described above and assessing how a microgrid can improve these factors, stakeholders and decision makers are better poised to address and analyze their installation's need for a microgrid and determine what a microgrid must change to improve their installation's energy resiliency in a cost-effective manner.

6.2 Gaps in case study; where future research is needed

This case study has expanded knowledge by identifying what variables determine a microgrid's feasibility on a military installation. There were several limitations to this study's depth. First, the interviews only addressed two stakeholders, limiting the quantity of viewpoints. Second, the stakeholders represented only two installations, which limits the diversity of problems associated with energy policy on military installations. Third, the facilities were only Army installations, which have unique mission requirements compared to Navy, Air Force, and even Marine Corps installations. Finally, the installations themselves were all located within the continental United States. Installations located overseas or in combat zones will have vastly different energy needs.

The next step for researchers is to determine a way to quantify these factors on military installations pre-microgrid and determine how a microgrid can quantifiably improve these factors. For example, in the case of Fort Huachuca, a microgrid will reduce the distance from their essential facilities to their power source, from over 50 miles away to on the installation itself. Being able to compare the impact that a microgrid will have on the installation and thereby quantify the value of the microgrid will provide decision makers greater understanding to develop and implement microgrids on their installation. It will also allow for a more precise measuring of the feasibility for a microgrid on military installations, strengthening the arguments behind funding the projects and making it easier to compare the cost of the system with its measured impact on energy resiliency. Ultimately, a better understanding of microgrids will lead to enhanced energy resiliency and thus, increased national security posture for the United States.

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8. Author Biography

Graham Haydon grew up in Downingtown, Pennsylvania. He attended the United States Military Academy at West Point, NY and graduated in 2015 with a Bachelor of Science in American Politics and a Bachelor of Science in French. He commissioned in the United States Army as an intelligence officer. After training at Fort Huachuca, Arizona, he was stationed at Fort Carson, Colorado. He deployed once to Europe in support of Operation Atlantic Resolve and twice to Kandahar, Afghanistan in support of Operation Freedom's Sentinel. Graham began his Master of Science in Energy Policy & Climate at Johns Hopkins in January, 2017. He will leave active duty in the summer of 2020 and plans to pursue a career in sustainable energy.