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Analysis of Marine Corps renewable energy planning to meet installation energy security requirement

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THESIS

ANALYSIS OF MARINE CORPS RENEWABLE ENERGY PLANNING TO MEET INSTALLATION ENERGY SECURITY REQUIREMENTS

by

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December 2013

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The purpose of this thesis is to analyze Marine Corps installation energy consumption and the pursuit of increased renewable energy generation goals across Marine Corps installations. The main objective of this report is to determine the cost of interruption and the net present value (NPV) of renewable energy generation needed to meet the Marine Corps' energy security objectives.

First, we determine installation-specific energy consumption, resource requirements, and current renewable energy generation projects. Second, we analyze current Marine Corps installation energy portfolios to determine shortfalls from minimum energy targets and the cost to generate those shortfalls through renewable energy technologies. Finally, we identify installation energy security requirements, determine cost of interruption, and conduct a sensitivity analysis of the cost-benefit of renewable energy generation alternatives to meet energy security requirements.

This study determines how investment in renewable energy to meet baseline energy consumption requirements increases energy security across Marine Corps installations. Furthermore, considering the cost of interruption, the investment in renewable energy technologies yields a positive NPV at the majority of Marine Corps installations. Based on this research, we recommend that the Marine Corps develops a quantitative method for assessing energy security and invest to meet energy security goals at each installation.

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MASTER OF SCIENCE IN MANAGEMENT

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LIST OF ACRONYMS AND ABBREVIATIONS

CDF	customer damage function
CMC	Commandant of the Marine Corps
COG	co-generation
CONUS	contiguous United States
DoD	Department of Defense
DoE	Department of Energy
DUERS	Defense Utility Energy Reporting System
EIA	Energy Information Administration
EPACT 2005	Energy Policy Act of 2005
FY	fiscal year
HQMC	Headquarters, United States Marine Corps
I&L	Installations and Logistics
kW	kilowatt
kWh	kilowatt hour
LFG	landfill gas
MCAS	Marine Corps Air Station
MCB	Marine Corps Base
MCD	Marine Corps District
MCLB	Marine Corps Logistics Base
MCRD	Marine Corps Recruit Depot
MCSF	Marine Corps Support Facility
MET	mission-essential task
mmBtu	million British thermal unit
MPT	Modern Portfolio Theory
mWh	megawatt hour
NPV	net present value
NREL	National Renewable Energy Laboratory
NSS	National Security Strategy
NZEI	Net-Zero Energy Installation
OCONUS	outside contiguous United States

PPA	power purchase agreement
PV	photovoltaic
RE	renewable energy
REopt	Renewable Energy Optimization
SAIFI	system average interruption frequency index
SECNAV	Secretary of the Navy
VEES	Value of Electrical Energy Security

EXECUTIVE SUMMARY

The mandate to increase renewable energy generation in the federal government began with the Energy Policy Act of 2005 (EPACT 2005) and, since then, the Marine Corps has undertaken an aggressive strategy to not only meet but also exceed the EPACT 2005 mandates by 2020. Renewable energy (RE) generation at the end of fiscal year (FY) 2013 achieved the congressional mandate of 7.5% and projects increases to 39% by the end of FY2020, as shown in Figures 1 and 2. Yet, despite these current and emerging projects, the Marine Corps has failed, in policy terms, to determine the economic value of energy security. Therefore, the Marine Corps remains vulnerable to electrical grid interruption. Furthermore, planned FY2014 and later investments at installations that already meet or exceed minimum energy requirements, such as Marine Corps Logistics Base (MCLB) Albany and Marine Corps Base (MCB) Twentynine Palms, only boost 2020 energy generation goals but do little to increase energy security. This strategy of over-investing in low-cost RE generation projects to meet energy goals comes at the expense of providing energy security to all installations.

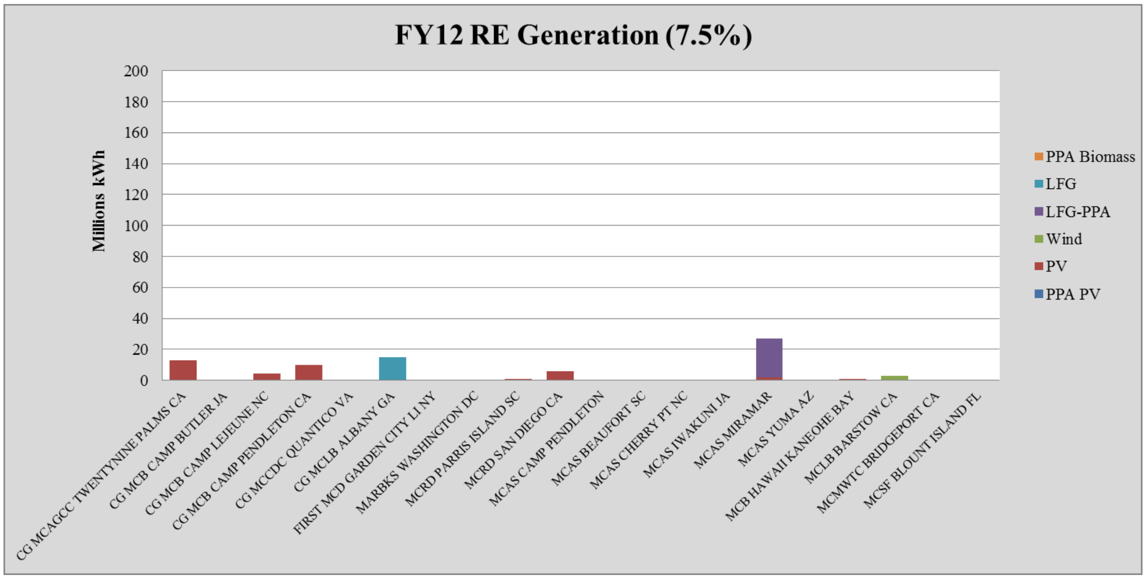

Figure 1. FY2012 Marine Corps RE Generation

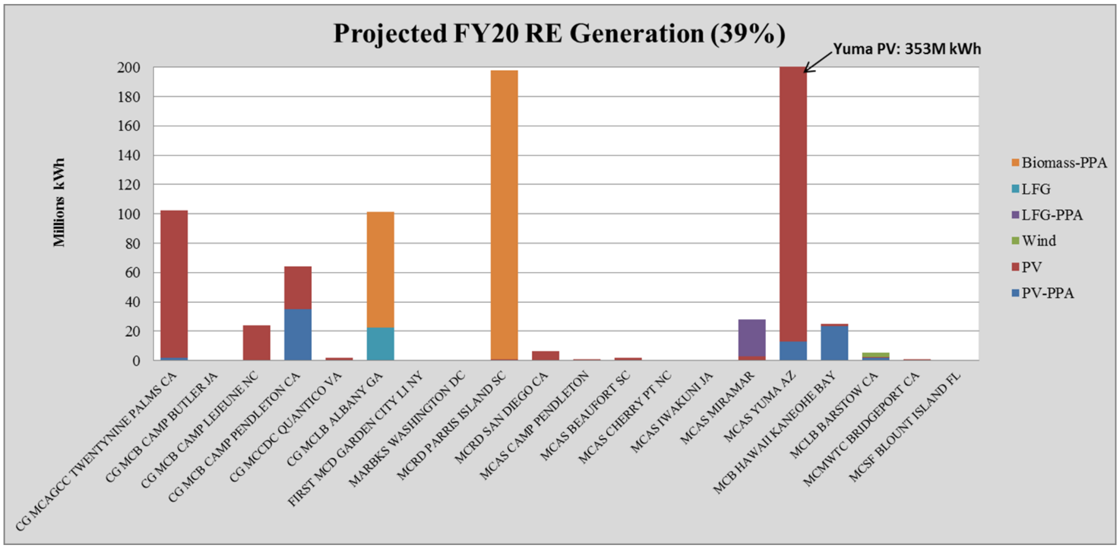

Figure 2. Projected FY2020 Marine Corps RE Generation

The Department of Defense (DoD) defines *energy security* as the access to reliable and affordable energy without the threat of disruption, either intentional or unintentional. In 2011, the commandant of the Marine Corps released the *United States Marine Corps Expeditionary Energy Strategy and Implementation Policy*, outlining three major installation energy goals and specifically discussing domestic installation vulnerability. The strategy stated:

> on the homefront, a secure source of energy is critical to our ability to maintain readiness. Our installations rely primarily on the commercial electrical grid and gas infrastructure to power the training and mission support operations that prepare Marines for combat. *This dependence leaves us vulnerable to accidental or intentional energy and power disruptions and places our mission-critical operations at risk.* (Emphasis added.) (Headquarters, United States Marine Corps [HQMC], 2011, p. 10)

The probability of grid interruption is inherent to each installation that relies on the national energy grid for electricity. This vulnerability translates into risk that is quantified into the costs of interruption (e.g., loss in productivity, food spoilage). An accurate representation of the cost of interruption provides commanders and energy planners with information to create strategies to counter this risk. More importantly, quantifying interruption in terms of cost serves as a useful surrogate for defining each installation's exposure to an unstable civilian infrastructure. To date, this is the first comprehensive study that analyzes Marine Corps installation grid energy risk in any measurable way that we are aware of.

Energy security is fundamental to operational readiness; therefore, energy planners must develop quantitative methods to avoid interruption risk and achieve installation energy security through RE projects. To accomplish this, the Marine Corps must first establish specific minimum energy requirements for each installation to meet mission-essential tasks (METs) during an interruption. These requirements will allow energy planners to determine where initial RE generation investments are needed and at what scale. For the purposes of this study, Headquarters, United States Marine Corps (HQMC) Installations and Logistics (I&L) has assessed the minimum installation energy required to meet METs between 10% and 20% of electricity consumption. Second, energy planners must develop methods for monitoring grid interruptions at each installation and their impact to operations. Collecting interruption data will assist in obtaining an accurate prediction of the frequency and the cost associated with grid interruption. Finally, each installation should evaluate current restrictions that are preventing the Marine Corps from investing in wind technology. Investment in this relatively low-cost form of RE technology can assist the Marine Corps in meeting both energy security and strategy goals.

In FY2012, grid electricity accounted for over half of total Marine Corps energy consumption, at 51%. Due to the potential risk of grid interruptions, both unintended and intended, there are significant energy security risks to Marine Corps installations. While consumption patterns differ across East Coast and West Coast contiguous United States (CONUS) installations, installations in both regions rely heavily on grid electricity (48% and 40% of consumption, respectively). In this study, we set RE generation targets at 10%, 15%, and 20% of electricity grid consumption at 20 installations to assess (a) how much RE would be needed for each installation to meet METs during a grid interruption at each target percentage; (b) what RE generation shortfalls exist, given generation targets, throughout the Marine Corps based on current RE projects; and (c) the comparison between the net present value (NPV) of investing in RE projects to meet consumption targets and the NPV of investing in RE projects when risk is accounted for. Figure 3 shows the projected FY2020 RE generation measured against RE generation required to meet the 20% energy security target. The horizontal axis, or zero, represents RE generation that meets the 20% energy security target. In the FY2020 projections, over half (shown in blue and below the X axis) of Marine Corps installations cannot generate the 20% RE target to meet minimum energy security requirements and are left vulnerable to intentional or unintentional interruption. On the other hand, nine installations will be over-invested at the 20% target and prevent investments at shortfall installations from meeting minimum energy security requirements (e.g., Marine Corps Air Station [MCAS] Yuma's FY2020 RE generation is seven times the projected consumption of all energy sources).

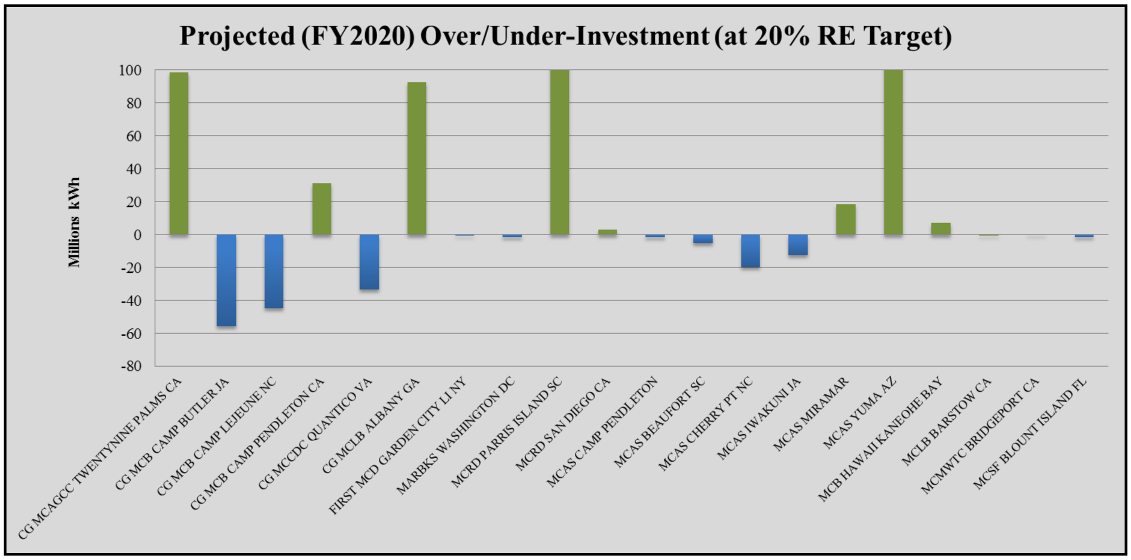

Figure 3. FY2020 RE Projections vs. 20% RE Targets

In this study, we determined that in terms of levelized life-cycle cost, the NPV of investing to meet minimum energy requirements at each target (10%, 15%, and 20%) is positive at half of the Marine Corps installations included in this study. **By including the cost of interruption (the risk) at each installation, the NPV of investment in RE technology is positive beyond the 20% target at 19 of the 20 installations studied.** Therefore, prioritizing installation RE investments to meet energy security requirements proves to (a) achieve energy security requirements by reducing installation grid energy vulnerability and (b) increase total RE generation toward FY20 goals by increasing RE generation at each installation. Figure 4 shows what the Marine Corps baseline RE investment (at the 20% target) should look like in order to first meet the commandant's stated intent for installation energy goals: provide a secure source of energy from which to maintain and increase operational readiness. From this baseline, the Marine Corps can build toward increased RE generation while maintaining energy security, through a more practical energy strategy that eliminates its vulnerability on the home front.

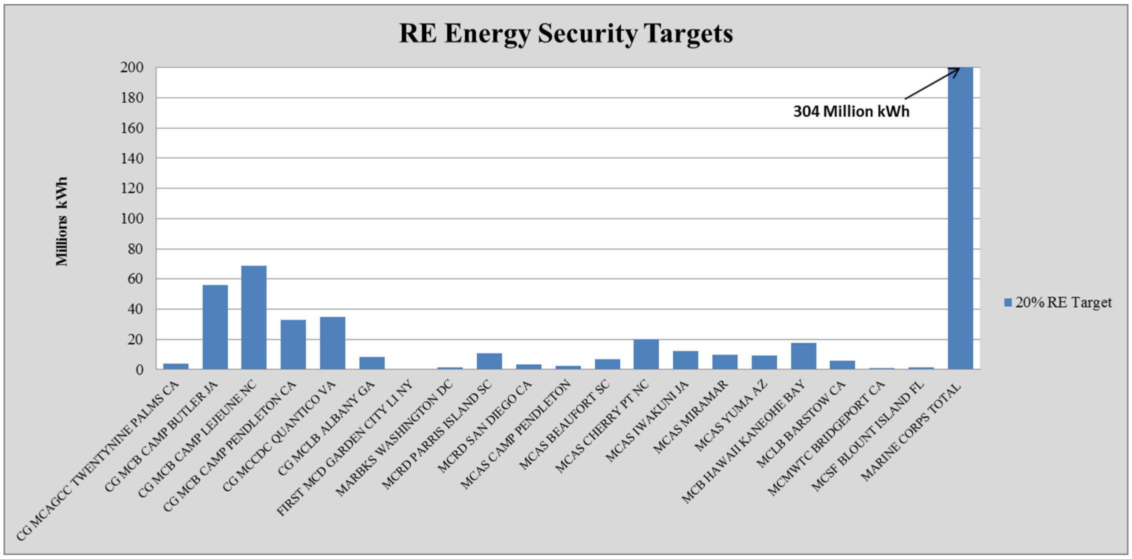

Figure 4. Proposed RE Projections at 20% Target for Energy Security

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I. BACKGROUND/LITERATURE REVIEW

A. PURPOSE

The purpose of this thesis is to examine a portfolio approach to Marine Corps installation energy consumption and the pursuit of increased RE generation goals across the Marine Corps' major installations. The main objective of this report is to determine the cost of interruption and the net present value of RE generation needed to meet the Marine Corps' energy security objectives. First, we determine installation-specific energy consumption, resource requirements, and current renewable energy generation projects. Second, we analyze current Marine Corps installation energy portfolios to determine shortfalls from minimum energy targets and the cost to generate those shortfalls through renewable energy technologies. Finally, we identify installation energy security requirements, determine cost of interruption, and conduct a sensitivity analysis of the cost–benefit of renewable energy generation alternatives to meet energy security requirements. The data used throughout this report is available through the U.S. Department of Energy (DoE), the U.S. Energy Information Administration (EIA), the National Renewable Energy Laboratory (NREL), and HQMC I&L.

The Marine Corps is overwhelmingly dependent on energy resources (particularly externally sourced resources) to meet mission requirements, increase operational readiness, and sustain the force in garrison. To this end, it is imperative that the Marine Corps acquire a long-term energy resourcing strategy that is sustainable, viable, and secure. Our analysis will assist the Marine Corps in determining optimal future investments in renewable energy initiatives using portfolio analysis and cost–benefit analysis.

B. RESEARCH OBJECTIVES

Our research objectives are as follows:

1. provide an overview of the Marine Corps' energy strategy and five lines of operation to achieving energy goals,
2. provide an overview of net-zero energy installations,

3. provide an overview of the application and analytical framework of Modern Portfolio Theory to energy planning,
4. provide an overview of learning curve (S-curve) analysis and the application to renewable energy resources and planning,
5. determine installation-specific energy consumption and minimum energy requirements to meet mission-essential tasks.
6. provide a current picture of the Marine Corps installation energy portfolios, including existing RE generation,
7. determine installation energy generation shortfalls to meet minimum energy requirements,
8. determine the cost of energy interruption per installation, and
9. determine the NPV of RE generation to meet minimum energy requirements.

C. RESEARCH QUESTIONS

Our research questions are as follows:

- Can a portfolio approach to energy planning determine a baseline RE investment needed to meet Marine Corps energy goals? This question addresses Objectives 1, 2, 3, 4, 5, and 6.
- Based on minimum energy consumption requirements and renewable generation shortfalls, what amount of RE generation, per installation, is needed to overcome the shortfall? This question addresses Objectives 5, 6, and 8.
- What is the cost of increased RE on each installation to meet energy security goals? This question addresses Objectives 4, 5, 6, 7, 8, and 9.
- What is the NPV of RE resource generation to meet energy security goals? This question addresses Objective 9.

D. SCOPE

In this paper, we examine the Marine Corps' energy portfolio from a macro perspective to determine whether Modern Portfolio Theory (MPT) can be applied to meet the installation energy strategy. For this analysis, we examined 13 CONUS-based installations and one outside contiguous United States (OCONUS) installation (i.e., MCB Kaneohe Bay, HI) based on existing RE generation capability. Additionally, we investigated 20 Marine Corps installations, both CONUS and OCONUS, to determine the value of energy security. Specifically, this study determines the cost of energy grid interruptions at multiple time intervals to determine the NPV of RE generation to achieve installation energy security goals. Installation energy goals for this part of the study are only defined as 10%–20% of installation energy consumption, which is the stated minimum energy needed to meet installation METs off of the grid. Finally, our study offers conclusions and recommendations for how the Marine Corps should incorporate economic analysis into energy planning.

E. STUDY BENEFITS

The *United States Marine Corps Installations Energy Strategy* (HQMC, 2013) provided the foundation for improved energy planning and increased RE generation; however, it did not discuss methods that analyze the economic feasibility of implementing energy efficiency, RE generation, or education to meet FY2020 installation goals. Our study offers a theoretical approach to energy planning by analyzing the entire Marine Corps energy portfolio. In our approach, we seek to determine if agency-wide energy efficiency and RE projects are a more viable means of reaching Marine Corps energy goals. Additionally, our study determines the value of energy security for Marine Corps installations and provides recommendations for RE generation, per installation, to meet minimum energy security requirements.

F. METHODOLOGY

This study is divided into two parts: (a) application of MPT to Marine Corps energy planning and (b) valuing energy security from cost of interruption and renewable energy generation cost. The first part of this study analyzes the work of Shimon Awerbuch on MPT application to Marine Corps energy planning. We gathered the data for the MPT application study from the Defense Utility Energy Reporting System (DUERS) database, NREL studies, the EIA, and HQMC I&L. The second part of this study determines the minimum amount of energy needed at each installation in the event of a power interruption, the cost of the interruption, and the amount of RE generation needed for the installation to meet METs off the grid. We compared this data to the life-cycle cost of the RE resource to analyze the NPV of energy security. We gathered data for the second part from NREL studies, HQMC I&L, and Eaton Corporation's power quality database.

G. ORGANIZATION

This study is presented in five chapters. The first chapter provided an executive summary of the study. Chapter II introduces background information related to the problem and provides a literature review of MPT, energy security, and learning curve analysis of solar and wind technologies. Chapter III outlines the methodology of the study. In Chapter IV, we examine the data analysis conducted for MPT and valuing energy security. Finally, in Chapter V, we discuss the study's conclusions and make recommendations for further research.

H. ENERGY PLANNING

1. Energy and the Department of Defense

The DoD accounts for 80% of the annual federal energy use and is the largest consumer of energy nationwide at $19.4 billion in energy costs in 2011. The NREL reported that "the majority of DoD energy consumption is fossil fuel based (coal, oil, natural gas, or electricity produced from these), often from foreign sources" (Booth, Barnett, Burman, Hambrick, & Westby, 2010, p. 2). Energy availability remains critical to maintaining military operational readiness and is therefore a strategic element of a national security strategy (NSS). Energy security is the vital connection between energy availability and national security; however, continued reliance on fossil fuels, particularly from foreign sources, weakens the NSS. Secretary of Defense Leo Panetta stated that "rising global demand for energy, changing geopolitics, and new threats mean the cost and availability of energy for deployed forces and for all Americans will be less certain" (DoD, 2012, p. 1). Domestically, the unpredictability of cost and the potential for power interruptions puts the military's installations and infrastructure at risk because of the military's reliance on the national energy grid. In an effort to mitigate the risks associated with national energy security and to change the methods that power the U.S. military, the DoD published *Operational Energy Strategy*. This strategy focuses on three areas: (a) reducing demand for energy, (b) expanding energy supplies, and (c) building energy security into our operational future (DoD, 2012).

2. The Marine Corps Energy Strategy

In 2009, the commandant of the Marine Corps (CMC) identified energy as a top priority. To achieve the DoD and Department of the Navy's energy goals, the CMC created the Expeditionary Energy Office specifically to "analyze, develop, and direct the Marine Corps's energy strategy in order to optimize expeditionary capabilities across all war-fighting functions" (HQMC, 2011, p. 5). The Marine Corps' warfighting capabilities originate from various nationwide training and garrison installations that are tethered to the nationwide energy grid for the Corps' electrical and natural gas resource needs. While reliance on the national energy grid provides a relatively reliable source of installation energy, this reliance leaves the Marine Corps vulnerable to intentional or unintentional power interruptions. Vulnerability is a risk that ultimately reduces the operational readiness of the Marine Corps and therefore must be mitigated.

In the *United States Marine Corps Expeditionary Energy Strategy and Implementation Policy* (HQMC, 2011), the commandant outlined three installation goals for changing the way that the Marine Corps resources and employs energy at its facilities. First, certify that the energy provided to support operations and housing at Marine Corps installations is safe, reliable, and affordable. Second, reduce the overall life-cycle costs and hedge against energy market volatility. Finally, support the national effort of conserving limited natural resources, increasing energy security, and lessening the environmental impact of operations (HQMC, 2011). The associated quantitative goals include

- reducing installation energy by 30% by 2020,
- increasing installation RE consumption by 50% by 2020, and
- decreasing non-tactical fuel usage by 50% by 2015 (HQMC, 2011).

By implementing its aggressive and proactive energy strategy, the Marine Corps intends to convert 50% of its installations to net-zero energy installations by FY2020.

3. The Marine Corps Installation Energy Strategy

As previously stated, combat effectiveness and operational readiness do not begin on the battlefield but at the various Marine Corps installations worldwide. Therefore, Major General Kessler, commander of Marine Corps Installations Command, published the *United States Marine Corps Installations Energy Strategy* as a guiding document to reinforce the commandant's energy priorities. The foundation of this energy strategy is to "maintain mission readiness, achieve mandates, and reduce energy costs" (HQMC, 2013, p. 2). Conceptually, this strategy will be implemented through five unique lines of operation: (a) energy information, (b) energy efficiency, (c) RE and alternative fuel, (d) energy security, and (e) energy ethos (HQMC, 2013). While energy ethos is not as tangible an initiative as the other four, it represents a top-down change in cultural perception through awareness, shared vision, and collaboration; it is a vital foundation to the success of the Marine Corps energy strategy. From an RE resource perspective, the Marine Corps will not only look to implement on-site, large-scale RE projects over 1 megawatt (MW) but also pursue increased capacity through small-scale generation projects (HQMC, 2013).

4. Net-Zero Energy Installations

In 2008, the DoD and the DoE worked diligently in cooperation to identify a strategy to reduce energy consumption and increase renewable resource use aboard military installations. The outcome was the net-zero energy installation (NZEI) model. The concept of the model is based on a self-sufficient system that reduces energy demand while implementing RE resources. The official NREL definition of a net-zero installation, as adopted by the DoD and DoE, is as follows: "a net-zero military installation produces as much energy on-site from renewable generation or through the on-site use of renewable fuels, as it consumes in its buildings, facilities, and fleet vehicles" (Booth, Barnett, Burman, Hambrick, Westby, 2010, p. 5). There are three tenants behind decreasing energy consumption at NZEIs: (a) reduce energy consumption through conservation efforts, (b) implement modern energy efficiency initiatives to reduce energy consumption, and (c) establish RE generation projects on installations.

While implementing these tenants appears relatively simple in principle, converting a military installation to an NZEI is far more complicated in practice. Anderson, Booth, Burman, and Callahan (2011) asserted that there are key considerations—such as impacts on installation mission, installation resource challenges, cost, security, and national and local energy mandates—associated with assessing an installation for net-zero potential. The NREL uses a specific net-zero assessment and planning strategy that provides the DoD and DoE with a comprehensive assessment of installation potential.

The MCAS in Miramar, CA, was the NREL's initial prototype installation assessment for NZEI potential. Analyzing MCAS Miramar's NREL assessment highlights the factors for consideration when attempting to implement renewable resource and energy-efficient projects at the installation level. Overall, Callahan, Anderson, Booth, Katz, and Tetreault (2011) assessed MCAS Miramar as having high potential to become a NZEI. Specifically, the NREL stated that:

> Net zero energy status is within reach if Miramar implements the recommended measures, replaces all remaining natural gas with biogas, and completely switches the government transport fleet to renewable fuels or to electric vehicles as these become more widely available. (Callahan et al., 2011, p. 53)

Additionally, Callahan et al. (2011) assessed Miramar for all possible renewable resource energy opportunities but found that photovoltaic (PV) energy was unaffordable while wind, biomass, and concentrating solar energies were not possible. The ideal renewable resource that was reliable and economically feasible for MCAS Miramar was fuel cells. From a financial perspective, the NREL assessed that the implantation of net-zero recommendations would save \$26 million (NPV of \$6.7 million) in energy costs over a 20-year lifetime (Callahan et al., 2011). The key highlight from the Miramar NZEI assessment is that the potential for any military installation to achieve net-zero objectives is specific to each installation and may not be a realistic option depending on many factors, such as constraints specific to each installation (i.e., there is a huge gap between what is desirable in principle and what is attainable in practice). For Miramar, the NREL stated that:

> the optimal energy strategy was not to recommend that the base become entirely a net zero energy installation. This largely is because it was cost-prohibitive to remove natural gas-fueled building systems that were relatively new and functioning properly and replacing them with electrical systems powered by RE. (Callahan et al., 2011, pp. 57–58)

Therefore, Callahan et al. (2011) contended that an independent NZEI for the DoD is not a cost-effective method of employing agency-wide energy efficiency and RE projects because of implementation limitations.

I. ENERGY PORTFOLIO THEORY

1. Overview

In financial theory, an investor's objective is to maximize expected return (minimize cost) while reducing exposure to risk. While financial investment theory emphasizes that higher risk leads to higher expected returns, it also asserts that holding a diversified portfolio of assets reduces risk exposure for a given level of return. MPT assesses the expected return and variances of different assets to determine the most efficient proportions of assets in a given investment portfolio. The efficient portfolio maximizes the expected return (minimizes cost) for a given level of risk or minimizes the risk for a precise expected return. The objective is to attain a collective portfolio risk lower than any individual asset within the portfolio. This fundamentally depends on the risk of the assets and the correlation between those assets in the portfolio. The less correlated assets are in a single portfolio, the less overall risk that portfolio will have (Humphreys & McClain, 1998). This is the basic mathematical property of statistics: Combining variances reduces the overall variance of the bundle of variances as long as the variances are less than perfectly correlated with one another. This application of variance statistics applies as much to supply chains and energy planning as it does to financial investments.

2. Analytical Framework for Energy Cost Assessment

The performance of a portfolio of assets depends on two variables: (a) determining the expected return of each individual asset in the portfolio and

(b) determining the risk of each asset, measured by the standard deviation (volatility) and correlation between the assets. Using a two-asset example, the expected return for a portfolio can be calculated with Equation 1:

$$E(R_{port}) = x_i \bullet E(R_i) + x_j \bullet E(R_j), \tag{1}$$

where E(Ri) and E(Rj) are the expected returns of assets *i* and *j* and Xi and Xj represent the proportions of assets *i* and *j* in the portfolio (Humphreys & McClain, 1998). The portfolio standard deviation is calculated using Equation 2:

$$\sigma_{port} = \sqrt{X_i^2\sigma_i^2 + X_j^2\sigma_j^2 + 2 \bullet X_i \bullet X_j \bullet cov(R_i, R_j)}, \tag{2}$$

where $cov(R_i,R_j)$ is the covariance between assets *i* and *j* and σ_i and σ_j are the standard deviations of assets *i* and *j* (Awerbuch, 2006). Once calculated, the portfolio can be graphed to show the overall risk against the expected portfolio return. Figure 1 illustrates the graphical representation of a mix of numerous assets at their respective risk-to-return locations. The efficient frontier (blue solid line) represents the desired optimal risk to return location for each portfolio. If a portfolio lies anywhere on this line, increasing the expected return will increase the standard deviation (risk) of that portfolio. Portfolios below the efficient frontier are deemed inefficient, since these portfolios increase or decrease expected return while holding standard deviation constant, and vice versa (Awerbuch, 2006).

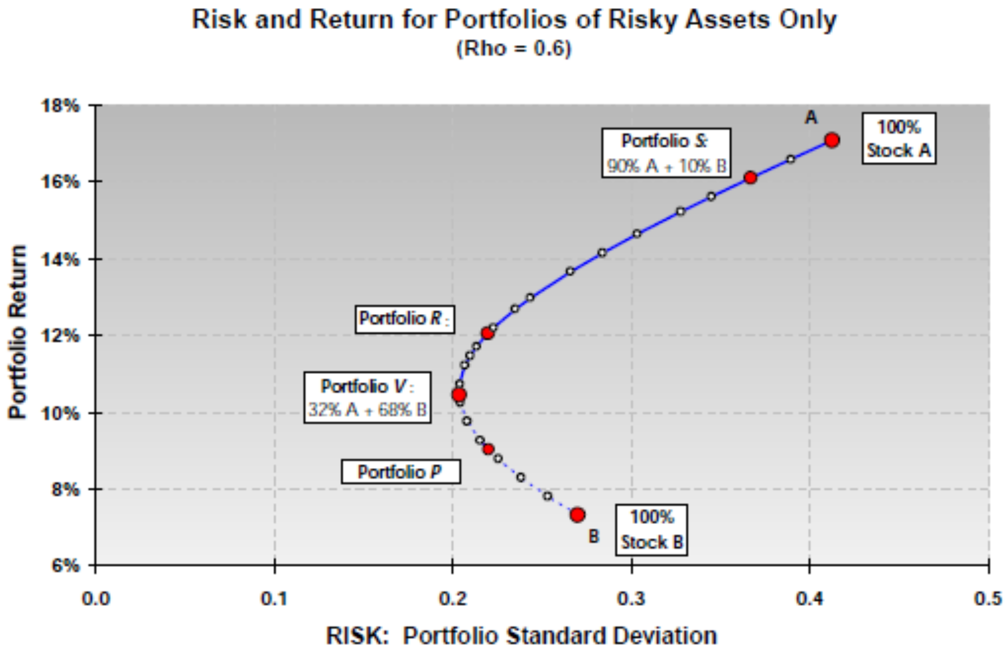

Figure 1. Efficient Frontier (from Awerbuch & Berger, 2003)

3. Application to Energy Planning

As previously stated, energy security is the vital connection between energy availability and national security. Understanding the market volatility of fossil fuels is critical to reducing costs through diversifying energy portfolios during energy planning. Alone, fossil fuels (petroleum, gas, and coal) represent highly volatile markets that expose investors to high-risk prices and weaken energy security. This volatility is difficult to forecast because of market unpredictability, despite markets having historic averages and variability. Figure 2 shows the volatility in the prices of crude oil over the past 27 years. Because fossil-fuel prices are highly volatile, renewable resources become more desirable since there is no correlation between fossil fuels and renewable resources such as wind, solar, hydro, biomass, and geothermal. Therefore, these alternative fuels tend to reduce the volatility of an energy portfolio (Awerbuch, 2006). Thus, price-risk mitigation enhances energy security when energy planners incorporate greater renewable resources over those rich in fossil fuels (Awerbuch, 2006).

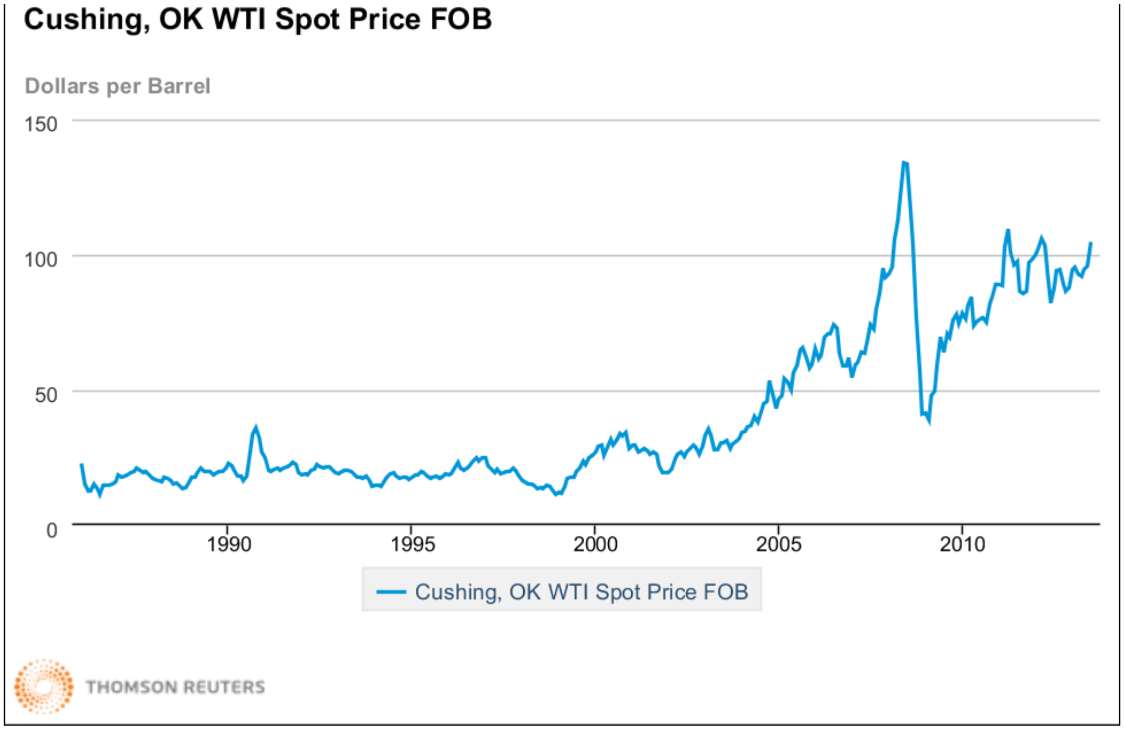

Figure 2. Historic Crude Oil Prices 1986–2013 (from Energy Information Administration [EIA], 2013b)

In addition to lessening the volatility of fossil fuels in energy portfolios, energy planners must also consider the long-run energy generation costs associated with the addition of RE resources. Traditionally, energy portfolios rich in fossil fuels have generally used the least-cost method of planning. This method asserts that energy alternatives with the lowest cost lead to overall energy systems with the lowest energy generation costs. Awerbuch (2006) explained that while this method worked well in eras of "relative cost-certainty, low rates of technical progress, technically homogeneous generating alternatives, and stable energy prices," energy planners face a highly uncertain future, making least-cost implementation nearly impossible (p. 1). Bazilian and Roques (2008) pointed out that Awerbuch wrote "when taken over a sufficiently dispersed geographical region, the cost of wind, solar and other capital-intensive renewables are relatively fixed over time (which implies that their value is greater when fossil energy prices rise)" (p. 697). Fixed-price renewable resources have the ability to provide static costs relative to fossil fuels, demonstrating that negative correlation within an energy portfolio has the capacity to buffer against market volatility. MPT provides DoD energy planners with an analytical tool for creating efficiently resourced energy portfolios that maximize energy security while minimizing generation costs.

4. Summary

Awerbuch's (2006) basic point was that the price of energy is cost plus risk, not cost alone. In the past, energy planners—especially in the DoD—have looked for least-cost energy solutions such as oil and coal, without regard to the price risks that they were exposing themselves (and the overall economy) to (e.g., severe economic downturns following the first and second oil crises of 1973 and 1979). Since least-cost energy solutions are commonly associated with local utility grid purchased energy, the supply of energy also carries risk. Energy planners must consider the exposure of installations to the risk of utility grid interruptions (planned or unplanned) and the costs associated. Awerbuch (2006) showed that once risk is incorporated into energy planning, energy planners should rationally move toward a portfolio of energy assets (i.e., you can inevitably justify much higher proportions of wind, solar, hydro, biomass, and geothermal in your energy portfolio than when you strictly look at least-cost-only analysis). This is especially useful when analyzing how interruption risk can be mitigated by the implementation of RE generation resources into installation energy portfolios.

J. APPLICATION OF S-CURVES AND RISK TO ENERGY PLANNING

1. Overview

The application of MPT to energy planning requires a detailed understanding of the relative maturity of the RE technology being used to balance the portfolio. RE technologies like wind and solar have, in recent years, been experiencing year-over-year decreases in their costs for a given output. By looking at these technologies through the lens of S-curve analysis, we can assess and forecast the relative maturity as compared to fossil fuels. In the following background, we discuss the application of S-curves to renewable technologies and their importance to each of the three largest technologies: solar, wind, and geothermal.

2. The Application of S-curves

In the most basic sense, an S-curve describes the improvement of performance over the amount of effort (cumulative investment) applied to a specific technology (see Figure 3). The idea is that most technologies begin to improve slowly at first and then increase rapidly until the point at which marginal improvement reduces and then approaches the limit of the technology itself. The shape of the curve comes from ignorance of each technology early in that technology's development followed by each technology's rapid development once it is well understood. The period of diminishing returns toward the limit of technology finally occurs as a mature technology begins to add fewer and fewer performance returns as effort is applied.

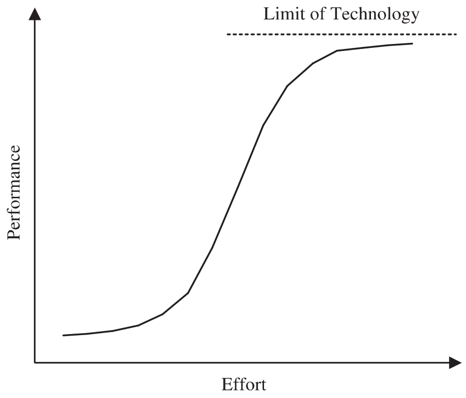

Figure 3. Basic S-Curve (from Schilling & Esmundo, 2009)

3. Technology Cycles

New technologies in a given industry typically go through a cyclical process. While an established technology is enjoying its period of rapid performance improvements, new technologies are in the early stages of development and are experiencing modest gains compared to the amount of money being invested.

Technologies such as RE, minicomputers, cement, and glass have all gone through a similar phased cyclical process. The first phase, where relatively few performance gains are being made, is commonly referred to as the fluid phase. In this phase, the technology is still very uncertain; researchers are pursuing many different approaches to find the most efficient product for the given market. At this point, many firms are experimenting with new ideas and applying limited products to niche markets (Schilling & Esmundo, 2009).

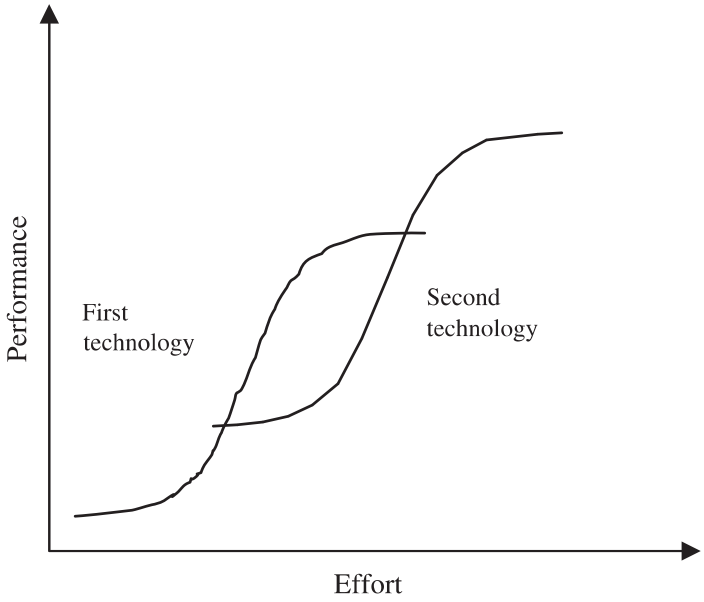

Figure 4. Technology Overlap (from Schilling & Esmundo, 2009)

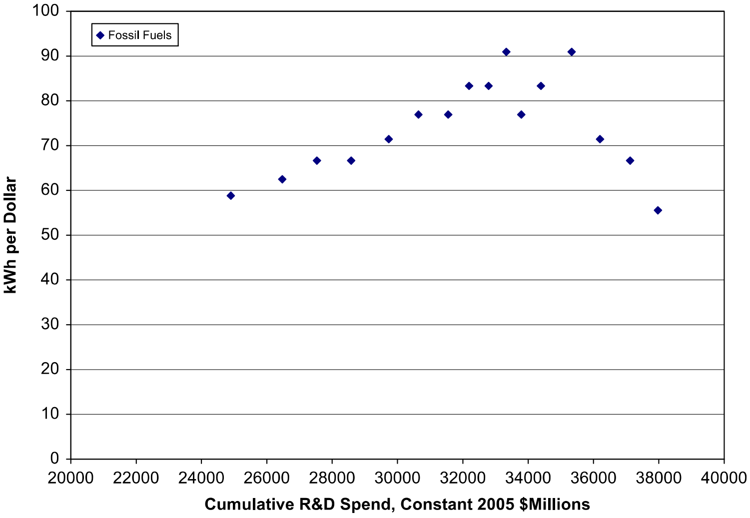

Figure 5. Cumulative R&D (from Schilling & Esmundo, 2009)

This period of experimentation eventually gives way to the era of ferment. A few new technologies break-through in the industry and are applied to a growing number of niche demands. The industry, however, still has not selected a single process for development but replaces many of the old products with the newest systems. The dominant designs at this point, while not perfect, often reflect many of the best capabilities of the original phase products (Schilling & Esmundo, 2009).

The two periods of experimentation and ferment eventually give way to an era of incremental change, where the industry down-selects to the most successful and efficient technologies and focuses specifically on market penetration. In this stage (see Figure 4), each firm in a given industry focuses on reducing the cost of a given technology and the firm’s own ability to broadly apply its process to the problems of the entire industry.

4. S-Curves and Existing Technology

When these three phases are applied to the RE market, it is clear why many new technologies are at a distinct disadvantage. Fossil fuels, which account for more than 85% of the current energy market (Schilling & Esmundo, 2009), are clearly in the later part of the era of incremental change. Most renewables, however, are only just now moving into the second phase, the era of ferment. Until the second phase, the decision of which RE technology to pursue was unclear, and many companies were investing in expensive products. In recent years, however, several technologies have demonstrated the ability to provide market penetration and increased performance returns relative to investment. Specifically, PV and concentrated solar, wind, and geothermal energy have demonstrated increasing performance returns (kilowatt hours [kWh] per dollar) relative to cumulative investment. Fossil fuels, however, are showing stagnant or negative performance returns relative to cumulative investment (see Figure 5).

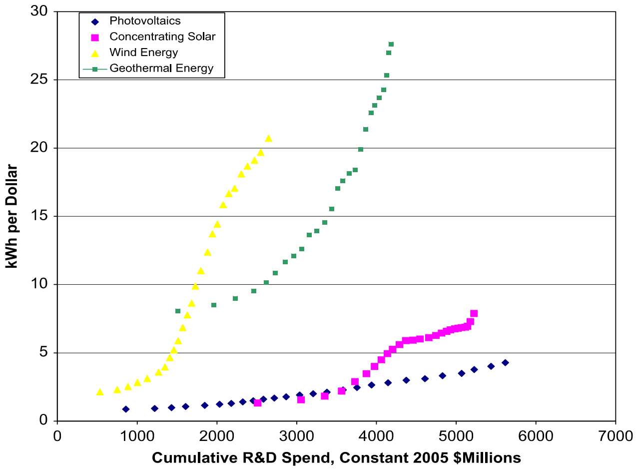

Figure 6. Cumulative R&D (from Schilling & Esmundo, 2009)

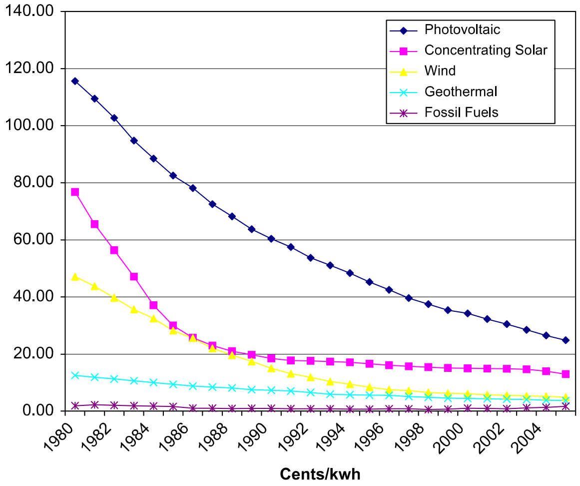

Figure 7. Cost Comparison of Various RE Technologies (from Schilling & Esmundo, 2009)

a. Solar

Unlike wind and geothermal resources, PV and concentrated solar technologies have yet to display a clearly defined S-curve pertaining to the relative maturity of the technology (see Figure 6). Both methods of generating energy have begun to demonstrate useful capacity, but have yet to enter an era of incremental change. Solar has the greatest capacity to provide the largest amount of energy, but currently it is not the most mature technology because of the inefficiency of most commercially available systems (see Figures 7–10).

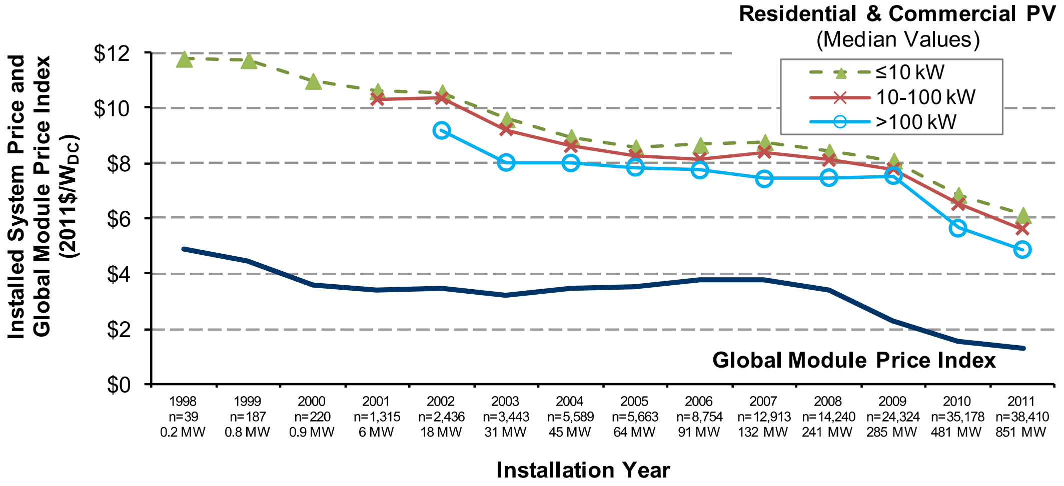

Figure 8. Historic PV System Prices (from Feldman et al., 2012)

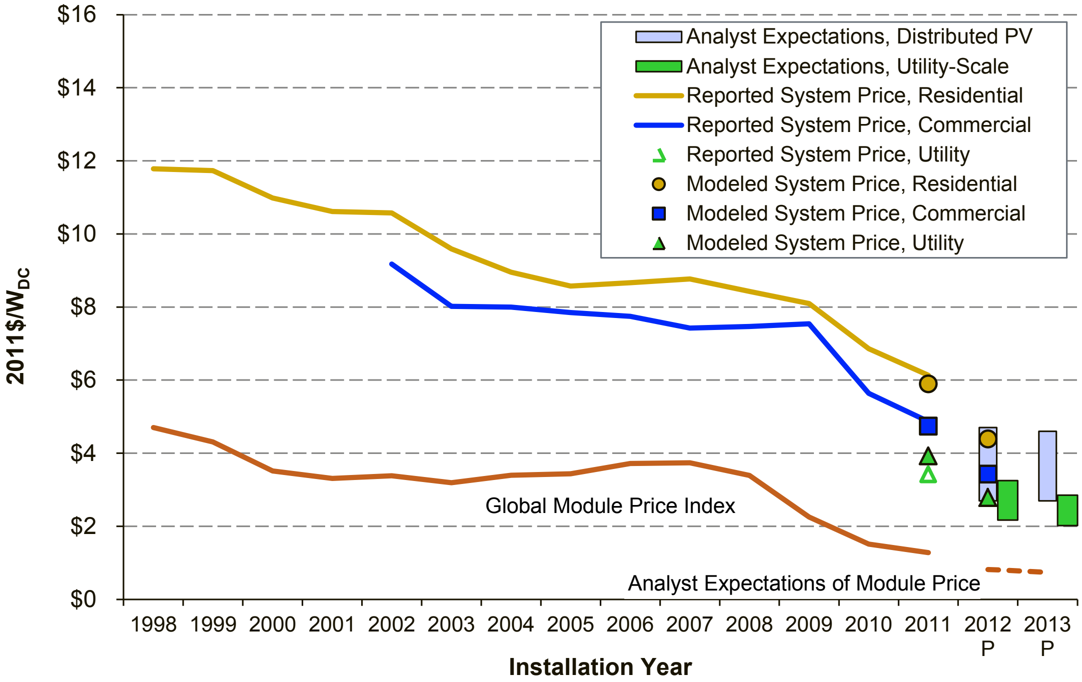

Figure 9. Historic PV Prices by System Size (from Feldman et al., 2012)

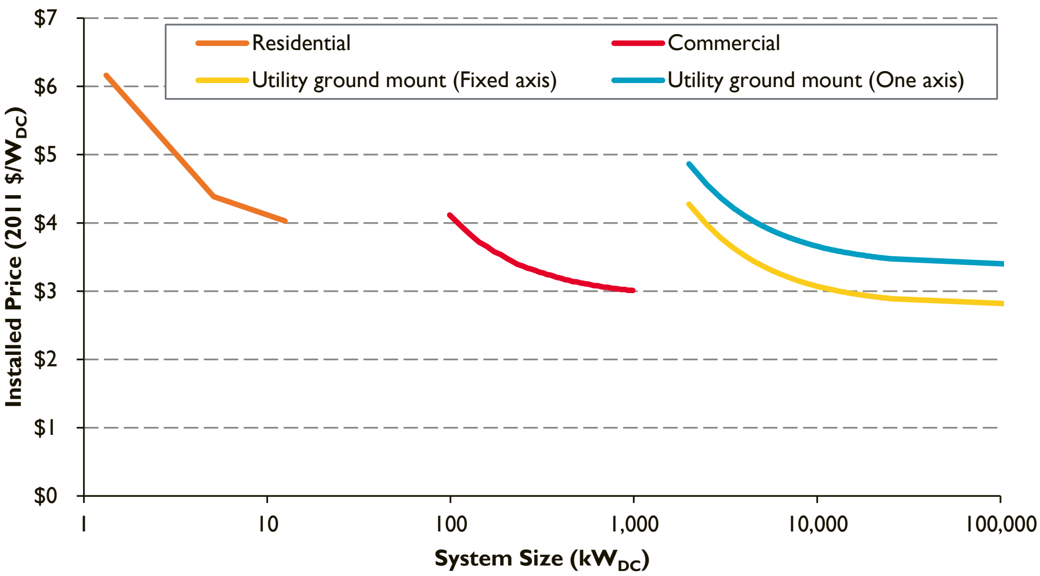

Figure 10. Historic PV Prices by System Type and Size (from Feldman et al., 2012)

b. Wind

Wind energy generation is currently experiencing rapid growth relative to cumulative investment. Prices for wind generation systems are falling rapidly as these systems become more mature on the commercial market. Although these systems are capital intensive to install, once in place, they are relatively maintenance-free and cost less, compared to fossil fuels.

c. Geothermal

Geothermal technology is also experiencing similar growth in output as compared to cumulative investment. This technology, however, is at a relatively immature stage in its development and has not begun to be widely implemented throughout the United States. The slow implementation of this clean and relatively inexpensive technology is partly because of the limited regions within the United States where it can be considered most effective. Figure 11 shows locations throughout the United States where geothermal technology is most advantageous. From a portfolio perspective, many of these locations contain Marine Corps bases that could benefit from this technology over time.

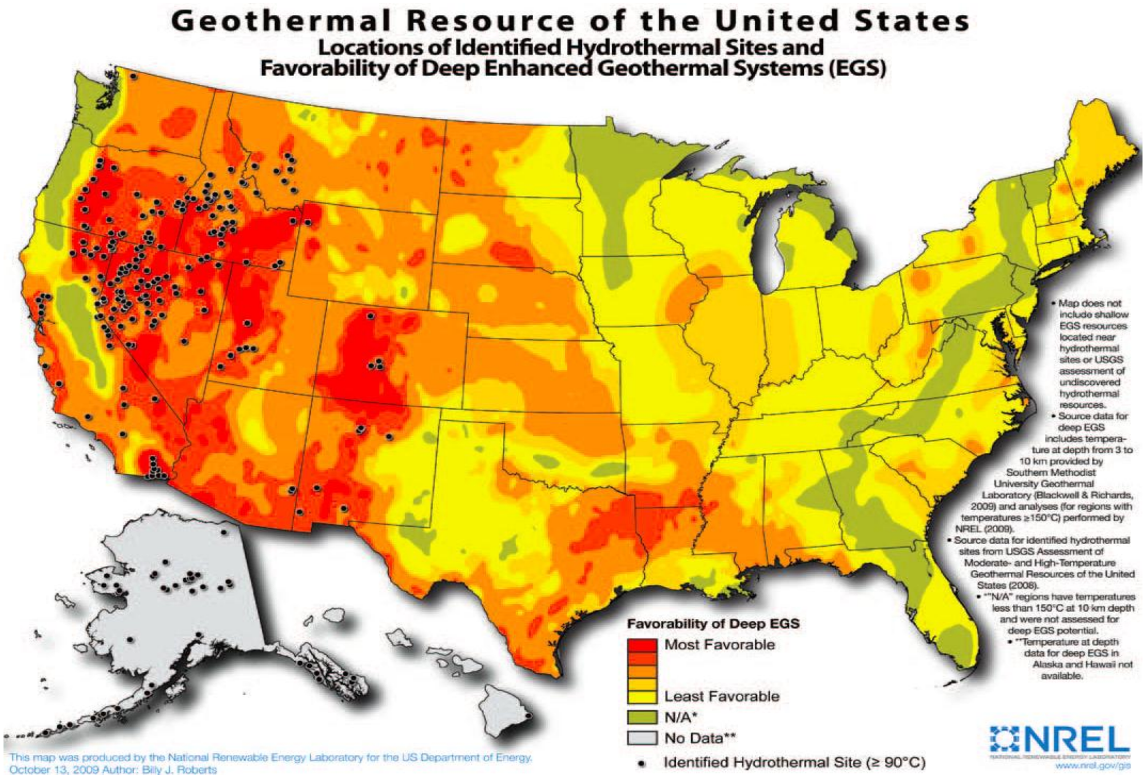

Figure 11. Geothermal Resource of the United States (from NREL, 2012)

5. Learning Curves and RE Technology

Similar to the S-curves applied to various types of technologies, learning curve theory can be applied to each kind of RE technology. By adjusting future prices for the technologies' relative position on an assumed learning curve, the Marine Corps can build a more accurate picture of future life-cycle costs. For the Marine Corps specifically, the most value would be gained by studying the relative position of PV technology along its respective learning curve.

McDonald and Schrattenholzer (2001) compiled existing studies and historic price data to derive a range for energy technology learning rates. By studying the distribution of learning rates from the past 15 years across various types of energy generation, they narrowed the sensitivity of the learning curve to 18%–25% with an overall learning rate around 20% (McDonald & Schrattenholzer, 2001).

By applying a similar learning curve to the purchase of Marine Corps PV systems—the predominant renewable technology—the Marine Corps can gain a more accurate picture of when to purchase systems in pursuit of energy goals. If the purchase of renewable technology is delayed to a point where technology prices have leveled out, the service may be able to realize per-unit cost savings simply by waiting for the right moment to purchase a particular type of technology.

6. Defining the Cost of Interruption

In response to a number of power interruptions at DoD installations, the NREL was commissioned to study the actual cost of interruptions to the DoD. This study, *Valuing Energy Security: Customer Damage Function Methodology and Case Studies at DoD Installations*, provided the analytical background necessary to assign a cost of interruption across Marine Corps installations (Giraldez, Booth, Anderson, & Massey, 2012).

The NREL began its study by conducting a survey of MCAS Miramar and Fort Belvoir energy managers and command representatives to determine the number of lost personnel hours, food spoilage, and damage caused by various durations of interruptions. Next, the NREL determined the reliability of the civilian power grid at the respective installations. Finally, the NREL applied the cost and probabilities from these two installations into its valuing electrical energy security (VEES) equation. This summary equation provides an annual cost figure for the value of interruption at each installation. If similar prices are assumed, at each duration of interruption across the East and West Coasts, a cost function can be created for each Marine Corps installation. This annual figure can give energy managers and installation commanders a better idea of exactly how exposed their installation is to interruptions caused by reliance on civilian infrastructure.

7. Summary

The United States Marine Corps has begun meeting its mandated RE targets through a highly decentralized strategy. Individual installations are carrying out independent projects that focus only on that installation's given targets. As current research in the area of energy planning shows, the Marine Corps stands to benefit from coordinating these efforts.

In one particular example, massing affordable solar generation technology at a base like Twentynine Palms could offset the high fossil-fuel volatility and cost coming from East Coast installations when viewed from a network portfolio perspective. Thus, applying MPT may be an effective framework for the Marine Corps to accurately analyze the amount of risk and performance of its existing portfolio. This approach enables the analysis of future projects' impact on network energy planning. The result moves the portfolio closer to the efficient frontier, reduces installation vulnerability to energy grid interruptions, and leads to enhanced energy security.

By assigning a value to the cost of interruption, energy planners at every level will have a better idea of the true costs of on-site RE technology implementation. These technologies can be used in the event of an interruption to help commanders continue to operate throughout the outage and offset the interruption costs that would normally occur.

Either of these frameworks could provide an effective tool for future Marine Corps energy planning. There is sufficient research in the area of RE technology for energy decision-makers to select when and how much of each technology to purchase in pursuit of stated DoD, secretary of the Navy [SECNAV], and Marine Corps energy goals.

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II. METHODOLOGY

A. MARINE CORPS ENERGY PORTFOLIO ANALYSIS

1. Assumptions

The assumptions for the Marine Corps energy portfolio analysis are as follows:

- Any generation by RE resources is 100% consumed on-site and added to the Marine Corps' total consumption.
- Biomass reported in the DUERS database for MCAS Miramar is included in RE totals.
- Co-generation (COG) reported in the DUERS database is not included in Headquarters, United States Marine Corps (HQMC) consumption totals and is not included in this study.
- Landfill Gas (LFG) is its own renewable resource but is categorized under *geothermal* for correlation purposes.

2. Energy Data Normalization

The Marine Corps installations evaluated for MPT application were MCB Twentynine Palms, MCB Camp Lejeune, MCB Camp Pendleton, MCAS Camp Pendleton, MCB Quantico, MCLB Albany, Marine Corps Recruit Depot (MCRD) Parris Island, MCRD San Diego, MCAS Beaufort, MCAS Cherry Point, MCAS Miramar, MCAS Yuma, MCB Kaneohe Bay, and MCLB Barstow. Bases in Japan were eliminated because of a lack of data regarding host nation purchased energy prices and volatility. Marine Corps installation fossil-fuel energy data was retrieved from the DUERS provided by HQMC I&L. This data was used to determine FY2012 installation consumption by month and utility source. The DUERS data uses unique codes to categorize consumption based on specific types of fossil resources. We further consolidated these codes into general resource categories for analysis, as shown in Table 1. We discuss general analysis codes in a subsequent section of this chapter.

Table 1. Marine Corps Energy Resources With DUERS Coding

General Analysis Codes	DUERS Code	Description
Biomass	BEP	Biomass Electricity
Coal	COL	Coal, Bituminous
*broken out by resource	ELC	Electricity
Oil	FOR	Fuel Oil, Reclaimed
Oil	FSD	Fuel Oil, Distillate
Oil	FSR	Fuel Oil, Residual
Oil	FSX	Fuel Oil, Mixed
Gas	NAG	Natural Gas
Gas	PPG	Propane/LPG/Butane
Gas	SHW	Purchased Steam/Hot Water
Geothermal	LFG	Landfill Gas
Geothermal	LFG PPA	Landfill Gas Power Purchase Agreement
Solar	PV	Photovoltaics
Wind	WND	Wind Power
Nuclear	-	Nuclear Electricity
Hydro	-	Hydroelectricity

During data consolidation, we determined that a large percentage of installation energy was consumed from electricity. Since electricity is not a direct energy resource but the product of multiple fossil-fuel and RE generation resources, we had to normalize reported consumption totals. To derive the energy resource percentages in generating electricity to the Marine Corps, we retrieved electricity generation data by state from the EIA and filtered the data by generation resource. We analyzed only states previously mentioned that host Marine Corps installations. We determined energy resource percentages by dividing the specified resource (e.g., coal, hydroelectric, oil, nuclear, solar) by total generation for the state. We completed this for all resources, including renewable resources used in state-generated electricity, and applied to the DUERS electricity data. The application of state energy resource generation percentages allowed the electricity category for Marine Corps installation energy consumption to be allocated to specific resources for data analysis purposes.

Marine Corps renewable generation data was provided by HQMC I&L and included FY2012 RE generation totals for solar PV, wind, LFG, and LFG power purchase agreements (PPAs) at installations that have existing RE resources. We combined installation RE generation totals with the state RE generation totals derived from DUERS ELC consumption to show the contribution of RE to the installation and to Marine Corps energy portfolios.

3. Data Consolidation and Energy Portfolios

In order to determine the overall Marine Corps energy portfolio, we first collated data from state electricity generation, DUERS, and Marine Corps RE into specific installation portfolios. We allocated installation energy resource consumption data to one of the nine energy resources and pooled resources to calculate the total consumption, per resource, for fossil fuels and RE resources for each installation. From total energy consumption per kWh, we calculated consumption percentages by resource by dividing energy resource totals by total installation energy consumption. Once this was completed for all 14 installations, we consolidated the data to determine the overall Marine Corps energy consumption and consumption percentages by resource.

B. VALUE OF ELECTRICAL ENERGY SECURITY METHOD

The methodology for valuing energy security to the Marine Corps and the process for assigning annual cost values to each installation were based largely on the 2012 study conducted by the NREL. To demonstrate the NPV of RE projects at each installation, we normalized current Marine Corps energy consumption data to standard units and calculated consumption targets, the cost of achieving these targets, and the cost of interruption. We then used all of these values to generate NPV percentages and cost figures for various RE targets.

1. Data Normalization

The office of I&L at HQMC provided energy consumption data for this study from the FY2012 DUERS database. This type of data is used primarily by the Marine Corps to track the purchase of energy (in both heat and electricity) across each installation and provides both monthly consumption and monthly cost data for each resource consumed. Similarly, I&L provided a database that detailed RE generation that occurred in 2012 at each installation across the Marine Corps.

The first step of data normalization was to move all of the consumption data into similar units. Since the purchase of heat energy is tracked by million British thermal units (mmBtu), we converted the sources of purchased heat energy to kWh for the purposes of this study. We turned all sources of purchased heat energy across the Marine Corps into kWh in Equation 3:

$$\begin{aligned} mWh &= (mmbtu / 3.412) \\ kWh &= mWh * 1000 \end{aligned} \quad . \tag{3}$$

We used the intermediate step to generate consumption data in megawatt hours (mWh) for purposes of cost comparison later in the analysis.

Second, we derived new per-unit cost data from the new kWh units and the existing monthly consumption cost values. We created the resulting value, $/mWh, to be used in comparison against existing NREL RE studies.

2. Calculating RE Targets and Shortfalls

An installation's RE generation target is defined as the amount of kWh required to operate in the event of an interruption on the civilian grid. For the purpose of this study, we set this target to 15%, as defined by Marine Corps energy planners at I&L. This 15% target represents the amount of power that each installation would need to generate to meet METs (e.g., physical security, basic life support, launch aircraft) in the event of an interruption to the civilian power grid.

We calculated RE generation targets per installation with both FY2012 DUERS and RE generation data. Per installation, we summed FY2012 monthly energy consumption in kWh and then added to the kWh generation figures provided by I&L. The sum of these two numbers reflected the total kWh consumed per installation for FY2012.

We multiplied this value (FY2012 consumption in kWh) by the target percentage (e.g., 10%, 15%, 20%) to create that installation's RE target value. We then subtracted the amount of RE generation currently occurring at that installation from the target value to arrive at the RE shortfall amount in kWh. This value was the key element to determining generation costs per installation.

3. Calculating the Cost of Achieving Stated Targets

We used each installation's RE shortfall (at a specified renewable energy percentage, RE%) to calculate the cost of generating that shortfall with RE vice purchased power from the civilian grid. In order to create these cost values, however, we first analyzed existing renewable technology on-site and the levelized cost of RE technology.

a. Existing Technology

We considered two factors when choosing the renewable technology that should be used to generate the shortfall value per installation. First, the percentage of the existing technology per installation was used in the majority of cases. For example, MCAS Miramar is currently generating RE with 5% PV, 77% LFG, and 18% biomass.

If, however, an installation did not generate any of its own energy through RE technologies, we used potential RE alternatives according to the NREL's RE optimization (REopt) tool (Anderson & Cutler, 2012). This tool provided per-installation recommendations for the type and amount of renewable technology in the absence of existing RE generation.

We also considered a third factor for further sensitivity analysis that is discussed in this section. Considering the current relative cost of wind power, our study analyzed the cost savings from forcing certain percentages of wind generation into the RE portfolio. This force of wind technology is against the existing on-site production and the NREL REopt recommendations but is useful for theoretical analysis.

b. Levelized Cost of Technology

The levelized cost of each renewable technology per installation was also required to calculate the cost of generating each percentage shortfall. These costs were again provided by the NREL's REopt tool. The tool provided a snapshot of each studied installation in a \$/kWh format for PV, wind, biomass, solar, geothermal, LFG, and waste-to-energy.

c. Renewable Energy Target Cost

To calculate the cost of the RE shortfall given a specific RE target percentage, we multiplied the shortfall by the installations' on-site technology percentage and the levelized cost of that technology. For example,

$$15\%TCost = 15\%Shortfall * ((\%PV * \$ / PV)(\%Wind * \$ / Wind)(\%LFG * \$ / LFG)(\%Bio * \$ / Bio)) \quad (4)$$

d. Calculating the Cost of Interruption

Calculating the cost of interruption to each Marine Corps installation required several steps to arrive at a single dollar value per year per installation. The NREL's VEES equation served as the basis for the calculations but required an analysis of each installation's peak site load, probability of interruption by duration, and the customer damage function (CDF) for each installation.

e. Valuing Electrical Energy Security Equation

The VEES equation used by the NREL in its 2012 cost of interruption is as follows:

$$VEES = Annual\ \#\ outages * CDF(Duration)\left[\frac{\$}{kWpeak}\right] * Peak[kW] \quad (5)$$

For the purpose of this analysis, "annual # of outages" and "CDF (Duration)" were calculated together using data provided by the senior marketing communications manager at the Eaton Corporation's Electrical Power Sector.

In this study, the baseline assumption for the value of "annual # of outages" was set to 1 but will be evaluated at various levels during sensitivity analysis. We used the assumed value due to its relative proximity to the national average (1.2) and due to a lack of accurate installation specific data.

Peak [kW], or peak site load, was derived from the NREL's REopt output slides that provided per-installation generation costs. The REopt tool detailed the peak [kW] output for each Marine Corps installation required for this calculation.

f. Peak Site Load

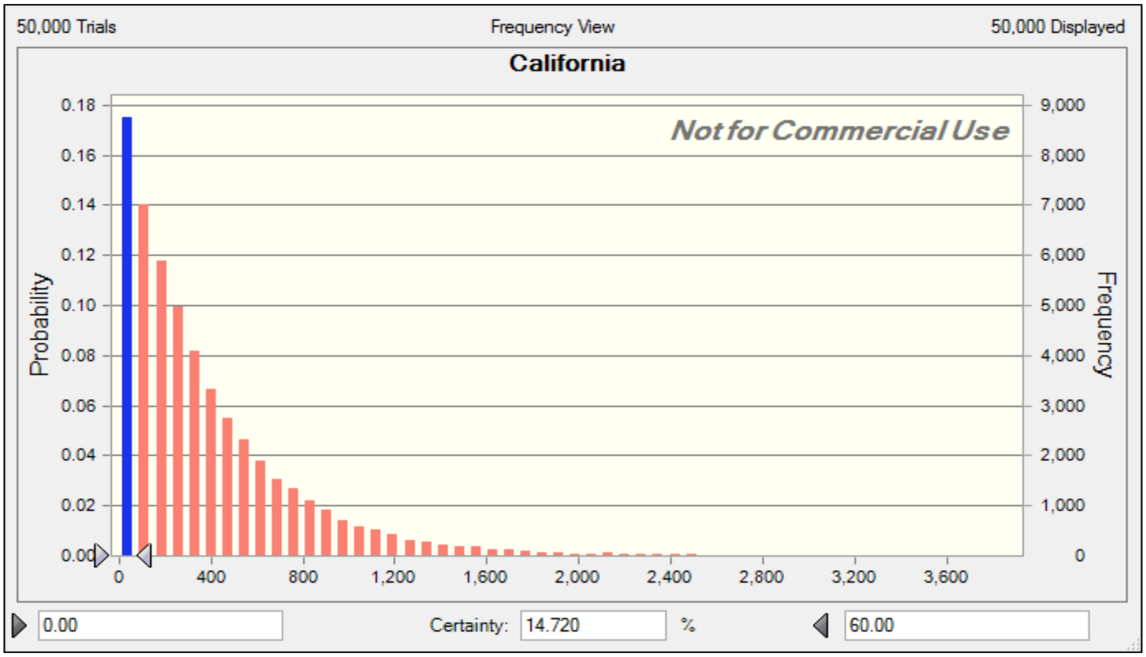
Peak [kW] was derived from the same NREL REopt output slides that provided per-installation generation costs. The REopt tool detailed the peak [kW] requirement for each Marine Corps installation required for this calculation.

Not all interruptions, however, occur during the period of peak load (e.g., mid-day, Monday through Friday). We conduct sensitivity analysis in later sections to reflect the reality of interruptions occurring during non-working hours.

g. Duration of Interruption (By State)

We derived the probability of interruption from data provided by the Eaton Corporation. This company sells backup power supplies for commercial applications and publishes its annual "Blackout Tracker" to demonstrate the fragility of civilian power infrastructure. Eaton provided five years of blackout data containing information on the duration of each outage, the type of outage, and the location for each outage.

First, we broke the data into divisions by state and then narrowed these to the states that contain Marine Corps installations. We then created probability distributions using Microsoft Excel and Oracle Crystal Ball by running Monte Carlo simulations on each state to arrive at that state's probability of interruption distribution. One example is California's frequency of interruptions, as shown in Figure 12.



0.00

Certainty: 14.720 %

60.00

Figure 12. California's Duration of Interruption

We derived probabilities for the most common durations of interruptions (in minutes); 0–60, 60–120, 120–240, 240–480, 480–720, 720–1440, one hour, two hours, four hours, eight hours, 12 hours, and 24 hours, respectively. These probabilities of interruption were later applied to the customer damage function for that specific duration of interruption.

h. Customer Damage Function

The customer damage function of the VEES equation is a very specific function for each installation. For the purpose of this study, the two functions created by the NREL in its 2012 analysis of MCAS Miramar and Fort Belvoir serve as the East Coast and West Coast customer damage functions, respectively. Future analysis in this area could provide a more accurate CDF for each Marine Corps installation.

Within the Miramar and Fort Belvoir functions, however, the NREL split the damage functions into an emergency outage and non-emergency outage function, as shown in Figure 13.

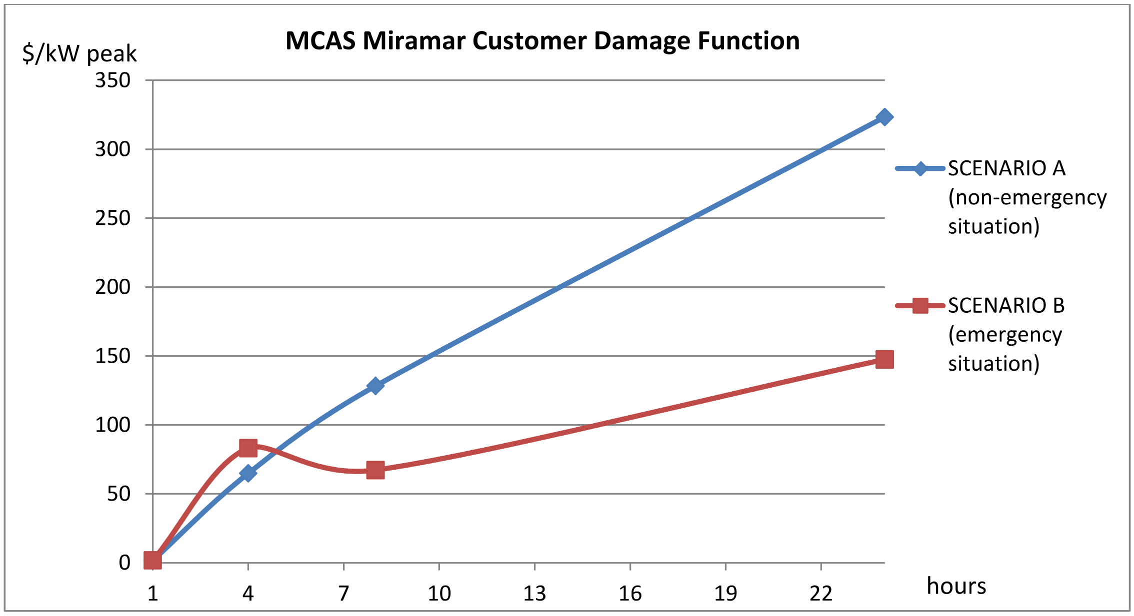


Figure 13. Miramar Customer Damage Functions (from NREL, 2012)

These two functions reflect the cost of an outage resulting from an emergency situation (e.g., natural disaster, act of terrorism) and a non-emergency situation (e.g., squirrels, equipment failure, overload). For the purpose of this study, we derived an average CDF for both East and West Coasts by averaging these two sets of data. We provide sensitivity analysis in this area in Chapter III.

4. Net Present Value Calculations

Finally, the net present value calculation of each varying level of RE percentage is as follows:

$$\%\text{Target NPV} = \%\ \text{Target x Annual Cost} - \%\text{Target Cost} + \text{Installation's Cost of Interruption} \quad (5)$$

Equation 5 gives the annual NPV of producing a certain percentage of energy at each installation through RE generation technology. Given various assumptions throughout the model, this equation shows each installation's percentage of RE that should be produced on-site to both avoid the cost of interruption and continue to accomplish METs.

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III. DATA ANALYSIS

A. MARINE CORPS ENERGY PORTFOLIO ANALYSIS

1. Marine Corps Installation Energy Goals

Under the commandant's energy strategy of 2011 and followed by the 2013 *United States Marine Corps Installations Energy Strategy*, the Marine Corps' two major installation energy goals are (a) 30% energy consumption reductions by 2020 and (b) 50% RE generation by 2020. As of the end of FY2012, the Marine Corps has reduced its energy consumption by 18%. This figure is based on the baseline of FY2003 energy consumption. Assuming efforts to reduce energy consumption began in FY2011, after the release of the commandant's energy strategy, reductions of 9% annually forecast that the Marine Corps can expect to meet its energy reductions goal by the end of FY2014. Similarly, if using FY2003 as a baseline indicates that reductions are calculated under the EPACT 2005 and began in FY2006, Marine Corps energy reductions are 2.6% annually. In this case, the Marine Corps will meet this goal in FY2018. In both cases, the Marine Corps will meet its 2020 goal.

Current Marine Corps RE generation is 7.5% (as of the end of FY2013), meeting the congressional requirement set forth in EPACT 2005. Assuming that RE generation goals began in FY2010 under the Department of the Navy, SECNAV energy guidance, the Marine Corps has achieved 2% annual increases in RE generation, per year, through FY2013. Under this assumption, it will take the Marine Corps an additional 21 years to meet its 50% renewable generation goal. Likewise, the Marine Corps will only achieve 20% RE generation by FY2020. Without a significant investment in RE generation, the Marine Corps will fail to achieve its 50% RE generation goal.

2. Marine Corps FY2012 Energy Portfolio

This section analyzes the total Marine Corps energy portfolio. The analysis is used to determine total Marine Corps energy consumption by utility and location to determine installation RE targets.

a. Consumption by Utility

According to DUERS data provided by HQMC I&L, the Marine Corps' FY2012 energy consumption totaled 3.02 billion kWh. Grid electricity accounted for over half of total consumption, at 51%. Figure 14 shows the breakdown of consumption by utility. Due to the potential risk of grid interruptions, both unintended and intended, this figure represents significant energy security risks to Marine Corps installations.

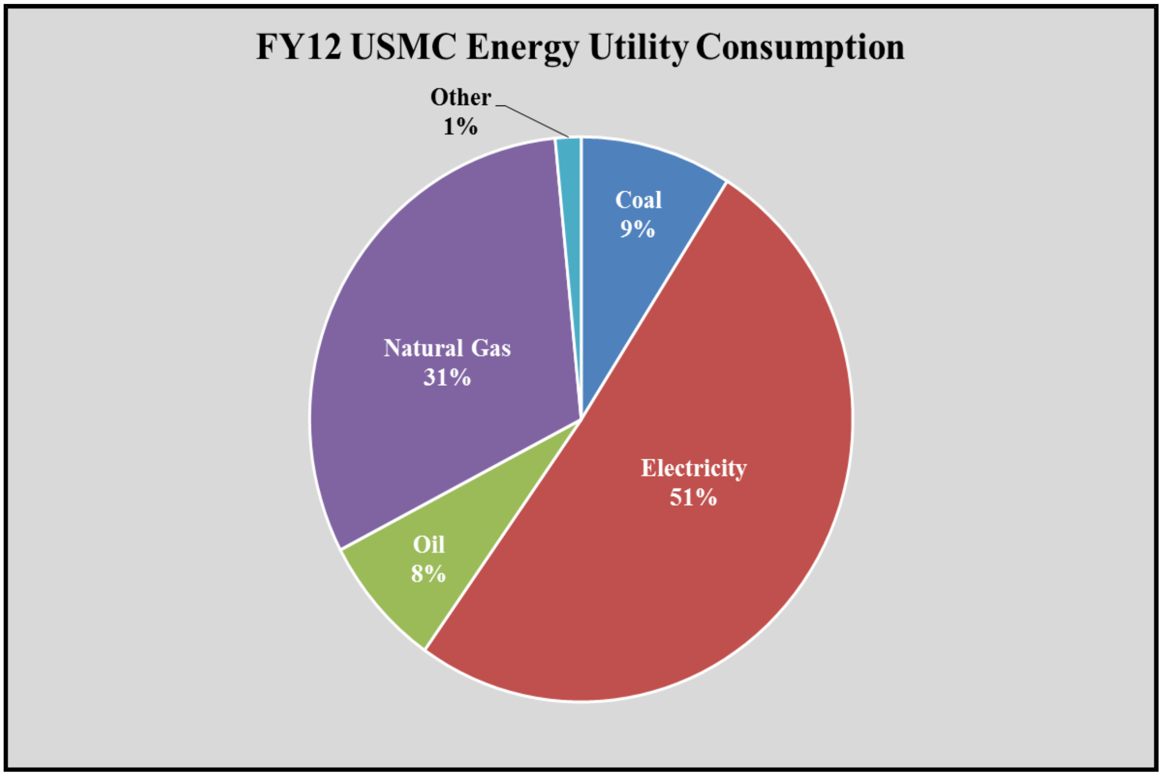

Figure 14. FY2012 Marine Corps Energy Utility Consumption

b. Energy Consumption by Location

Consumption patterns by utility differ across East Coast and West Coast CONUS installations. East Coast installations rely heavily on grid electricity (48% of consumption) and use natural gas and coal (30% and 17%, respectively) to account for non-grid fossil energy. West Coast installations consume larger amounts of natural gas (55% of consumption) and supplement with grid electricity (40% of consumption). Figure 15 shows energy consumption by installation and utility.

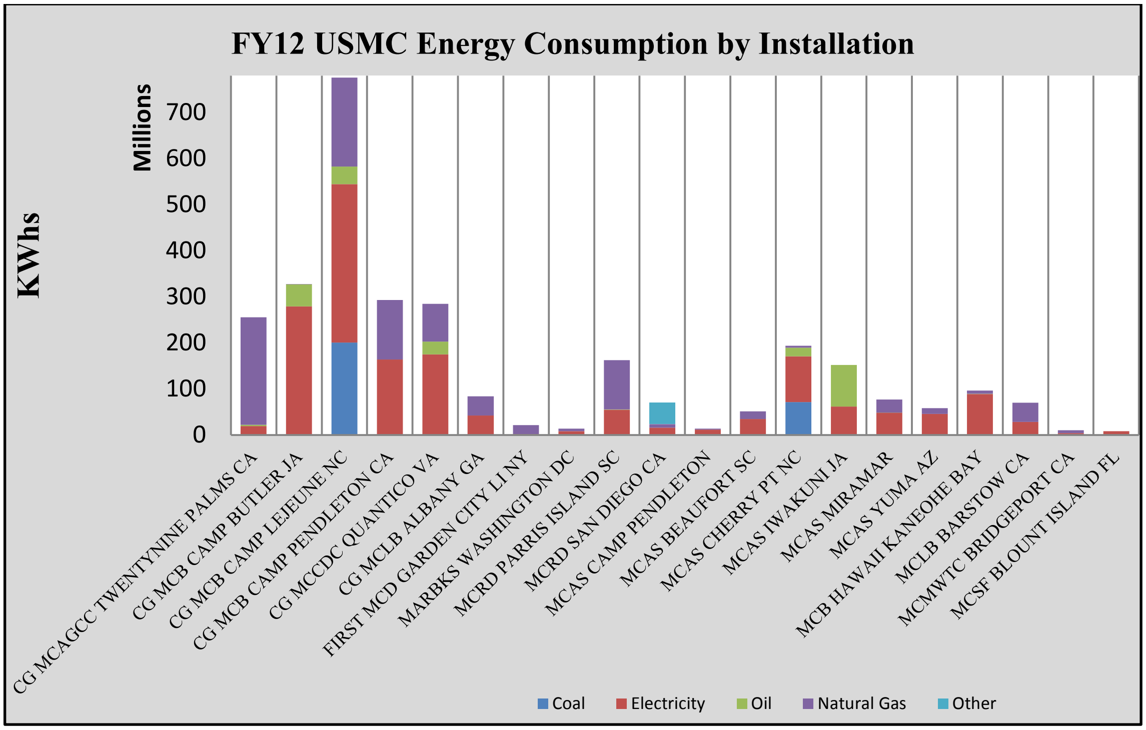

Figure 15. FY2012 Marine Corps Energy Consumption by Installation

c. *Energy Security Requirements and Shortfalls*

As previously discussed, installation RE generation targets are defined as the amount of kWh required to operate in the event of an interruption on the civilian grid. This analysis examined total Marine Corps and by-installation electricity consumption and set 10%, 15%, and 20% targets. These targets represent the amount of electricity that each installation needs to generate in RE to meet METs (e.g., physical security, basic life support, launch aircraft) in the event of an interruption to the civilian power grid. We compared targets to FY2012 RE generation to identify where shortfalls existed by installation. Installations that currently meet the 10%, 15%, and 20% targets for RE generation are MCB Twentynine Palms, MCLB Albany, MCRD San Diego, and MCAS Miramar. MCLB Barstow meets the 10% renewable generation target. Figures 16, 17, and 18 show energy generation target requirements versus existing RE generation at each installation. Specific target requirements and shortfall numbers per installation can be found in the appendix.

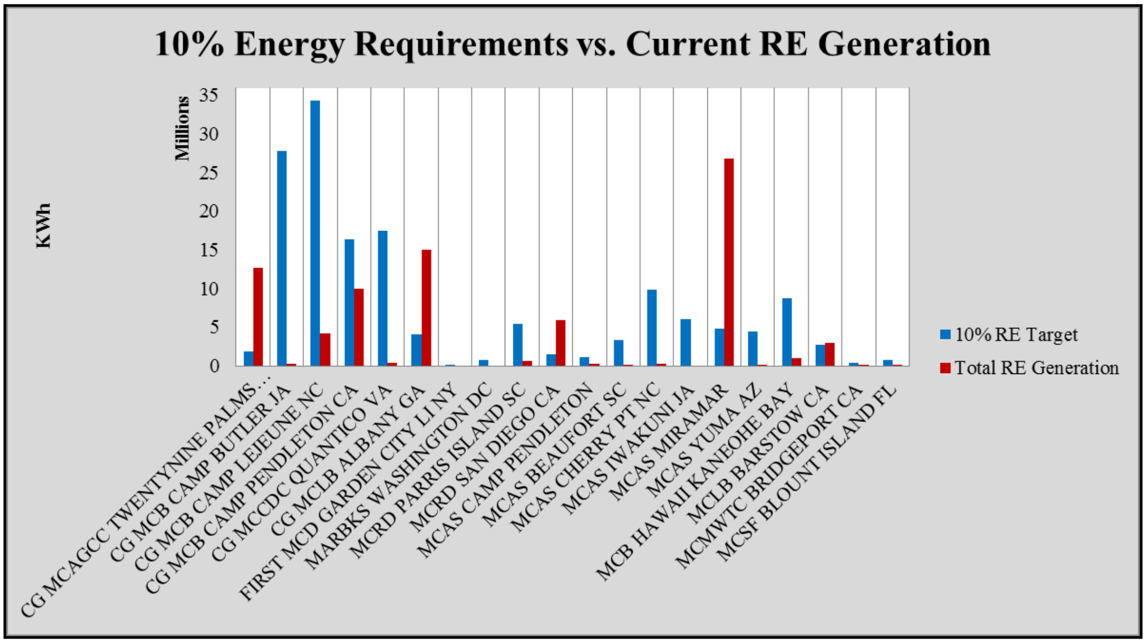

Figure 16. Energy Requirement (10%) vs. Current RE Generation

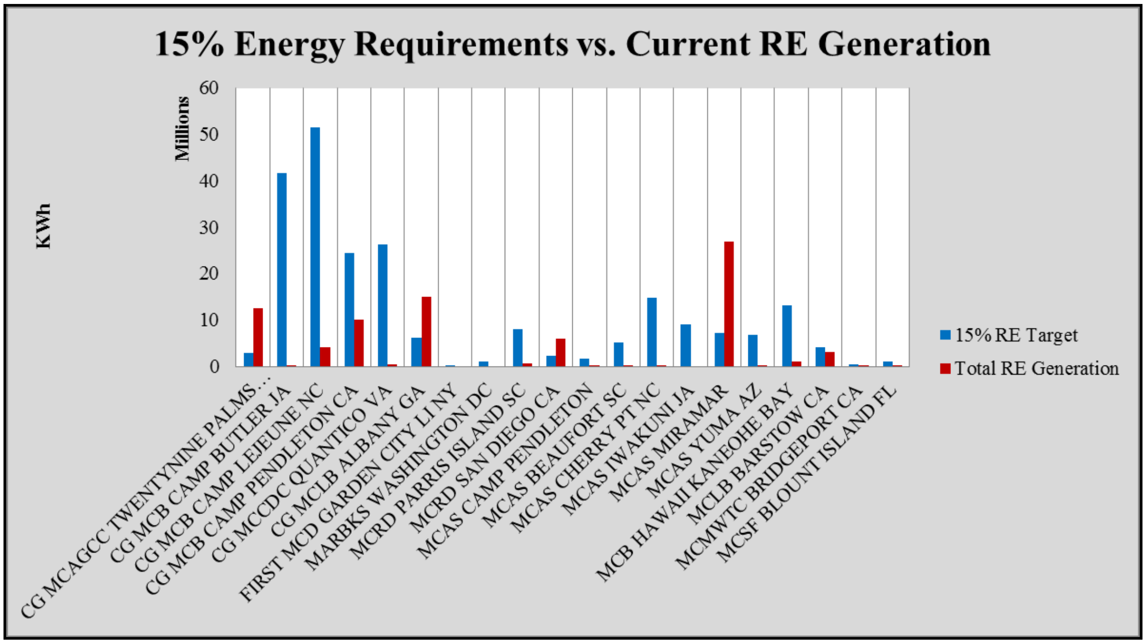

Figure 17. Energy Requirement (15%) vs. Current RE Generation

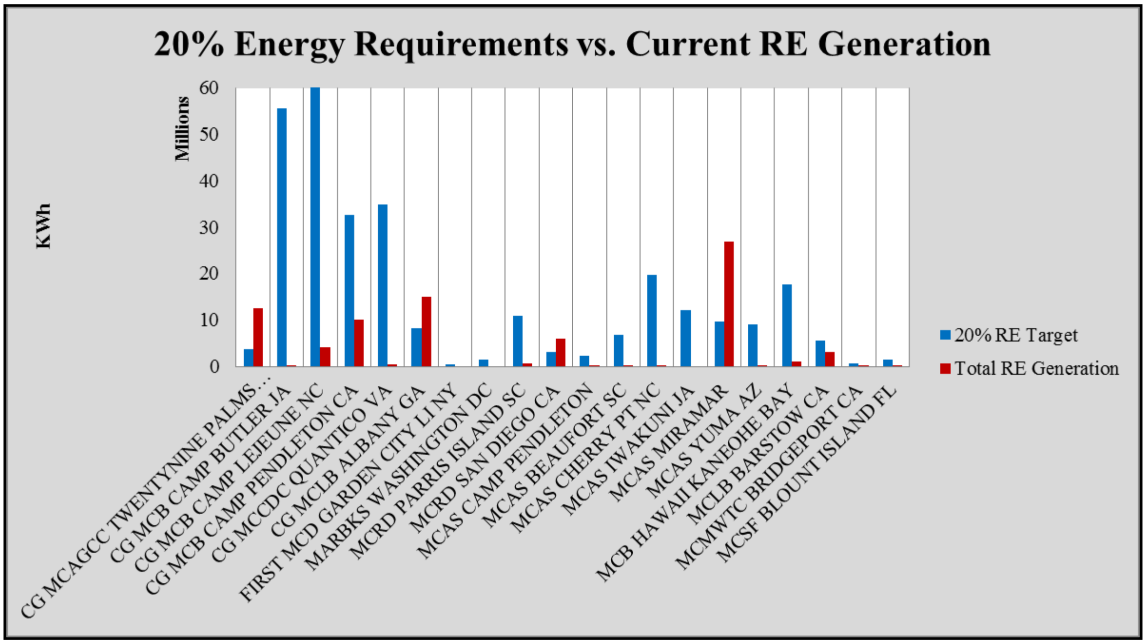

Figure 18. Energy Requirement (20%) vs. Current RE Generation

B. RENEWABLE ENERGY GENERATION

1. Overview

During FY2012, the Marine Corps generated 81.5 million kWh of electricity in RE. While PV generation was the main contributor, LFG, LFG PPA, and wind also provided RE generation. Figure 19 shows the distribution of generation by RE resource. Similar to patterns in regional electricity consumption, RE generation differs between East Coast and West Coast installations. East Coast generation accounts for 20.9 million kWh and is principally generated from LFG and, to a lesser extent, PV (71% and 29%, respectively). West Coast installations produce 59.2 million kWh of electricity, mainly from PV and LFG PPA (52% and 43%, respectively) but also a small percentage from wind (5%). Overall, East Coast installations generate only one third of the energy that West Coast installations produce.

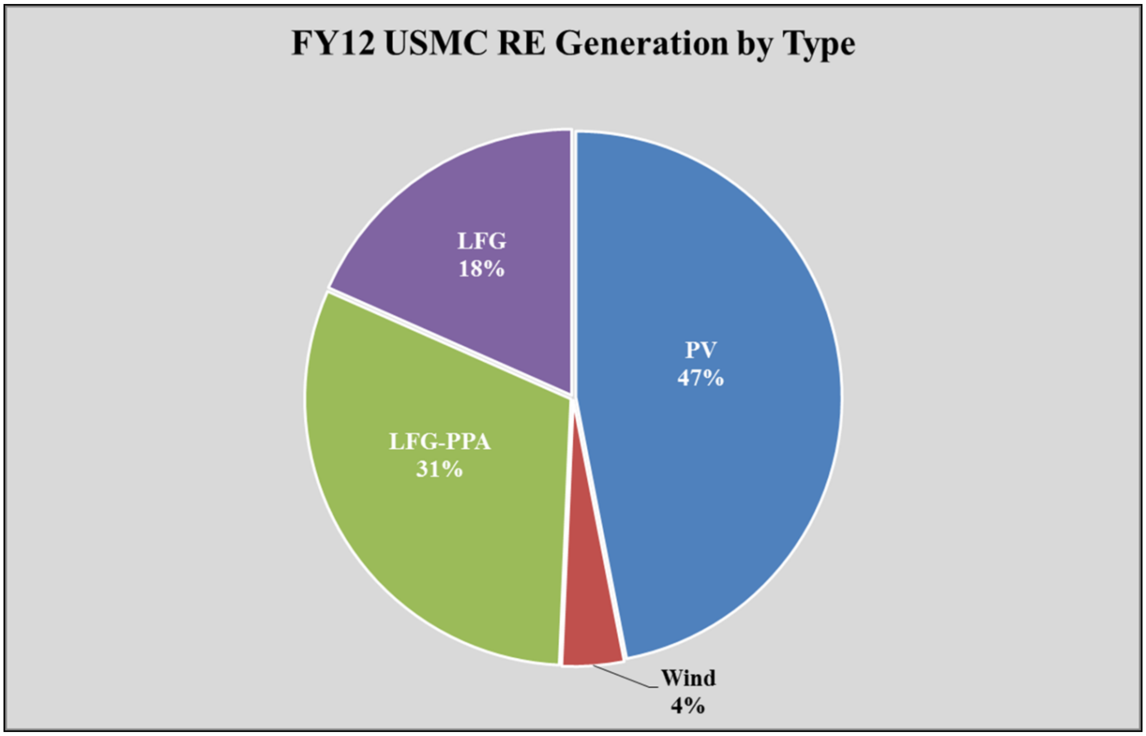

Figure 19. FY2012 Marine Corps RE Generation by Resource

2. Renewable Energy Generation Potential

This study does not outline regional RE resource feasibility; however, previous research has investigated this facet. McFaul and Rojas (2012) analyzed U.S. regional feasibility of RE generation potential in their thesis, *Comparative Cost-Benefit Analysis of Renewable Energy Resource Trade Offs for Military Installations*. They concluded that "certain areas and regions of the country are more favorable for a particular type of renewable energy…" (McFaul & Rojas, 2012, p. 68). This conclusion offers an explanation of the region differences in RE generation on Marine Corps installations; however, Anderson and Cutler (2012) assessed the potential for RE generation on East Coast installations at more than double that of West Coast installations (98 mWh versus 45 mWh). An important point is that 47.5% of East Coast generation potential comes from the most expensive RE resource: biomass. Also, the NREL identifies 25 mWh of potential wind energy generation across both regions—a low-cost renewable resource largely untapped by Marine Corps installation energy planners. Anderson and Cutler's (2012) findings suggest that the disparity in RE generation between East Coast and West

Coast installations is not due to regional resource feasibility, particularly for PV and biomass, but perhaps a reluctance to invest in expensive renewable resources, such as biomass.

3. Future Marine Corps Renewable Energy Projects

Based on HQMC I&L FY2014 projections for future RE projects under development, investments in RE generation seek to increase total Marine Corps RE generation from 11% in FY2015 to 39% by FY2020. Figure 20 shows the projected breakdown by installation and RE resource; specific numbers are found in the appendix.

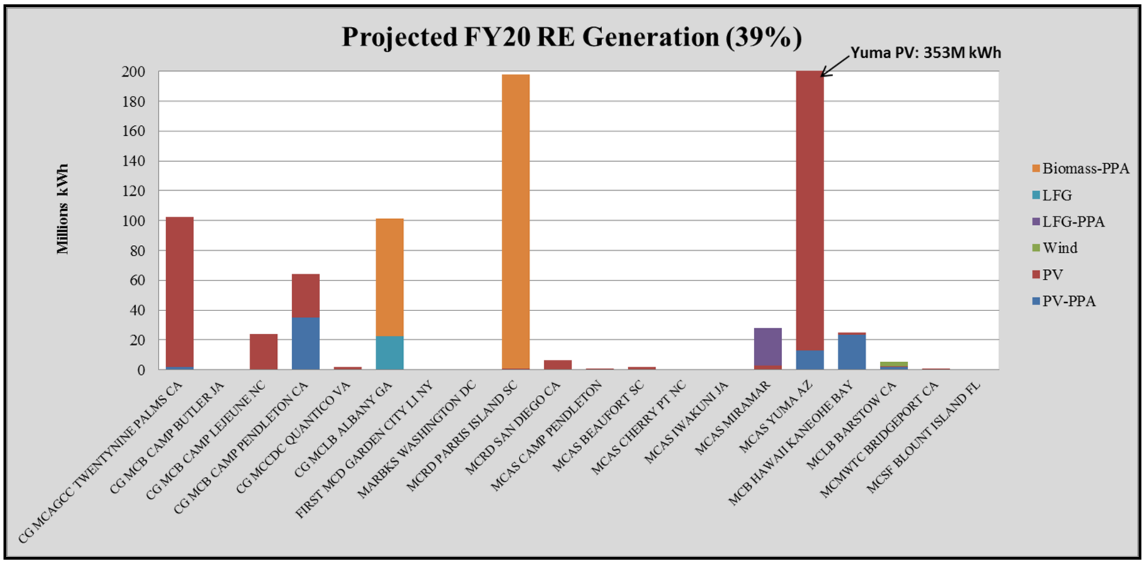

Figure 20. Projected Marine Corps FY2020 RE Generation

The dramatic 28% increase in generation is dispersed across six installations, two of which already meet minimum energy requirements at each target through established projects (MCLB Albany and MCB Twentynine Palms). Additional investments in RE projects at these two installations prevent investments at other installations from seeking to meet minimum energy security requirements. Likewise, MCAS Yuma will account for 44.5% of new Marine Corps investments in PV energy generation between FY2014 and FY2020. This investment will yield over 363 million kWh of energy for MCAS Yuma; seven times the total energy consumed by all fossil-fuel utilities (52 million kWh, projected FY2020 consumption assuming 30% energy reductions from FY2003 baseline). Renewable energy investment of this size is not proportional to the energy security needs for MCAS Yuma. In fact, the only contribution that investments at installations such as MCAS Yuma, MCLB Albany, MCRD Parris Island, and MCB Twentynine Palms serve is to increase total RE generation percentages. These investments do nothing to increase energy security of other installations that remain vulnerable to grid interruptions. Additionally, 87.7% of the FY2020 RE generation, programmed and planned, is based on PPAs and leased PV, not on-site generation. In the case of MCB Twentynine Palms, 87.6 million kWh (11% of planned FY2020 RE generation) of leased PV will come from the Barry M. Goldwater range in Arizona and must be transmitted over a distance of greater than 172 miles. MCAS Yuma's leased PV energy accounts for 45% of the Marine Corps planned FY2020 RE generation and must be transmitted farther than 63 miles. Therefore, this kind of RE must be transmitted into installations via the same methods as grid energy and likely carries similar risk.

Figure 21 shows the projected FY2020 RE generation measured against the RE generation required to meet the 20% energy security target. The horizontal axis, or zero, represents RE generation that meets the 20% energy security target. Values in green (or above the X axis) represent over-investments in RE technologies at the 20% target while values in blue (or below the X axis) represent under-investments at the 20% target. In the FY2020 projections, over half of Marine Corps installations cannot generate the 20% RE target to meet minimum energy security requirements and are left vulnerable to intentional or unintentional interruption. These installations include MCB Camp Butler, MCB Camp Lejeune, MCB Quantico, 1st Marine Corps District (1st MCD) Garden City, Marine Barracks, MCAS Camp Pendleton, MCAS Beaufort, MCAS Cherry Point, MCAS Iwakuni, MCLB Barstow, and Marine Corps Support Facility (MCSF) Blount Island. If PPAs and leased PV carried the same risk for interruption (as mentioned in the previous paragraph), MCAS Yuma, MCB Camp Pendleton, MCB Kaneohe Bay, and MCAS Miramar would be added to the list of installations unable to meet minimum energy security requirements at the 20% target; this would account for 75% of the 20 installations analyzed in this study.

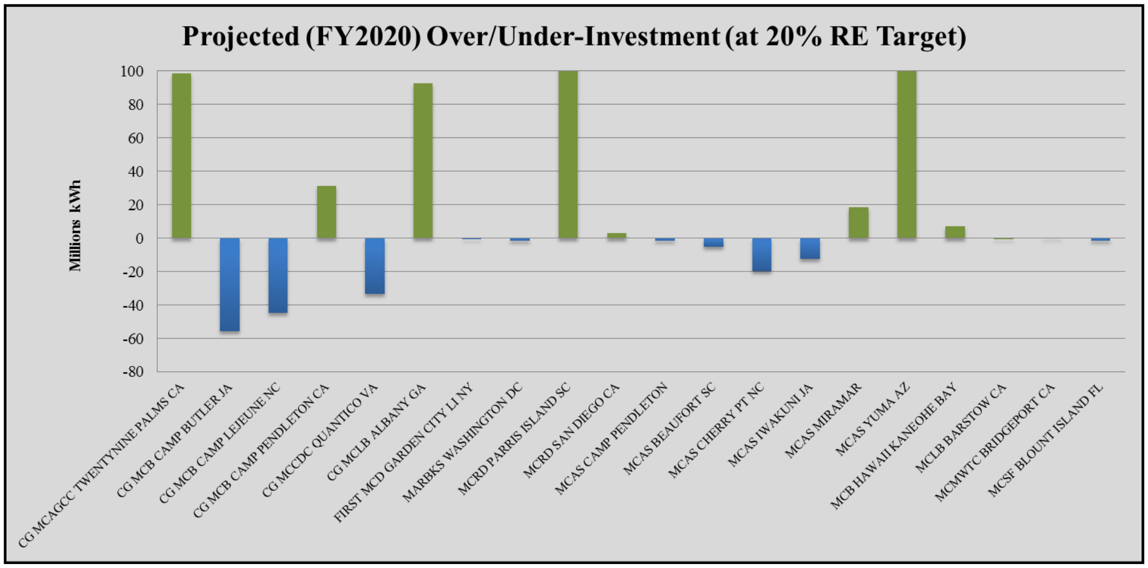

Figure 21. FY2020 RE Projections vs. 20% RE Targets

4. Levelized Cost of Renewable Energy

In assessing RE opportunities for the Marine Corps, the NREL developed levelized costs of RE, by resource and installation. These include full life-cycle costs for a 30-year period. The NREL's findings were used in our study to calculate the cost of target energy shortfalls, per installation, if RE resources were applied to compensate for grid-purchased electricity. The NREL's levelized cost data was adjusted two years along an 18% learning curve to more accurately represent today's RE prices per kWh. Table 2 lists these adjusted levelized costs per kWh for PV, wind, LFG, and biomass compared to the cost per kWh for grid-purchased electricity.

Table 2. Levelized Costs of Renewable Energy Technologies (from Anderson & Cutler, 2012)

		Levelized Cost of RE Technology ($/kWh)			
Installations	ELC	PV	Wind	Landfill Gas	Biomass
CG MCAGCC TWENTYNINE PALMS CA	0.19	0.12	0.05	0.00	0.00
CG MCB CAMP BUTLER JA	0.22	0.16	0.14	0.00	0.00
CG MCB CAMP LEJEUNE NC	0.05	0.13	0.05	0.00	0.00
CG MCB CAMP PENDLETON CA	0.08	0.12	0.09	0.00	0.00
CG MCCDC QUANTICO VA	0.07	0.14	0.07	0.00	0.00
CG MCLB ALBANY GA	0.10	0.15	0.21	0.09	0.00
FIRST MCD GARDEN CITY LI NY	0.16	0.00	0.07	0.23	0.00
MARBKS WASHINGTON DC	0.12	0.14	0.07	0.00	0.47
MARCORCRUITDEP PARRIS ISLAND SC	0.08	0.13	0.04	0.00	0.00
MARCORCRUITDEP SAN DIEGO CA	0.12	0.12	0.09	0.00	0.00
MARINE CORPS AIR STATION CAMP PENDLETON	0.14	0.12	0.09	0.00	0.00
MCAS BEAUFORT SC	0.09	0.13	0.05	0.00	0.00
MCAS CHERRY PT NC	0.07	0.09	0.03	0.00	0.00
MCAS IWAKUNI JA	0.14	0.16	0.14	0.00	0.00
MCAS MIRAMAR	0.15	0.12	0.14	0.09	0.19
MCAS YUMA AZ	0.08	0.12	0.05	0.00	0.00
MCB HAWAII KANEOHE BAY	0.27	0.16	0.14	0.00	0.00
MCLB BARSTOW CA	0.13	0.11	0.03	0.00	0.00
MCMWTC BRIDGEPORT CA	0.13	0.12	0.04	0.00	0.00
MCSF BLOUNT ISLAND FL	0.11	0.15	0.12	0.00	0.43

C. COST OF INTERRUPTION AND THE CUSTOMER DAMAGE FUNCTION

1. Introduction

Several key components are required to calculate the annual cost of interruption that each installation carries. As stated in Chapter III, the equation for the VEES used by the NREL in its 2012 study is as follows:

$$VEES = Annual\ \#\ outages * CDF(Duration)\left[\frac{\$}{kWpeak}\right] * Peak[kW] \tag{6}$$

The major components of this equation are the CDFs per duration of outage, the annual number of outages, and the installation's peak site load (measured in kilowatts). For the purpose of this study, we measured all three of these components in various ways to arrive at an annual cost per installation for interruption. The baseline case assumes that the value of “Annual # of outages” is 1 but will be addresses at various levels during sensitivity analysis.

2. Annual Number of Outages

The number of outages experienced by each installation is a value that was analyzed by the NREL in their 2012 study on MCAS Miramar and Fort Belvoir. Similar to the customer damage function, these probabilities can be broken down into an east and west coast delineation, 2.2 and 0.75 outages per year, respectively (NREL, 2012). For the purpose of this study, however, we assumed a value of 1 for all net present value cases outside of sensitivity analysis. In sensitivity analysis, we will demonstrate the impact that the variation in the number of outages per year can have on the cost of interruption.

3. Customer Damage Function

The CDF for our study was derived directly from the NREL’s 2012 study on blackouts at MCAS Miramar and Fort Belvoir. The NREL study provided a CDF in both emergency and non-emergency scenarios. For the purpose of this study, however, we used an average of these two scenarios to derive an average East Coast and average West Coast damage function.

These two CDFs provide the cost per duration element of the VEES equation from the 2012 NREL study. This data is best summarized by Table 3.

Table 3. Average Cost ($/kW Peak) per Duration (hr)

Customer Damage Function ($/kW Peak)	**Duration (hr)**					
	1	2	4	8	12	24
Average East Coast	$92.35	$114.90	$160.00	$250.20	$340.40	$611.00
Non-Emergency East	$97.58	$124.48	$178.26	$285.83	$393.40	$716.11
Emergency East Coast	$87.12	$105.32	$141.74	$214.57	$287.40	$505.89
Average West Coast	$38.22	$47.24	$65.29	$101.40	$137.50	$245.81
Non-Emergency West	$34.62	$47.96	$74.65	$128.03	$181.40	$341.52
Emergency West Coast	$41.82	$46.52	$55.94	$74.77	$93.60	$150.09

4. Probability of Interruption

Second, as we mentioned in Chapter III, we derived the probability of interruption from data provided by the Eaton Corporation. The basis for our state-by-state frequency of outage duration (listed in Table 3) was from root data provided by Eaton Corporation’s annual “Blackout Tracker.”

We first filtered the data by the states with existing Marine Corps installations and then screened for missing duration data. We then used the remaining data to create probability distributions by state. We used the probability of each given duration as the value for the annual number of outages in the VEES equation. A summary of this data is shown in Table 4.

Table 4. Probability of Interruption by State and Duration

P(Blackout) duration by	**Duration (Min)**					
State	**0–60**	**60–120**	**120–240**	**240–480**	**480–720**	**720–1440**
National	21.5%	17.5%	23.6%	23.7%	9.1%	5.1%
AZ	21.6%	17.4%	23.9%	23.9%	8.8%	4.9%
CA	14.7%	12.6%	19.7%	25.2%	13.3%	12.9%
DC/VA	17.7%	14.9%	22.3%	25.0%	11.2%	8.7%
FL	29.6%	21.3%	25.2%	18.5%	4.7%	1.6%
GA	28.6%	20.6%	25.3%	19.4%	5.1%	1.8%
HI	16.5%	26.2%	36.5%	19.9%	1.9%	0.2%
NC	30.0%	21.1%	25.3%	18.6%	4.4%	1.6%
NY	19.9%	16.4%	23.3%	24.3%	10.0%	6.3%
NC	26.8%	20.2%	24.9%	20.7%	5.9%	2.2%

5. Peak Site Load

Finally, the peak site load for each installation is required to complete the NREL’s VEES equation for each installation. For the VEES equation, the peak site load represents two major components: the installation’s peak kW requirement and the probability that the outage will occur during that peak.

As mentioned in Chapter II, paragraph 3g, Probability of Interruption(By State), the probability that the outage will occur during the installation's peak site load is set at 50% for the base-case in this analysis. We adjust that figure later in this chapter during sensitivity analysis.

For each installation, the 2012 NREL study provided data on the peak site load in kW for each installation, as summarized in Table 5. There were, however, installations that were not studied by the NREL but that are included in this analysis. In these cases, the peak site load assigned was based on installations with a similar size and annual consumption. These installations are annotated in Table 5 with an asterisk.

Table 5. Peak Site Load per Installation

Installation	State	Peak Site
CG MCAGCC TWENTYNINE PALMS CA	CA	29000
*CG MCB CAMP BUTLER JA	JA	49500
CG MCB CAMP LEJEUNE NC	NC	87800
CG MCB CAMP PENDLETON CA	CA	45000
CG MCCDC QUANTICO VA	VA	45000
CG MCLB ALBANY GA	GA	12000
FIRST MCD GARDEN CITY LI NY	NY	400
MARBKS WASHINGTON DC	DC	1500
MARCORCRUITDEP PARRIS ISLAND	SC	12900
MARCORCRUITDEP SAN DIEGO CA	CA	3200
MCAS CAMP PENDLETON	CA	3500
MCAS BEAUFORT SC	SC	8400
MCAS CHERRY PT NC	NC	41600
*MCAS IWAKUNI JA	JA	12900
MCAS MIRAMAR	CA	12000
MCAS YUMA AZ	AZ	14000
*MCB HAWAII KANEOHE BAY	HI	12000
MCLB BARSTOW CA	CA	7300
MCMWTC BRIDGEPORT CA	CA	850
MCSF BLOUNT ISLAND FL	FL	4500

6. Cost

With all three components of the VEES equation satisfied, we assigned a cost value for each installation in FY2012 thousands of dollars. As an example, Tables 6 and 7 step through the equation and then summarize the cost values for all of the installations.

Table 6. Example of Cost of Outage Based on Duration

CG MCB CAMP LEJEUNE NC		
Probability(Outage)*Average East Coast CDF		
Duration	P(Blackout)	Cost / Hour
1 hour	30%	$92.35
2 hour	21%	$114.90
4 hours	25%	$160.00
8 hours	19%	$250.20
12 hours	4%	$340.40
24 hours	2%	$611.00

By taking the sum of the product of these values, we arrived at a value of $164.00/kW peak. The remainder of the VEES equation is simply solved by plugging the remaining values into their respective locations.

$$VEES = Annual\ \#\ outages * CDF(Duration)\left[\frac{\$}{kWpeak}\right] * Peak[kW] \tag{7}$$

$$VEES = 164[\$/kWpeak]*50\%*87800kW \tag{8}$$

Equation 9 demonstrates that the Marine Corps base at Camp Lejeune carries an annual cost of interruption of around $7.2 million.

$$\$7{,}199{,}800 = \$164*.50*87800 \tag{9}$$

The VEES equation can be used for each installation by substituting installation-specific cost and kW peak information. Table 7 summarizes the annual cost of interruption for each installation.

Table 7. Annual Cost of Interruption per Installation

Peak Site load (kW)	50%	Annual Cost
Installation	State	
CG MCAGCC TWENTYNINE PALMS CA	CA	$1,449.6
*CG MCB CAMP BUTLER JA	JA	$1,624.9
CG MCB CAMP LEJEUNE NC	NC	$7,199.8
CG MCB CAMP PENDLETON CA	CA	$2,249.4
CG MCCDC QUANTICO VA	VA	$5,017.2
CG MCLB ALBANY GA	GA	$1,004.9
FIRST MCD GARDEN CITY LI NY	NY	$41.6
MARBKS WASHINGTON DC	DC	$167.2
MARCORCRUITDEP PARRIS ISLAND	SC	$1,118.0
MARCORCRUITDEP SAN DIEGO CA	CA	$319.9
MCAS CAMP PENDLETON	CA	$175.0
MCAS BEAUFORT SC	SC	$728.0
MCAS CHERRY PT NC	NC	$3,411.3
*MCAS IWAKUNI JA	JA	$423.5
MCAS MIRAMAR	CA	$599.8
MCAS YUMA AZ	AZ	$563.1
*MCB HAWAII KANEOHE BAY	HI	$393.9
MCLB BARSTOW CA	CA	$364.9
MCMWTC BRIDGEPORT CA	CA	$42.5
MCSF BLOUNT ISLAND FL	FL	$368.8

D. THE NET PRESENT VALUE MODEL

The NPV model used in this study is best represented in a balance-sheet format. For the purpose of this analysis, FY2012 was the focus, but a similar balance-sheet approach could be used to assess the full life cycle of RE technology.

1. Net Present Value Balance Sheet

As an example, Figure 22 includes a balance sheet for Camp Lejeune.

CG MCB CAMP LEJEUNE NC			
RE Target		10%	
2012 Cost of ELC			**$17,373,304.00**
2012 Consumption (kWh)		343752000	
	10%		**$1,737,330**
Current RE Generated (kWh)		4193237	
RE Shortfall from Target % (kWh)		30181963	
Cost to Generate Shortfall with RE		-	**$3,966,598**
2012 NPV without Interruption			**$(2,229,268)**

Figure 22. Example Balance Sheet

The NPV model in Figure 22 shows the most important pieces in an installation's decision about how much RE should be applied to meet METs. The current cost of purchasing electricity at target percentages, as compared to the cost of generating the same amount on-site through RE, is the heart of this analysis. The basic NPV analysis is a comparison between the current cost of purchasing a target percentage of electricity on the market and the cost of generating that same energy on-site through renewables, less what is currently being generated.

2. The Cost of Electricity at Target Percentages

Using the 2012 DUERS data provided by Installation and Logistics Command, we arrived at a summary of each installation's electricity cost. Table 8 summarizes these costs at the 10%, 15%, and 20% target percentages. Table 9 summarizes the FY2012 electricity consumed in kWh and the kWh required to meet the target percentages.

Table 8. Cost of Electricity at 10%, 15%, and 20% Target Consumption

Installation	State	Total 2012 ELC Cost (FY12$K)	10%	15%	20%
MCAGCC TWENTYNINE PALMS	**CA**	$2,125	$213	$319	$425
CG MCB CAMP BUTLER JA	**JA**	$61,449	$6,145	$9,217	$12,290
CG MCB CAMP LEJEUNE NC	**NC**	$17,373	$1,737	$2,606	$3,475
CG MCB CAMP PENDLETON CA	**CA**	$12,268	$1,227	$1,840	$2,454
CG MCCDC QUANTICO VA	**VA**	$11,834	$1,183	$1,775	$2,367
CG MCLB ALBANY GA	**GA**	$4,044	$404	$607	$809
FIRST MCD GARDEN CITY LI NY	**NY**	$326	$33	$49	$65
MARBKS WASHINGTON DC	**DC**	$1,108	$111	$166	$222
MCRD PARRIS ISLAND SC	**SC**	$4,620	$462	$693	$924
MCRD SAN DIEGO CA	**CA**	$1,821	$182	$273	$364
MCAS CAMP PENDLETON	**CA**	$1,570	$157	$236	$314
MCAS BEAUFORT SC	**SC**	$3,220	$322	$483	$644
MCAS CHERRY PT NC	**NC**	$6,574	$657	$986	$1,315
MCAS IWAKUNI JA	**JA**	$9,768	$977	$1,465	$1,954
MCAS MIRAMAR	**CA**	$6,907	$691	$1,036	$1,381
MCAS YUMA AZ	**AZ**	$3,373	$337	$506	$675
MCB HAWAII KANEOHE BAY	**HI**	$23,969	$2,397	$3,595	$4,794
MCLB BARSTOW CA	**CA**	$3,773	$377	$566	$755
MCMWTC BRIDGEPORT CA	**CA**	$508	$51	$76	$102
MCSF BLOUNT ISLAND FL	**FL**	$826	$83	$124	$165

Table 9. FY2012 Electricity Consumed Compared to Target RE Generation

		2012 ELC	**10%**	**15%**	**20%**
Installation	**State**	**(kWh)**	**RE**	**RE**	**RE**
MCAGCC TWENTYNINE PALMS	**CA**	19170000	1917000	2875500	3834000
CG MCB CAMP BUTLER JA	**JA**	278708000	27870800	41806200	55741600
CG MCB CAMP LEJEUNE NC	**NC**	343752000	34375200	51562800	68750400
CG MCB CAMP PENDLETON CA	**CA**	163607000	16360700	24541050	32721400
CG MCCDC QUANTICO VA	**VA**	175070000	17507000	26260500	35014000
CG MCLB ALBANY GA	**GA**	41739000	4173900	6260850	8347800
FIRST MCD GARDEN CITY LI NY	**NY**	2095000	209500	314250	419000
MARBKS WASHINGTON DC	**DC**	7775000	777500	1166250	1555000
MCRD PARRIS ISLAND SC	**SC**	54476000	5447600	8171400	10895200
MCRD SAN DIEGO CA	**CA**	15781000	1578100	2367150	3156200
MCAS CAMP PENDLETON	**CA**	11425000	1142500	1713750	2285000
MCAS BEAUFORT SC	**SC**	34286000	3428600	5142900	6857200
MCAS CHERRY PT NC	**NC**	99152000	9915200	14872800	19830400
MCAS IWAKUNI JA	**JA**	61318000	6131800	9197700	12263600
MCAS MIRAMAR	**CA**	48130000	4813000	7219500	9626000
MCAS YUMA AZ	**AZ**	45222000	4522200	6783300	9044400
MCB HAWAII KANEOHE BAY	**HI**	88331000	8833100	13249650	17666200
MCLB BARSTOW CA	**CA**	27875000	2787500	4181250	5575000
MCMWTC BRIDGEPORT CA	**CA**	4015000	401500	602250	803000
MCSF BLOUNT ISLAND FL	**FL**	7729000	772900	1159350	1545800

3. Current RE Generation and Shortfalls

The next piece of information needed to calculate the NPV of RE generation is the amount of RE energy currently generated on-site and each installation's shortfall from that amount. Some installations are already generating above these percentage targets. Table 10 shows each installation's current RE generation and its shortfall from the target percentages. Installations generating above-percentage targets are represented in red with parentheses.

Table 10. Per Installation RE Targets and RE Generation Shortfalls

	10%		15%		20%	
Installation	RE Target	Shortfall	RE Target	Shortfall	RE Target	Shortfall
CG MCAGCC TWENTYNINE PALMS CA	1917000	(10772736)	2875500	(9814236)	3834000	(8855736)
CG MCB CAMP BUTLER JA	27870800	27537920	41806200	41473320	55741600	55408720
CG MCB CAMP LEJEUNE NC	34375200	30181963	51562800	47369563	68750400	64557163
CG MCB CAMP PENDLETON CA	16360700	6316484	24541050	14496834	32721400	22677184
CG MCCDC QUANTICO VA	17507000	17033960	26260500	25787460	35014000	34540960
CG MCLB ALBANY GA	4173900	(10891548)	6260850	(8804598)	8347800	(6717648)
FIRST MCD GARDEN CITY LI NY	209500	209500	314250	314250	419000	419000
MARBKS WASHINGTON DC	777500	777500	1166250	1166250	1555000	1555000
MARCORCRUITDEP PARRIS ISLAND SC	5447600	4822136	8171400	7545936	10895200	10269736
MARCORCRUITDEP SAN DIEGO CA	1578100	(4408484)	2367150	(3619434)	3156200	(2830384)
MARINE CORPS AIR STATION CAMP PENDLETON	1142500	856101	1713750	1427351	2285000	1998601
MCAS BEAUFORT SC	3428600	3248144	5142900	4962444	6857200	6676744
MCAS CHERRY PT NC	9915200	9563048	14872800	14520648	19830400	19478248
MCAS IWAKUNI JA	6131800	6131800	9197700	9197700	12263600	12263600
MCAS MIRAMAR	4813000	(22038152)	7219500	(19631652)	9626000	(17225152)
MCAS YUMA AZ	4522200	4306704	6783300	6567804	9044400	8828904
MCB HAWAII KANEOHE BAY	8833100	7790310	13249650	12206860	17666200	16623410
MCLB BARSTOW CA	2787500	(278500)	4181250	1115250	5575000	2509000
MCMWTC BRIDGEPORT CA	401500	354196	602250	554946	803000	755696
MCSF BLOUNT ISLAND FL	772900	667780	1159350	1054230	1545800	1440680

a. Generation Costs per Installation

The next step in RE generation NPV is to calculate the cost to generate the installation’s identified shortfall with RE. There are two parts to calculating the cost of producing the installation’s shortfall: (a) identifying the type and share of RE technology at each installation and (b) multiplying by the cost of each type of RE.

Table 11 shows the share of each type of RE technology at each installation. For sites that were not currently producing any electricity through RE, we used potential shares as determined by the NREL in 2012. Later in this chapter, we apply sensitivity analysis to the amount of wind generation existing at each installation.

Table 11. Current Percentage of RE Generation at Marine Corps Installations

		Existing Technology On-site			
Installation	**State**	**PV**	**Wind**	**LFG**	**Biomass**
CG MCAGCC TWENTYNINE PALMS CA	**CA**	100%	0%		
CG MCB CAMP BUTLER JA	**JA**	100%	0%		
CG MCB CAMP LEJEUNE NC	**NC**	100%	0%		
CG MCB CAMP PENDLETON CA	**CA**	100%	0%		
CG MCCDC QUANTICO VA	**VA**	100%	0%		
CG MCLB ALBANY GA	**GA**	1%	0%	99%	
FIRST MCD GARDEN CITY LI NY	**NY**		0%	100%	
MARBKS WASHINGTON DC	**DC**	46%	0%		54%
MARCORCRUITDEP PARRIS ISLAND SC	**SC**	100%	0%		
MARCORCRUITDEP SAN DIEGO CA	**CA**	100%	0%		
MCAS CAMP PENDLETON	**CA**	100%	0%		
MCAS BEAUFORT SC	**SC**	100%	0%		
MCAS CHERRY PT NC	**NC**	100%	0%		
MCAS IWAKUNI JA	**JA**	100%	0%		
MCAS MIRAMAR	**CA**	5%		78%	18%
MCAS YUMA AZ	**AZ**	100%	0%		
MCB HAWAII KANEOHE BAY	**HI**	100%	0%		
MCLB BARSTOW CA	**CA**		100%		
MCMWTC BRIDGEPORT CA	**CA**	100%	0%		
MCSF BLOUNT ISLAND FL	**FL**	78%	12%		10%

Next, the cost of each RE technology at each installation must be determined. The NREL provided levelized cost estimates for each type of technology at each installation based on outputs from its RE optimization model. Table 12 is a summary of the cost in $/kWh of each technology at each installation.

Table 12. Cost ($/kWh) of RE Technology per Installation

		Levalized Cost of Technology ($/kWh)			
Installation	**State**	**PV**	**Wind**	**LFG**	**Biomass**
CG MCAGCC TWENTYNINE PALMS CA	**CA**	0.12	0.05	0.00	0.00
CG MCB CAMP BUTLER JA	**JA**	0.16	0.14	0.00	0.00
CG MCB CAMP LEJEUNE NC	**NC**	0.13	0.05	0.00	0.00
CG MCB CAMP PENDLETON CA	**CA**	0.12	0.09	0.00	0.00
CG MCCDC QUANTICO VA	**VA**	0.14	0.07	0.00	0.00
CG MCLB ALBANY GA	**GA**	0.15	0.21	0.09	0.00
FIRST MCD GARDEN CITY LI NY	**NY**	0.00	0.07	0.23	0.00
MARBKS WASHINGTON DC	**DC**	0.14	0.07	0.00	0.47
MARCORCRUITDEP PARRIS ISLAND SC	**SC**	0.13	0.04	0.00	0.00
MARCORCRUITDEP SAN DIEGO CA	**CA**	0.12	0.09	0.00	0.00
MCAS CAMP PENDLETON	**CA**	0.12	0.09	0.00	0.00
MCAS BEAUFORT SC	**SC**	0.13	0.05	0.00	0.00
MCAS CHERRY PT NC	**NC**	0.09	0.03	0.00	0.00
MCAS IWAKUNI JA	**JA**	0.16	0.14	0.00	0.00
MCAS MIRAMAR	**CA**	0.12	0.14	0.09	0.19
MCAS YUMA AZ	**AZ**	0.12	0.05	0.00	0.00
MCB HAWAII KANEOHE BAY	**HI**	0.16	0.14	0.00	0.00
MCLB BARSTOW CA	**CA**	0.11	0.03	0.00	0.00
MCMWTC BRIDGEPORT CA	**CA**	0.12	0.04	0.00	0.00
MCSF BLOUNT ISLAND FL	**FL**	0.15	0.12	0.00	0.43

b. Cost to Generate Renewable Energy Shortfall

Using these inputs, we easily determined the cost of generating the shortfall with RE technology. By taking the sum of the product of the RE technology share and the associated costs, and then multiplying that value by the shortfall amount, we arrived at the cost of generating the shortfall through renewable technologies.

$$Shortfall * \quad (LevalizedCost * REshare) \tag{10}$$

Table 13 is a summary of the cost to generate the shortfall amount at each of the RE target percentages. Values reflected by parentheses are installations that are already generating over these target amounts with renewable technologies.

Table 13. Cost to Generate RE Shortfall at Each Target (FY2012$M)

FY2012$M	**Target Cost**		
Installation	**10%**	**15%**	**20%**
CG MCAGCC TWENTYNINE PALMS CA	($1.26)	($1.15)	($1.03)
CG MCB CAMP BUTLER JA	$4.42	$6.66	$8.90
CG MCB CAMP LEJEUNE NC	$3.97	$6.23	$8.48
CG MCB CAMP PENDLETON CA	$0.74	$1.69	$2.65
CG MCCDC QUANTICO VA	$2.36	$3.58	$4.79
CG MCLB ALBANY GA	($1.04)	($0.84)	($0.64)
FIRST MCD GARDEN CITY LI NY	$0.05	$0.07	$0.09
MARBKS WASHINGTON DC	$0.25	$0.37	$0.49
MARCORCRUITDEP PARRIS ISLAND SC	$0.63	$0.99	$1.35
MARCORCRUITDEP SAN DIEGO CA	($0.52)	($0.42)	($0.33)
MCAS CAMP PENDLETON	$0.10	$0.17	$0.23
MCAS BEAUFORT SC	$0.43	$0.65	$0.88
MCAS CHERRY PT NC	$0.84	$1.27	$1.71
MCAS IWAKUNI JA	$0.98	$1.48	$1.97
MCAS MIRAMAR	($2.48)	($2.21)	($1.94)
MCAS YUMA AZ	$0.50	$0.77	$1.03
MCB HAWAII KANEOHE BAY	$1.25	$1.96	$2.67
MCLB BARSTOW CA	($0.01)	$0.03	$0.07
MCMWTC BRIDGEPORT CA	$0.04	$0.07	$0.09
MCSF BLOUNT ISLAND FL	$0.12	$0.19	$0.26

4. Initial NPV Outputs

Using the inputs provided throughout this chapter, we were then able to arrive at an initial NPV output. This output reflects the positive or negative value of investing in RE technology at a given target percentage at each installation. Table 14 is a summary of this initial output of the NPV model. Values highlighted in red and in parentheses in Table 13 indicate a negative NPV at that target percentage.

Table 14. Summary of NPV of RE Generation Investments Without Interruption Cost (FY2012$M)

Net Present Value of RE Targets			
FY2012$M	**TARGET**		
Installation	**10%**	**15%**	**20%**
CG MCAGCC TWENTYNINE PALMS CA	$1.47	$1.47	$1.46
CG MCB CAMP BUTLER JA	$1.72	$2.56	$3.39
CG MCB CAMP LEJEUNE NC	($2.23)	($3.62)	($5.01)
CG MCB CAMP PENDLETON CA	$0.49	$0.15	($0.20)
CG MCCDC QUANTICO VA	($1.18)	($1.80)	($2.42)
CG MCLB ALBANY GA	$1.44	$1.45	$1.45
FIRST MCD GARDEN CITY LI NY	($0.01)	($0.02)	($0.03)
MARBKS WASHINGTON DC	($0.14)	($0.20)	($0.27)
MARCORCRUITDEP PARRIS ISLAND SC	($0.17)	($0.30)	($0.43)
MARCORCRUITDEP SAN DIEGO CA	$0.70	$0.70	$0.69
MCAS CAMP PENDLETON	$0.06	$0.07	$0.08
MCAS BEAUFORT SC	($0.10)	($0.17)	($0.23)
MCAS CHERRY PT NC	($0.18)	($0.29)	($0.39)
MCAS IWAKUNI JA	($0.01)	($0.01)	($0.02)
MCAS MIRAMAR	$3.17	$3.25	$3.32
MCAS YUMA AZ	($0.17)	($0.26)	($0.36)
MCB HAWAII KANEOHE BAY	$1.15	$1.63	$2.12
MCLB BARSTOW CA	$0.39	$0.53	$0.68
MCMWTC BRIDGEPORT CA	$0.01	$0.01	$0.01
MCSF BLOUNT ISLAND FL	($0.04)	($0.06)	($0.09)
TOTAL NPV AT TARGET %	$6.36	$5.06	$3.76

5. Including the Cost of Interruption in the Net Present Value Balance Sheet

As discussed earlier, the cost of interruption carried on an annual basis by each installation is not an insignificant dollar amount. By adjusting the model to account for the cost of interruption carried by each installation, a different picture of RE NPV is presented.

As an example, the balance sheet of MCB Camp Lejeune for FY2012 would look similar to Table 15 with the cost of interruption included.

Table 15. Example Balance Sheet With Interruption Cost

CG MCB CAMP LEJEUNE NC		
RE Target	10%	
2012 Cost of ELC		**$17,373,304.00**
2012 Consumption (kWh)	343752000	
10%		**$1,737,330**
Current RE Generated (kWh)	4193237	
RE Shortfall from Target % (kWh)	30181963	
Cost to Generate Shortfall With RE	-	**$3,966,598**
2012 NPV Without Interruption		**$(2,229,268)**
Cost of Interruption	+	**$7,199,813**
2012 NPV including Cost of Interruption		**$4,970,546**

The interruption costs included in Table 16 are assumed at 50% peak site load using the average East Coast and West Coast damage functions. Table 17 shows the NPV of RE generation to meet each generation target with and without interruption risk.

Table 16. Summary of NPV of RE Generation Investments With Interruption Cost (FY2012$M)

Net Present Value of RE Targets			
FY2012$M	**TARGET**		
Installation	**10%**	**15%**	**20%**
CG MCAGCC TWENTYNINE PALMS CA	$2.92	$2.91	$2.91
CG MCB CAMP BUTLER JA	$3.35	$4.18	$5.01
CG MCB CAMP LEJEUNE NC	$4.97	$3.58	$2.19
CG MCB CAMP PENDLETON CA	$2.74	$2.40	$2.05
CG MCCDC QUANTICO VA	$3.84	$3.21	$2.59
CG MCLB ALBANY GA	$2.45	$2.45	$2.45
FIRST MCD GARDEN CITY LI NY	$0.03	$0.02	$0.01
MARBKS WASHINGTON DC	$0.03	($0.04)	($0.10)
MARCORCRUITDEP PARRIS ISLAND SC	$0.95	$0.82	$0.69
MARCORCRUITDEP SAN DIEGO CA	$1.02	$1.02	$1.01
MCAS CAMP PENDLETON	$0.23	$0.24	$0.26
MCAS BEAUFORT SC	$0.62	$0.56	$0.49
MCAS CHERRY PT NC	$3.23	$3.13	$3.02
MCAS IWAKUNI JA	$0.42	$0.41	$0.41
MCAS MIRAMAR	$3.77	$3.85	$3.92
MCAS YUMA AZ	$0.40	$0.30	$0.21
MCB HAWAII KANEOHE BAY	$1.54	$2.03	$2.52
MCLB BARSTOW CA	$0.75	$0.90	$1.05
MCMWTC BRIDGEPORT CA	$0.05	$0.05	$0.05
MCSF BLOUNT ISLAND FL	$0.33	$0.31	$0.28
TOTAL NPV AT TARGET %	$33.63	$32.33	$31.03

Table 17. Dollar Difference Between NPV

Net Present Value of RE Targets (Without and With Interruption)			
TOTAL NPV WITHOUT COST OF INTERRUPTION TARGET %	$6.36	$5.06	$3.76
TOTAL NPV WITH COST OF INTERRUPTION TARGET %	$33.63	$32.33	$31.03
$ CHANGE	$27.27		

Given the values from Tables 15–17, we drew breakeven percentages for each installation. Table 18 shows a side-by-side analysis of each installation's breakeven NPV percentage both with and without the cost of interruption included in the calculation. Installations with a breakeven percentage that exceeded 100% were thus limited to 100% for the purposes of this analysis.

Table 18. Installation RE Generation Breakeven NPV Percentage

Breakeven Target Percentage		
Installation	**Without Interruption**	**With Cost of Interruption**
CG MCAGCC TWENTYNINE PALMS CA	**100%**	**100%**
CG MCB CAMP BUTLER JA	**100%**	**100%**
CG MCB CAMP LEJEUNE NC	**2%**	**28%**
CG MCB CAMP PENDLETON CA	**17%**	**50%**
CG MCCDC QUANTICO VA	**1%**	**41%**
CG MCLB ALBANY GA	**100%**	**100%**
FIRST MCD GARDEN CITY LI NY	**0%**	**28%**
MARBKS WASHINGTON DC	**100%**	**12%**
MARCORCRUITDEP PARRIS ISLAND SC	**3%**	**47%**
MARCORCRUITDEP SAN DIEGO CA	**100%**	**100%**
MCAS CAMP PENDLETON	**100%**	**100%**
MCAS BEAUFORT SC	**2%**	**58%**
MCAS CHERRY PT NC	**1%**	**100%**
MCAS IWAKUNI JA	**100%**	**100%**
MCAS MIRAMAR	**100%**	**100%**
MCAS YUMA AZ	**1%**	**31%**
MCB HAWAII KANEOHE BAY	**100%**	**100%**
MCLB BARSTOW CA	**100%**	**100%**
MCMWTC BRIDGEPORT CA	**100%**	**100%**
MCSF BLOUNT ISLAND FL	**3%**	**71%**

By investing at the percentage levels given in Table 18, the Marine Corps would arrive at the following overall energy portfolio percentages on the way to the SECNAV's FY2020 goal of 50%. Table 19 summarizes the Marine Corps' overall portfolio given investment at the stated percentages.

Table 19. Percentage of Total Installation Consumption Covered by RE Given Recommended Investment Percentages (from Table 18)

	% of Total Installation Consumption	
Installation	Without INT	With INT
CG MCAGCC TWENTYNINE PALMS CA	8%	8%
CG MCB CAMP BUTLER JA	85%	85%
CG MCB CAMP LEJEUNE NC	9%	12%
CG MCB CAMP PENDLETON CA	10%	28%
CG MCCDC QUANTICO VA	0%	25%
CG MCLB ALBANY GA	50%	50%
FIRST MCD GARDEN CITY LI NY	10%	10%
MARBKS WASHINGTON DC	57%	57%
MARCORCRUITDEP PARRIS ISLAND SC	1%	16%
MARCORCRUITDEP SAN DIEGO CA	23%	23%
MCAS CAMP PENDLETON	83%	83%
MCAS BEAUFORT SC	1%	39%
MCAS CHERRY PT NC	1%	51%
MCAS IWAKUNI JA	40%	40%
MCAS MIRAMAR	59%	59%
MCAS YUMA AZ	1%	24%
MCB HAWAII KANEOHE BAY	92%	92%
MCLB BARSTOW CA	40%	40%
MCMWTC BRIDGEPORT CA	39%	39%
MCSF BLOUNT ISLAND FL	3%	71%
MARINE CORPS TOTAL	26%	34%

By including the cost of interruption in the equation for investing in RE projects, the Marine Corps can move closer to the SECNAV's stated RE goals. First, by investing across the Marine Corps at the recommended breakeven percentages from Table 18, the Marine Corps can cover 26% of its total energy consumption with on-site renewable energy at a breakeven NPV. With the cost in interruption factored into that same analysis, the Marine Corps can cover 34% of its total energy consumption with RE and move even closer to meeting the SECNAV's FY2020 while remaining at a breakeven NPV.

E. SENSITIVITY ANALYSIS

1. Introduction

We conducted sensitivity analysis in the areas that most affected the outcome of the NPV model. We made assumptions during both data collection and data analysis; in this section, we address the impact of those assumptions on the overall NPV outcome. The considerations for sensitivity analysis are the percentage of peak site load, the percentage of wind energy in the portfolio, the purchase year of solar technologies, and the learning curve rate. We conclude this section with an analysis that reflects altering all sensitivity analysis considerations at once, according to different probability distributions.

2. Annual Number of Outages

For all of the included outputs in this study we assumed the annual number of outages occurring at each site to be a value of 1. However, from the NREL's 2012 study on the value of electrical energy security there can be variance in this number from installation to installation. While the national average for the number of outages occurring each year is around 1.2, from the east coast to the west it varies from 2.2 to 0.75 (NREL, 2012). Indeed, this study as well as others shows this probability as high as 8 and as low as 0.5 for overseas installations.

Table 20 shows the impact that adjusting these numbers can have on the cost of interruption being carried by each installation. By including these variations from the assumed value of 1, the cost of interruption to the Marine Corps goes from \$27.26 million to \$32.76 million by including the national average SAIFI of 1.2. When east coast/west coast delineation is made the value increases even further to \$49.18 million.

Table 20. Cost of Interruption With varying SAIFI values

Installation (FY$12M)	Cost of Int with SAIFI=1	Cost of Int with National Avg SAIFI (1.2)	Cost of Int with East/West/Nat SAIFI (2.2, 0.75, 1.2)
CG MCAGCC TWENTYNINE PALMS CA	$1.45	$1.74	$1.09
***CG MCB CAMP BUTLER JA**	$1.62	$1.95	* $1.95
CG MCB CAMP LEJEUNE NC	$7.20	$8.64	$15.84
CG MCB CAMP PENDLETON CA	$2.25	$2.70	$1.69
CG MCCDC QUANTICO VA	$5.02	$6.02	$11.04
CG MCLB ALBANY GA	$1.00	$1.21	$2.21
FIRST MCD GARDEN CITY LI NY	$0.04	$0.05	$0.09
MARBKS WASHINGTON DC	$0.17	$0.20	$0.37
MARCORCRUITDEP PARRIS ISLAND SC	$1.12	$1.34	$2.46
MARCORCRUITDEP SAN DIEGO CA	$0.32	$0.38	$0.24
MCAS CAMP PENDLETON	$0.17	$0.21	$0.13
MCAS BEAUFORT SC	$0.73	$0.87	$1.60
MCAS CHERRY PT NC	$3.41	$4.09	$7.50
***MCAS IWAKUNI JA**	$0.42	$0.51	* $0.51
MCAS MIRAMAR	$0.60	$0.72	$0.45
MCAS YUMA AZ	$0.56	$0.68	$0.42
***MCB HAWAII KANEOHE BAY**	$0.39	$0.47	* $0.47
MCLB BARSTOW CA	$0.36	$0.44	$0.27
MCMWTC BRIDGEPORT CA	$0.04	$0.05	$0.03
MCSF BLOUNT ISLAND FL	$0.37	$0.44	$0.81
MARINE CORPS TOTAL	**$27.26**	**$32.72**	**$49.18**
***National Average SAIFI was applied to overseas installations**			

3. Percentage of Peak Site Load

In the base model (Table 16), we made the assumption that the average peak site load for any given interruption was 50%. Table 20 demonstrates the impact that adjusting the peak site load has on the cost of interruption to each installation. The analysis provided in the table is useful because while an installation may spend the average of its time around 50%, outages are more likely to occur during hours of peak usage, closer to 75%–100% of peak site load. As might be expected, costs increase linearly as the percentage of peak site load increases, thus also making the NPV equation more favorable to RE as the percentage of peak site load increases.

Table 21. Sensitivity Analysis of Adjusted Peak Site Load on the Cost of Interruption (FY2012$M)

FY2012$M	20%	50%	75%	100%
Installation	**Annual Cost**	**Annual**	**Annual Cost**	**Annual Cost**
MCAGCC TWENTYNINE PALMS CA	$0.58	$1.45	$2.17	$2.90
***CG MCB CAMP BUTLER JA**	$0.65	$1.62	$2.44	$3.25
CG MCB CAMP LEJEUNE NC	$2.88	$7.20	$10.80	$14.40
CG MCB CAMP PENDLETON CA	$0.90	$2.25	$3.37	$4.50
CG MCCDC QUANTICO VA	$2.01	$5.02	$7.53	$10.03
CG MCLB ALBANY GA	$0.40	$1.00	$1.51	$2.01
FIRST MCD GARDEN CITY LI NY	$0.02	$0.04	$0.06	$0.08
MARBKS WASHINGTON DC	$0.07	$0.17	$0.25	$0.33
MCRD PARRIS ISLAND SC	$0.45	$1.12	$1.68	$2.24
MARCORCRUITDEP SAN DIEGO CA	$0.32	$0.32	$0.32	$0.32
MCAS CAMP PENDLETON	$0.07	$0.17	$0.26	$0.35
MCAS BEAUFORT SC	$0.29	$0.73	$1.09	$1.46
MCAS CHERRY PT NC	$1.36	$3.41	$5.12	$6.82
***MCAS IWAKUNI JA**	$0.17	$0.42	$0.64	$0.85
MCAS MIRAMAR	$0.24	$0.60	$0.90	$1.20
MCAS YUMA AZ	$0.23	$0.56	$0.84	$1.13
***MCB HAWAII KANEOHE BAY**	$0.16	$0.39	$0.59	$0.79
MCLB BARSTOW CA	$0.15	$0.36	$0.55	$0.73
MCMWTC BRIDGEPORT CA	$0.02	$0.04	$0.06	$0.08
MCSF BLOUNT ISLAND FL	$0.15	$0.37	$0.55	$0.74
TOTAL COST OF INTERRUPTION	**$ 11.12**	**$ 27.24**	**$ 40.73**	**$ 54.21**

As we predicted, the cost of each site’s annual interruption increases as that installation moves closer to 100% of its peak site load. If an installation averages closer to 100% of its daily peak site load throughout the year, its annual cost of interruption will be greater than an installation that spends more of its day in the lower ranges of its peak site load.

4. Percentage of Wind Forced into the Model

As shown in the preceding paragraphs, when it comes to the share of RE technology considered by the Marine Corps, solar ranks well above everything else. This is contrary to the fact that wind energy carries a lower levelized cost than all other technologies (see page 56 for a comparative cost breakdown). For this reason, this section demonstrates the decrease in the cost of generating the shortfall amounts by forcing wind technology into the NPV model. Tables 21, 22, and 23 are a summary of these cost figures at the target RE percentages.

Table 22. Cost of Wind Technologies at 10% RE Target (FY2012$M)

Cost of Generation at 10% RE Target (FY12$M)			
Installation	**0% Wind**	**25% Wind**	**50% Wind**
CG MCAGCC TWENTYNINE PALMS CA	*($1.26)*	($1.08)	($0.90)
CG MCB CAMP BUTLER JA	*$4.42*	$4.27	$4.12
CG MCB CAMP LEJEUNE NC	*$3.97*	$3.36	$2.75
CG MCB CAMP PENDLETON CA	*$0.74*	$0.70	$0.67
CG MCCDC QUANTICO VA	*$2.36*	$2.08	$1.80
CG MCLB ALBANY GA	*($1.04)*	($1.36)	($1.67)
FIRST MCD GARDEN CITY LI NY	*$0.05*	$0.04	$0.03
MARBKS WASHINGTON DC	*$0.25*	$0.23	$0.22
MARCORCRUITDEP PARRIS ISLAND SC	*$0.63*	$0.52	$0.40
MARCORCRUITDEP SAN DIEGO CA	*($0.52)*	($0.49)	($0.47)
MARINE CORPS AIR STATION CAMP PENDLETON	*$0.10*	$0.10	$0.09
MCAS BEAUFORT SC	*$0.43*	$0.36	$0.30
MCAS CHERRY PT NC	*$0.84*	$0.70	$0.56
MCAS IWAKUNI JA	*$0.98*	$0.95	$0.92
MCAS MIRAMAR	*($2.48)*	($2.48)	($2.48)
MCAS YUMA AZ	*$0.50*	$0.50	$0.50
MCB HAWAII KANEOHE BAY	*$1.25*	$1.25	$1.25
MCLB BARSTOW CA	*($0.01)*	($0.01)	($0.01)
MCMWTC BRIDGEPORT CA	*$0.04*	$0.04	$0.04
MCSF BLOUNT ISLAND FL	*$0.12*	$0.12	$0.11
AMOUNT SAVED BY FORCING WIND	***$ 0.16***	**$ 0.16**	**$ 0.15**

Table 23. Cost of Wind Technologies at 15% RE Target (FY2012$M)

Cost of Generation at 15% RE Target (FY12$M)			
Installation	**0% Wind**	**25% Wind**	**50% Wind**
CG MCAGCC TWENTYNINE PALMS CA	*($1.15)*	($0.99)	($0.82)
CG MCB CAMP BUTLER JA	*$6.66*	$6.43	$6.21
CG MCB CAMP LEJEUNE NC	*$6.23*	$5.27	$4.32
CG MCB CAMP PENDLETON CA	*$1.69*	$1.61	$1.53
CG MCCDC QUANTICO VA	*$3.58*	$3.15	$2.73
CG MCLB ALBANY GA	*($0.84)*	($1.10)	($1.35)
FIRST MCD GARDEN CITY LI NY	*$0.07*	$0.06	$0.05
MARBKS WASHINGTON DC	*$0.37*	$0.35	$0.33
MARCORCRUITDEP PARRIS ISLAND SC	*$0.99*	$0.81	$0.63
MARCORCRUITDEP SAN DIEGO CA	*($0.42)*	($0.40)	($0.38)
MARINE CORPS AIR STATION CAMP PENDLETON	*$0.17*	$0.16	$0.15
MCAS BEAUFORT SC	*$0.65*	$0.55	$0.45
MCAS CHERRY PT NC	*$1.27*	$1.06	$0.85
MCAS IWAKUNI JA	*$1.48*	$1.43	$1.38
MCAS MIRAMAR	*($2.21)*	($2.21)	($2.21)
MCAS YUMA AZ	*$0.77*	$0.77	$0.77
MCB HAWAII KANEOHE BAY	*$1.96*	$1.96	$1.96
MCLB BARSTOW CA	*$0.03*	$0.03	$0.03
MCMWTC BRIDGEPORT CA	*$0.07*	$0.07	$0.07
MCSF BLOUNT ISLAND FL	*$0.19*	$0.18	$0.18
AMOUNT SAVED BY FORCING WIND	*$ 3.02*	**$ 3.01**	**$ 3.01**

Table 24. Cost of Wind Technologies at 20% RE Target (FY2012$M)

Cost of Generation at 20% RE Target (FY12$M)			
Installation	**0% Wind**	**25% Wind**	**50% Wind**
CG MCAGCC TWENTYNINE PALMS CA	*($1.03)*	($0.89)	($0.74)
CG MCB CAMP BUTLER JA	*$8.90*	$8.60	$8.29
CG MCB CAMP LEJEUNE NC	*$8.48*	$7.19	$5.89
CG MCB CAMP PENDLETON CA	*$2.65*	$2.52	$2.40
CG MCCDC QUANTICO VA	*$4.79*	$4.22	$3.66
CG MCLB ALBANY GA	*($0.64)*	($0.84)	($1.03)
FIRST MCD GARDEN CITY LI NY	*$0.09*	$0.08	$0.06
MARBKS WASHINGTON DC	*$0.49*	$0.47	$0.44
MARCORCRUITDEP PARRIS ISLAND SC	*$1.35*	$1.11	$0.86
MARCORCRUITDEP SAN DIEGO CA	*($0.33)*	($0.32)	($0.30)
MARINE CORPS AIR STATION CAMP PENDLETON	*$0.23*	$0.22	$0.21
MCAS BEAUFORT SC	*$0.88*	$0.74	$0.61
MCAS CHERRY PT NC	*$1.71*	$1.42	$1.14
MCAS IWAKUNI JA	*$1.97*	$1.90	$1.84
MCAS MIRAMAR	*($1.94)*	($1.94)	($1.94)
MCAS YUMA AZ	*$1.03*	$1.03	$1.03
MCB HAWAII KANEOHE BAY	*$2.67*	$2.67	$2.67
MCLB BARSTOW CA	*$0.07*	$0.07	$0.07
MCMWTC BRIDGEPORT CA	*$0.09*	$0.09	$0.09
MCSF BLOUNT ISLAND FL	*$0.26*	$0.25	$0.24
AMOUNT SAVED BY FORCING WIND	*$ 4.12*	**$ 4.11**	**$ 4.10**

While forcing wind at 25% and 50% does result in potential cost savings on an annual basis, the difference is not very large. For example, at the 10% and 15% RE target investment levels, the difference in the cost of generating the required shortfall amount is only around $10,000 per year if half of the RE investment is made in wind technology. Similarly, at the 20% RE target level, the difference between 0% and 50% investment in wind technology only amounts to about $20,000 per year across the entire Marine Corps.

Forcing wind into the model does, however, provide a useful examination of the practical application of RE during interruptions lasting greater than 12 hours. Because of the inherent swing in solar output on a daily basis, from day to night, a consistent base-load RE generation technology needs to be applied to cover interruptions that last through the evening. By forcing wind into the RE equation at the 25% level, a base-load can be established that could provide a practical remedy to this problem. Table 24 summarizes the cost of generation at various RE target percentages with 25% wind forced into the equation. Table 25 reflects the NPV of investing in this particular portfolio.

Table 25. Summary of the Cost of Generating Percentage Shortfall Amounts Given 25% Forced Wind (FY2012$M)

FY2012$M	Target Cost		
Installation	**10%**	**15%**	**20%**
CG MCAGCC TWENTYNINE PALMS CA	($1.08)	($0.99)	($0.89)
CG MCB CAMP BUTLER JA	$4.27	$6.43	$8.60
CG MCB CAMP LEJEUNE NC	$3.36	$5.27	$7.19
CG MCB CAMP PENDLETON CA	$0.70	$1.61	$2.52
CG MCCDC QUANTICO VA	$2.08	$3.15	$4.22
CG MCLB ALBANY GA	($1.36)	($1.10)	($0.84)
FIRST MCD GARDEN CITY LI NY	$0.04	$0.06	$0.08
MARBKS WASHINGTON DC	$0.23	$0.35	$0.47
MARCORCRUITDEP PARRIS ISLAND SC	$0.52	$0.81	$1.11
MARCORCRUITDEP SAN DIEGO CA	($0.49)	($0.40)	($0.32)
MCAS CAMP PENDLETON	$0.10	$0.16	$0.22
MCAS BEAUFORT SC	$0.36	$0.55	$0.74
MCAS CHERRY PT NC	$0.70	$1.06	$1.42
MCAS IWAKUNI JA	$0.95	$1.43	$1.90
MCAS MIRAMAR	($2.48)	($2.21)	($1.94)
MCAS YUMA AZ	$0.50	$0.77	$1.03
MCB HAWAII KANEOHE BAY	$1.25	$1.96	$2.67
MCLB BARSTOW CA	($0.01)	$0.03	$0.07
MCMWTC BRIDGEPORT CA	$0.04	$0.07	$0.09
MCSF BLOUNT ISLAND FL	$0.13	$0.20	$0.28

Table 26. NPV of RE Target Portfolios With 25% Forced Wind (FY2012$M)

Net Present Value of RE Targets				
FY2012$M		**TARGET**		
Installation	**State**	**10%**	**15%**	**20%**
CG MCAGCC TWENTYNINE PALMS CA	**CA**	$2.74	$2.75	$2.76
CG MCB CAMP BUTLER JA	**JA**	$3.50	$4.41	$5.32
CG MCB CAMP LEJEUNE NC	**NC**	$5.58	$4.53	$3.49
CG MCB CAMP PENDLETON CA	**CA**	$2.77	$2.48	$2.18
CG MCCDC QUANTICO VA	**VA**	$4.12	$3.64	$3.16
CG MCLB ALBANY GA	**GA**	$2.76	$2.71	$2.65
FIRST MCD GARDEN CITY LI NY	**NY**	$0.03	$0.03	$0.03
MARBKS WASHINGTON DC	**DC**	$0.05	($0.02)	($0.08)
MARCORCRUITDEP PARRIS ISLAND SC	**SC**	$1.06	$1.00	$0.94
MARCORCRUITDEP SAN DIEGO CA	**CA**	$0.99	$1.00	$1.00
MARINE CORPS AIR STATION CAMP PENDLETON	**CA**	$0.24	$0.25	$0.27
MCAS BEAUFORT SC	**SC**	$0.69	$0.66	$0.63
MCAS CHERRY PT NC	**NC**	$3.37	$3.34	$3.30
MCAS IWAKUNI JA	**JA**	$0.45	$0.46	$0.47
MCAS MIRAMAR	**CA**	$3.77	$3.85	$3.92
MCAS YUMA AZ	**AZ**	$0.40	$0.30	$0.21
MCB HAWAII KANEOHE BAY	**HI**	$1.54	$2.03	$2.52
MCLB BARSTOW CA	**CA**	$0.75	$0.90	$1.05
MCMWTC BRIDGEPORT CA	**CA**	$0.05	$0.05	$0.05
MCSF BLOUNT ISLAND FL	**FL**	$0.32	$0.29	$0.25
MARINE CORPS TOTAL		$35.18	$34.65	$34.11

5. Solar Purchase Year and Learning Curve Rate

The next two areas for sensitivity analysis are closely related in their importance. The year in which the Marine Corps decides to purchase solar technology and the learning curve rate at which costs are decreasing are both important factors to consider. Much like forcing wind technology, these two factors also directly affect the cost of covering an installation's shortfall amount in relation to the RE target percentages. Tables 26, 27, and 28 show the impact of delaying the purchase of solar technology at a single installation at varying learning curve rates. Installations not depicted in the following tables perform in a similar fashion, holding all else constant.

Table 27. PV Learning Curve Sensitivity Analysis at 10% RE Target (FY2012$M)

Cost of Generating Shortfall Amount at 10% RE Target Cost (FY2012$M)			
CG MCB CAMP LEJEUNE NC			
Solar Purchase Year	**18% LC Rate**	**20% LC Rate**	**25% LC Rate**
2012	$3.97	$3.81	$3.44
2013	$3.65	$3.48	$3.06
2018	$2.90	$2.68	$2.18
2025	$2.46	$2.23	$1.72
2030	$2.27	$2.04	$1.54

Table 28. PV Learning Curve Sensitivity Analysis at 15% RE Target (FY2012$M)

Cost of Generating Shortfall Amount at 15% RE Target Cost (FY2012$M)			
CG MCB CAMP LEJEUNE NC			
Solar Purchase Year	**18% LC Rate**	**20% LC Rate**	**25% LC Rate**
2012	$6.22	$5.99	$5.40
2013	$5.73	$5.46	$4.80
2018	$4.55	$4.20	$3.42
2025	$3.86	$3.49	$2.70
2030	$3.57	$3.20	$2.41

Table 29. PV Learning Curve Sensitivity Analysis at 20% RE Target (FY2012$M)

Cost of Generating Shortfall Amount at 20% RE Target Cost (FY2012$M)			
CG MCB CAMP LEJEUNE NC			
Solar Purchase Year	**18% LC Rate**	**20% LC Rate**	**25% LC Rate**
2012	$8.48	$8.16	$7.37
2013	$7.81	$7.44	$6.54
2018	$6.20	$5.73	$4.67
2025	$5.25	$4.76	$3.68
2030	$4.86	$4.36	$3.28

The delay of the purchase of solar technology can result in very real annual cost savings to the Marine Corps. As seen in Table 28, assuming the most conservative learning curve, putting off the purchase of solar technology reduces the cost of generating the shortfall amount by $2.2 million per year. However, during this delay, the installation will still carry the inherent cost of interruption and will still be purchasing market electricity. For example, by delaying the purchase of solar technology until 2030 (given a 25% learning curve rate), the cost to generate the shortfall amount each year falls by more than $4 million on Camp Lejeune alone. This savings will be offset by $7 million per year, for 12 years, in interruption costs alone, a total difference of more than $105 million. Therefore, delaying the purchase of solar technology only makes sense after the target baseline has been met.

6. Casualty during an Interruption

The 2012 NREL study added one last important dimension to the cost of interruption. If a casualty occurs during the course of an interruption and as a result of an interruption, what effect would that have on the NPV balance sheet for each installation? While the installation commander does not directly carry the cost of each casualty, the Marine Corps as a service is forced to compensate for the loss. By including a single casualty during any duration of interruption, the NPV equation immediately reaches a 100% breakeven point.

Table 29 demonstrates the damage that a single casualty during an interruption can cause to an installation. At $6.3 million per service member, the value of avoiding a casualty during some kind of interruption event is very high.

Table 30. Addition of a Single Casualty to the NPV Equation for Each Installation (FY2012$M)

Net Present Value of RE Targets		
FY2012$M	TARGET	WITH CASUALTY
Installation	**20%**	
CG MCAGCC TWENTYNINE PALMS CA	$2.91	$9.21
CG MCB CAMP BUTLER JA	$5.01	$11.31
CG MCB CAMP LEJEUNE NC	$2.19	$8.49
CG MCB CAMP PENDLETON CA	$2.05	$8.35
CG MCCDC QUANTICO VA	$2.59	$8.89
CG MCLB ALBANY GA	$2.45	$8.75
FIRST MCD GARDEN CITY LI NY	$0.01	$6.31
MARBKS WASHINGTON DC	($0.10)	$6.20
MARCORCRUITDEP PARRIS ISLAND SC	$0.69	$6.99
MARCORCRUITDEP SAN DIEGO CA	$1.01	$7.31
MARINE CORPS AIR STATION CAMP PENDLETON	$0.26	$6.56
MCAS BEAUFORT SC	$0.49	$6.79
MCAS CHERRY PT NC	$3.02	$9.32
MCAS IWAKUNI JA	$0.41	$6.71
MCAS MIRAMAR	$3.92	$10.22
MCAS YUMA AZ	$0.21	$6.51
MCB HAWAII KANEOHE BAY	$2.52	$8.82
MCLB BARSTOW CA	$1.05	$7.35
MCMWTC BRIDGEPORT CA	$0.05	$6.35
MCSF BLOUNT ISLAND FL	$0.28	$6.58

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. What Gets Measured, Gets Done

The Marine Corps is currently investing in RE projects in an effort to meet the SECNAV's stated goal of 50% RE by FY2020. However, the current investment strategy to meet this goal fails to address the energy security concerns of over half of Marine Corps installations, including Camp Butler, MCB Camp Lejeune, MCB Quantico, 1st MCD Garden City, Marine Barracks, MCAS Camp Pendleton, MCAS Beaufort, MCAS Cherry Point, MCAS Iwakuni, MCLB Barstow, and MCSF Blount Island.

By planned investment in large projects at a few installations, the Marine Corps is able to drastically increase its annual RE generation numbers. However, achieving the SECNAV's stated goals in this manner does not increase the security of the remaining Marine Corps installations where little to no investments in RE technology is taking place.

Most importantly, the Marine Corps has not, in policy terms, defined a quantitative method for assessing installation energy security. This lack of definition has allowed energy planners at all levels to interpret the service's objectives in loose terms. In the present case, over-investing in low-cost RE comes at the expense of providing energy security to the remaining installations.

2. The Cost of Interruption and Installation Risk

Each installation carries a quantifiable cost of interruption on an annual basis. This value can be presented to installation commanders in terms of anticipated loss in productivity and can be budgeted for accordingly. By applying the NREL's model for the cost of interruption, annual cost per installation figures can be accurately assessed for each Marine Corps installation. Given site-specific outage information, the probability of these outages, and their respective durations, the Marine Corps can accurately account for the risk of grid interruption.

An accurate representation of the cost of interruption provides commanders and energy planners with the information needed to create strategies to counter this risk. More importantly, quantifying interruption in terms of cost serves as a useful surrogate for defining each installation's relative energy security.

Also, accurate cost data can be used by installation energy planners to negotiate cost reductions in annual energy contracts. The cost of interruption carried by each installation should be refunded by local utility providers through increased grid investment or lower annual contract prices.

3. Net Present Value of RE Projects

In terms of levelized life-cycle cost, the NPV of investing to meet minimum energy requirements (10%, 15%, 20%) is positive at half of the Marine Corps installations included in this study without including the cost of interruption. This percentage increases if wind is forced into the RE mix because at most locations, wind is the lowest cost alternative. The introduction of wind technology can also serve as a production source of base-load energy when other RE technologies are unable to function. As seen in Table 30, by forcing 25% wind into the portfolio, the NPV increases by $1,550,000, $2,320,000, and $3,080,000, respectively.

Table 31. NPV of RE Targets With and Without Interruption and With 25% Forced Wind (FY2012$M)

Net Present Value of RE Targets (FY2012$M)			
	10%	15%	20%
TOTAL NPV WITHOUT COST OF INTERRUPTION TARGET %	$6.36	$5.06	$3.76
TOTAL NPV WITH COST OF INTERRUPTION TARGET %	$33.63	$32.33	$31.03
NPV WITH INTERRUPTION AND 25% FORCED WIND	$35.18	$34.65	$34.11

By including the cost of interruption at each installation, the NPV of investment in RE technology is positive beyond the 20% target at 19 of the 20 installations studied.

In summary, this means that the Marine Corps can justify RE investments across its whole installation network on the basis of a combination of energy savings and interruption cost avoidance.

Added to the equation, the cost of a casualty occurring because of a grid interruption tips the equation even more in favor of investing in RE technology. Initial RE investment across the Marine Corps should look more like Figure 23 first, on the way to meeting the SECNAV's 50% goals.

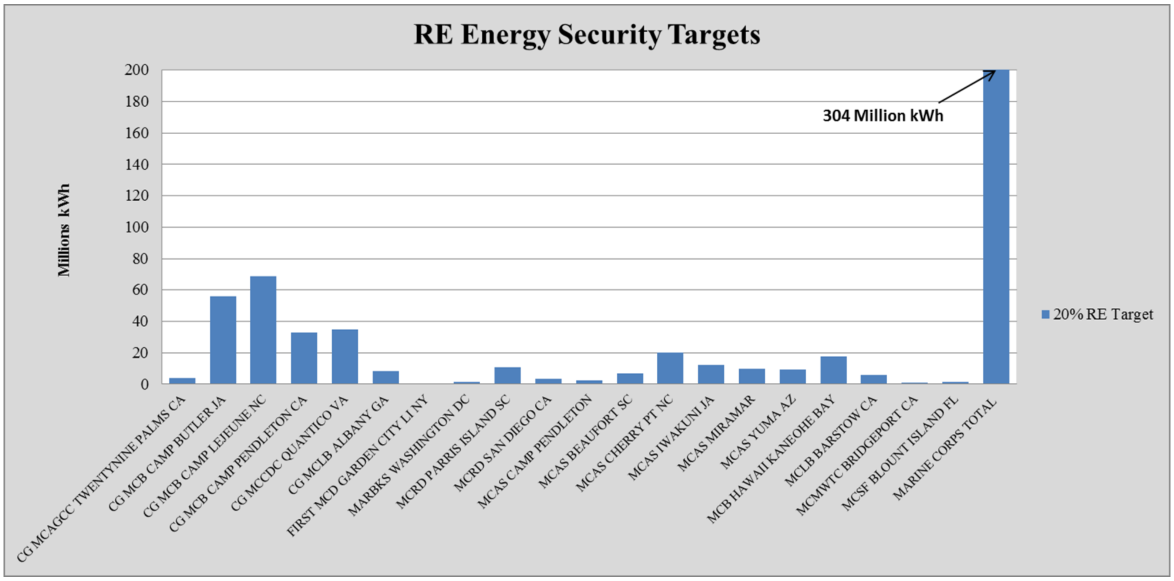

Figure 23. Marine Corps RE Investment at 20% RE Target

B. RECOMMENDATIONS

Our recommendations are as follows:

1. United States Marine Corps

- Develop a quantitative method to achieve installation energy security through RE generation projects that first meet minimum energy requirements by installation.
- Establish specific minimum energy requirements for each installation to meet METs during an interruption.

- Focus on investing in RE projects that meet the Marine Corps' installation-specific minimum energy requirements while continuing to achieve the SECNAV's stated goals.
- Monitor both the number of interruptions and their associated duration at each installation and its impact on operations to accurately capture the cost of each interruption.
- Evaluate current installation restrictions that are preventing the Marine Corps from investing in wind technology. The relative low-cost of this form of RE technology can help the Marine Corps meet its security and SECNAV goals. A significant portfolio investment in wind technology, upwards of 50%, could save the Marine Corps more than $20,000 per year, as compared to a portfolio consisting primarily of solar resources.

2. Future Research

Our recommendations for future research are as follows:

- Commission a study of the CDF for each Marine Corps installation. Damage functions applied during this analysis are broad generalizations based on East Coast and West Coast delineation. The cost of interruption to MCB Quantico is undoubtedly not the same as the cost to MCB Camp Lejeune. Commanders and energy planners cannot begin to effectively use cost data if it is not applicable to their own installation.
- Based on the results of the aforementioned study, develop an investment plan for the Marine Corps based on current and future cost, consumption, and budget restrictions.
- Study the impact of PPAs and leased PV on Marine Corps energy security and portfolio volatility.

APPENDIX. CURRENT AND PROJECTED MARINE CORPS RENEWABLE ENERGY GENERATION

USMC Renewable Electricity (Generation Capacity)

"On-Line" as of 30 SEPT of FY.

	FY 2010 MW Capacity	FY 2010 MWH Generation	FY 2011 MW Capacity	FY 2011 MWH Generation	FY 2012 MW Capacity	FY 2012 MWH Generation	FY 2013 MW Capacity	FY 2013 MWH Generation	FY 2014 MW Capacity	FY 2014 MWH Generation	FY 2015 MW Capacity	FY 2015 MWH Generation	FY 2016 MW Capacity	FY 2016 MWH Generation	FY 2017 MW Capacity	FY 2017 MWH Generation	FY 2018 MW Capacity	FY 2018 MWH Generation	FY 2019 MW Capacity	FY 2019 MWH Generation	FY 2020 MW Capacity	FY 2020 MWH Generation
PV Systems	6.721	11,776	15.717	27,536	22.187	38,872	38.859	68,081	49.568	86,843	50.053	87,693	50.053	87,693	50.053	87,693	50.053	87,693	50.053	87,693	50.053	87,693
Wind	1.000	3,066	1.000	3,066	1.000	3,066	1.300	3,986	1.300	3,986	1.300	3,986	1.300	3,986	1.300	3,986	1.300	3,986	1.300	3,986	1.300	3,986
PPA - PV Systems	-	-	-	-	-	-	1.158	2,029	1.158	2,029	1.158	2,029	1.158	2,029	1.158	2,029	1.158	2,029	1.158	2,029	1.158	2,029
PPA - Miramar LFG	-	-	-	-	3.200	25,229	3.200	25,229	3.200	25,229	3.200	25,229	3.200	25,229	3.200	25,229	3.200	25,229	3.200	25,229	3.200	25,229
LFG - MCLB Albany	-	-	-	-	1.900	14,980	1.900	14,980	4.000	22,338	4.000	22,338	4.000	22,338	4.000	22,338	4.000	22,338	4.000	22,338	4.000	22,338
Programmed SUB TOTAL	7.721	14,842	16.717	30,602	28.287	82,146	46.417	114,304	59.226	140,425	59.711	141,274	59.711	141,274	59.711	141,274	59.711	141,274	59.711	141,274	59.711	141,274
MCB Hawaii (PPA - PV)	-	-		-	-	-	-	-	2.000	3,504	7.563	13,250	11.046	19,352	13.428	23,525	13.428	23,525	13.428	23,525	13.428	23,525
MCAGCC 29 Palms (PPA - PV)	-	-		-	-	-	-	-	1.200	2,102	1.200	2,102	1.200	2,102	1.200	2,102	1.200	2,102	1.200	2,102	1.200	2,102
MCAS Yuma (PPA - PV)	-	-		-	-	-	-	-	-	-	7.500	13,140	7.500	13,140	7.500	13,140	7.500	13,140	7.500	13,140	7.500	13,140
MCB Camp Pendleton (PPA - PV)	-	-		-	-	-	-	-	-	-	-	-	20.000	35,040	20.000	35,040	20.000	35,040	20.000	35,040	20.000	35,040
MCAGCC 29 Palms (BMGR EUL- PV))	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.000	87,600	50.000	87,600
MCLB Albany (PPA - Biomass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.000	78,840	10.000	78,840
MCAS Yuma (BMGR EUL- PV))	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	200.000	350,400
MCRD Parris Island (PPA - Biomass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25.000	197,100
Planned SUB TOTAL	-	-	-	-	-	-	-	-	3.200	5,606	16.263	28,492	39.746	69,634	42.128	73,807	42.128	73,807	102.128	240,247	327.128	787,747
TOTAL		14,842	16.717	30,602	28.287	82,146	46.417	114,304	62.426	146,031	75.974	169,766	99.457	210,909	101.839	215,082	101.839	215,082	161.839	381,522	386.839	929,022
Purchased ELC		1,550,000		1,550,000		1,550,000		1,550,000		1,534,500		1,519,000		1,503,500		1,488,000		1,472,500		1,457,000		1,441,500
Programmed Only		1,564,842		1,580,602		1,632,146		1,664,304		1,674,925		1,660,274		1,644,774		1,629,274		1,613,774		1,598,274		1,582,774
Programmed only RE %		0.95%		1.94%		5.03%		6.87%		8.38%		8.51%		8.59%		8.67%		8.75%		8.84%		8.93%
Plus Planned RE		1,564,842		1,580,602		1,632,146		1,664,304		1,680,531		1,688,766		1,714,409		1,703,082		1,687,582		1,838,522		2,370,522
RE %		0.95%		1.94%		5.03%		6.87%		8.69%		10.05%		12.30%		12.63%		12.74%		20.75%		39.19%

Note. The source of this table is HQMC (2013).

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