Methodology for Prioritization of Investments to Support Energy Security and Net Zero Investments for Military Installations

John V. Farr, Ph.D., PE, George Alsfelder, 2nd LT, Timothy Hartong, 2nd LT, and Michael Rodriguez, 2nd LT
Center for Nation Reconstruction and Capacity Development
Department of Systems Engineering, United States Military Academy
West Point, NY 10996

Abstract

The current state of the energy grid in the United States is a threat not only to energy production but to our national security as well. Currently the energy infrastructure is extremely vulnerable and fragile. In the event of a major attack against the United States, the energy grid would be one of the most vulnerable and important targets to cripple our military capacity to project forces. In addition to the threat that is posed by a fragile energy grid, the military is also under pressure from the senior decision and policy makers to use more renewable energy. With more than 30 presidential mandates having been imposed on the Army, significant funding cuts, and a strategic objective to have secure and reliable energy from renewable sources, the Army must have a defensible and transparent investment strategy. Unfortunately, there are insufficient funds allocated to construct renewable energy projects focused on energy security. This study attempts to use multi objective decision analysis and data envelopment analysis to evaluate the return on investment of different energy security measures and renewable energy for military installations. We used a portfolio approach because education, conservation, and new technologies are all key to proving solutions to the energy security challenge. This paper will propose methods, processes, and tools for the decision makers to compare the portfolios' cost effectiveness. This paper will culminate in a demonstration of the methodology to illustrate its' utility.

Introduction

Currently, the United States (U.S.) is in a state of extreme dependence on fossil fuels to support our economic and social well being. Articles about rolling blackouts, cyber attacks, electromagnetic pulses from the sun, natural disasters, increased reliance on electricity, etc., are commonplace in news. After decades of underinvestment, environmental debates, and increased energy reliance we are now more reliant on a system that is fragile, not hardened, and not resilient.

The power grid is also of strategic interest for the military. Intertwined with our national policies are the energy concerns, both tactical/operational and for facilities, that affect our nation's military complex. In times of war or major disaster the military must be able to execute its mission and power is needed to operate equipment, support soldiers, and other elements needed to operate a power projection focused military installation. Given the outsourcing of power on these installations and the corresponding reliance on commercial vendors, lack of renewable power sources tied to military installations, etc., the military is as reliant on the commercial sector for power as any town or homeowner in the U.S. If the U.S. were attacked from either a sophisticated enemy or even a disgruntled employee, the energy grid as shown in Exhibit 1 would be an easy target to destroy or interrupt with catastrophic results. This would cut power off to military bases and would greatly degrade the force projection capability of the military installation along with crippling the U.S. economy.

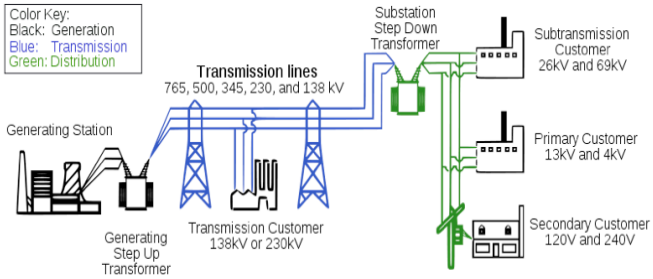


Exhibit 1. *The power infrastructure (Wikipedia, 2012)*

Investments in energy efficiencies, alternative power, and redundant and resilient systems are needed by the military. Unfortunately, these investments do not have a positive return on investment (ROI) when compared against traditional fossil fuel alternatives (US Energy Administration, 2012). Given the current drawdowns and associated funding reductions, capital projects that do not have a positive ROI are not viable. The only exceptions might be green energy projects. Thus, this research was conducted to 1) quantify the value of energy security investments and 2) link energy security with energy efficiency and environmental outcomes to capture the synergy.

A Systemigram more accurately shows the kind of dependencies that exist and need to be understood

in order to develop a systemic solution to this problem. Exhibit 2 shows the interdependencies between elements of the U.S. government, the military and private corporations. Note from Exhibit 2 that energy security is related to the Net Zero. Note that a Net Zero Energy Installation (NZEI) is an installation that produces as much energy on site as it uses, over the course of a year.

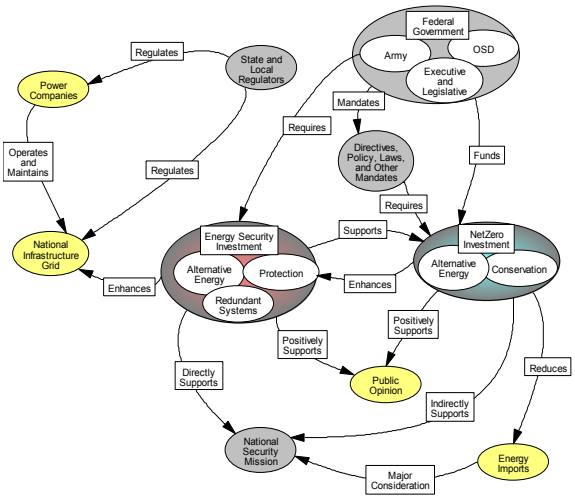


Exhibit 2. *Systemigram demonstrating energy security dependencies*

The U.S. Army, and the rest of our nation's military, needs a framework that will allow it to quantify the ROI of programs and projects that seek to use renewable energy as a means of ensuring the security of the energy supply to its installations. For this research we are only focused on installation energy and will not address the operational concerns even though they are intertwined. Given the fragility of the nation's infrastructure, the requirement to project power in times of war and our entire economic and social well-being require a hardened, resilient, and redundant energy infrastructure that can survive a host of cyber and physical attacks.

Methodology

We used two methodologies to quantifying energy security and Net Zero investments and develop a resource prioritization schema. Multi-objective Decision Analysis, or MODA, ranks options based on value. When combined with the life cycle or total ownership costs the deciding organization can choose which option best satisfies the stakeholder's values. In our project, MODA is useful in enhancing decision making for the allocation of resources and solidifying support for a particular portfolio of projects. Using the objectives we obtained from a review of the various energy security and environmental requirements documents, this methodology is well suited for portfolio prioritization and/or optimization. The model will help identify an appropriate mix of projects at the installation level, to maximize overall value versus cost. We also used Data Envelopment Analysis (DEA) as a quantitative tool for assessing energy security investments. The basic concept for DEA is taking data from an existing entity or producer referred to as the decision making unit (DMU), evaluating their performance, and then producing multiple possible alternatives (Brockhoff, 1970). There are a great amount of uses for DEA since it uses few assumptions, and creates multiple outputs. As an "extreme point" method, DEA compares each measure of a producer with the best producer for that measure. A simple DEA solution combines the best of all measures to produce "virtual best producers" (Cooper et al., 2000). DEA focuses on efficiency instead of the value based models like MODA. The advantage of the efficiency focus is the comparison of the projects against each other, instead of comparing them to ideal situations that may or may not be possible. For each DMU, there is one or more producer that is the best. No virtual producer can be better than the best existing producer in each DMU. The combination of all the best of each DMU is what creates the efficiency frontier.

Note that the Military Operations Research Society or MORS initially investigated the use of MODA to evaluated energy security technologies and investment strategies (Hope, 2010) that served as a stating point for this research. Also, Hughes (2011) presents an Analytical Hierarchy Process very similar to the technique we are proposing. However, that work was mainly focused on national energy security.

The MODA process begins with the development of a value hierarchy that is shown in Exhibit 3. It contains core functions and sub-functions as needed which are further broken down into objectives. The objectives identified can again be broken down into evaluation criteria in the value hierarchy model. Note that we aligned our sub-functions with the Army energy security goals (ESGs) (Army Senior Energy Council, 2009).

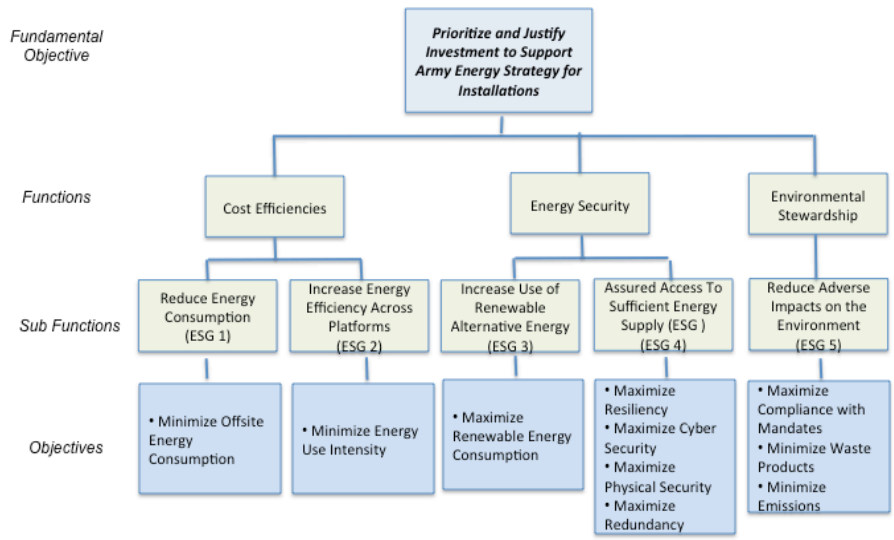


Exhibit 3. *Fundamental objective and functions for the energy strategy model*

As the evaluation criteria are dependent upon stakeholder analysis, weights must be assigned to the objectives in the value hierarchy model. With the help of the stakeholders, weights are decided based on the importance of each function. The weighted value is then found by multiplying the weights by the score the portfolio gets in each category. MODA uses an overall value function that combines the multiple evaluation measures into a single measure of the overall value of each evaluation alternative, or portfolio of projects. Thus, different mixes of projects in a portfolio may be compared to determine the appropriate mix for maximizing value. MODA is useful for structuring the judgments used in assessing the value of projects that comprise a portfolio in an organization with multiple and conflicting objectives. MODA methods are based upon structured objectives, evaluation measures, value functions, and weights. Simply, the mix of projects with the highest overall score adds the most value. We can then view projects as a function of cost or some other variable to find what the appropriate portfolio is depending on how much value is needed against how much they are willing to spend.

A multiple criteria value function based upon weights and scores is used to rank alternatives as shown in Equation 1. An additive value function is used for this research since it is common (Keeney, 1992). The additive multi criteria function $V(a_i)$ can be expressed as

$$V(a_i) = \sum_{k=1}^{m} W_k V_k(a_i) \qquad (1)$$

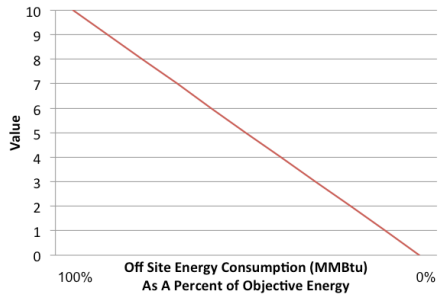
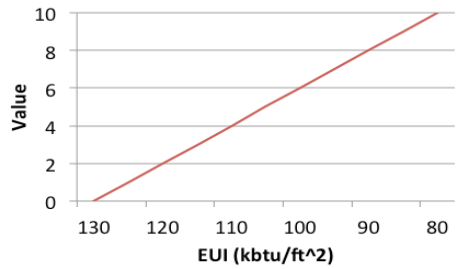
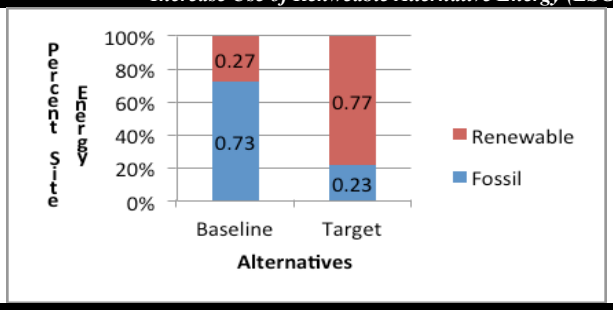
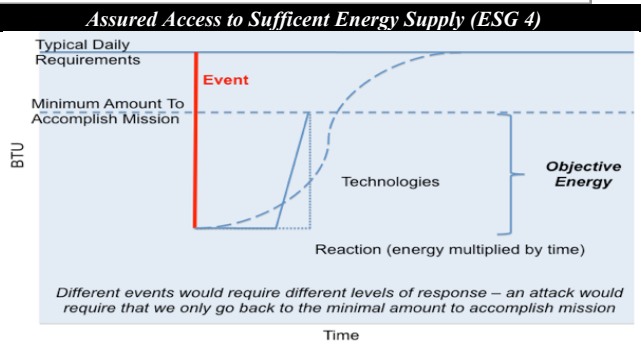
where $\sum_{k=1}^{m} W_k = 1$ and $0 \le v_k(a_i) \le 10$ for all $k = 1, \ldots\ldots M$.

The quantity $v_k(a_i)$ is the assessed value of the portfolio a_i. The weights W_k represent the tradeoffs across the criteria (weight and values). A set of portfolios is constructed and defined $P=\{p_1, \ldots\ldots p_n\}$ and used described the various energy solutions. For these portfolios we are interested how security, efficiency, regulations, etc., change how the portfolios or alternatives are scored.

Using MODA, we compared eight portfolios containing various combinations of photovoltaic cells, wind generation, and other methods of creating energy. We loosely based our portfolios on the requirements and solutions for Fort Carson (National Renewable Energy Laboratory or NREL, 2010). Unfortunately, NREL report did not provide all of the components needed to implement a renewable energy solution (i.e., batteries for storage, etc). Like all MODA analysis, developing quantifiable relationships for the value scoring can be difficult. Much research was needed to quantify the value measures associated with each objective in Exhibit 3. Note that we used 10 value measures for our MODA analysis that are shown in Exhibit 4.

Note that when we discuss energy security (and not Net Zero) that we are interested in operational energy or the amount of energy needed to sustain systems, information, and processes required to train, move, and sustain forces for military operations. This term is often confused with operational energy needed to conduct a military operation in the field (mainly fuel).

Exhibit 4. *Value measures for the energy security and Net Zero investment model*

Value Measure	***Comments***
Reduce Energy Consumption (ESG 1)	
	The amount of energy consumed will be measured by using the amount of site energy and source energy is used on the entire installation. It is necessary to reduce the offsite energy consumption because it makes the army reliant on an unprotected energy grid.
Increase Energy Efficiecny Across Platofrms (ESG 2)	
	Energy use will be measured using energy use intensity (EUI), which is calculated by energy consumed per year divided, by total floor space (kbtu/ft^2). This can be expressed as percent of the average energy use intensity for a similar building. Average energy use intensity is an important measure of building energy efficiency.
Increase Use of Renweable Alternative Energy (ESG 3)	
	To illustrate a shift from fossil fuels to renewable energies, percent of site energy supplied by renewable sources can be measured. An increase in this percent is a way to measure renewable energy consumption**.** For every percent of power produced by renewable energy, one tenth of a point of value will be attached. In the example, the target alternative is supplied by 77% renewable energy, thus a change in value of 1 corresponds to a 7.7% change in renewable energy consumption.
Assured Access to Sufficent Energy Supply (ESG 4)	
	Resiliency is the context of our problem is the time it takes for a military installation to return to a level of service needed to accomplish the mission. This includes infrastructure/physical layers and the services layer. Note that the units are time-energy. Note that objective energy is simply the minimum amount needed for the installation to conduct its mission.
	All energy solutions depending upon the level of SCADA (supervisory control and data acquisition), exposure, complexity, etc., are all vulnerable to cyber attacked. For our value measure for cyber security we must consider the vulnerability. We chose to base our value model loosely on the confidentiality, integrity, and availability (CIA) model for information security. As shown, we lumped confidentiality and integrity into general susceptibility value. We combined this with an impact value to measure both risk and outcomes.

		Impact	
	Significant		*Minor*
Significant	0	2	5
Susceptibility	1	4	7
Minor	4	8	10

Exhibit 4. *Value measures for the energy security and Net Zero investment model (cont.)*

<table>
<tr><th>Value Measure</th><th>Comments</th></tr>
<tr><td>
<table>
<tr><td></td><td></td><td>Impact</td><td></td></tr>
<tr><td></td><td>Significant</td><td></td><td>Minor</td></tr>
<tr><td>Significant</td><td>0</td><td>2</td><td>5</td></tr>
<tr><td>Susceptibility</td><td>1</td><td>4</td><td>7</td></tr>
<tr><td>Minor</td><td>4</td><td>8</td><td>10</td></tr>
</table>
</td><td>Our energy infrastructure is also at risk from physical attacks. Whether from a disgruntled employee or an actual terrorist physical security is a major issue for all elements of the national energy grid. We must protect the energy infrastructure from unauthorized access, disruption, modification, and/or destruction. As before, we chose to base our value model loosely on the confidentiality, integrity, and availability (CIA) model for information security. Like cyber security, physical security has a high value scores for those technologies/solutions that are not susceptible nor have a major impact on the energy delivered.</td></tr>
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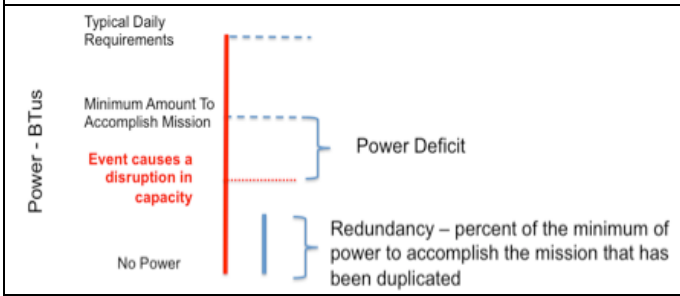

</td><td>Many believe that in lieu of additional capacity that we should be developing power sources that are not only hardened from an attack but also maximize redundancy at minimal costs and that can quickly be restored. The corresponding figure shows that value function is determined.</td></tr>
<tr><td colspan="2">Reduce Adverse Impacts on the Environment (ESG 5)</td></tr>
<tr><td>
<table>
<tr><th colspan="2">NetZero Significance Key</th></tr>
<tr><td>1</td><td>Significant NetZero initiative</td></tr>
<tr><td>2</td><td>Minor NetZero initiative</td></tr>
<tr><td>3</td><td>Modern common building practices or Not applicable</td></tr>
</table>
</td><td>Currently a near endless list of laws, mandates, executive orders, and regulations exists (around 70) in regards to the issues we are addressing in our study all designed to be in compliance with mandates. These mandates set a variety of goals and standards for military installations to meet. A portfolio or project can subjectively be categorized based upon one of the three categories presented.</td></tr>
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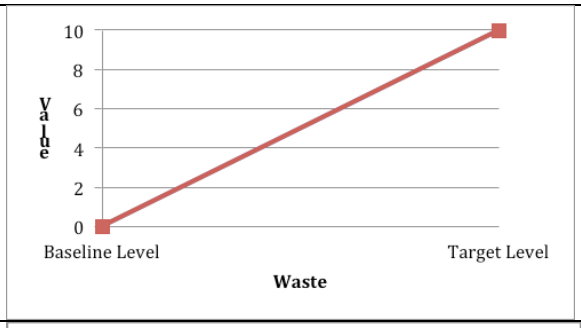
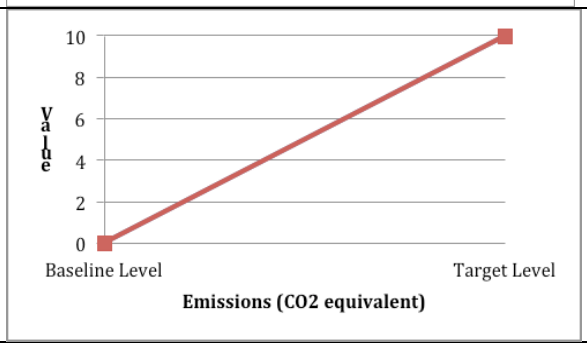


</td><td>Waste products are defined as the byproducts of source energy generation that cannot be recycled to generate more energy, and must be evacuated from the site. Minimizing waste products is a concern for Army installations not only for its environmental implications, but also because of the cost associated with removing waste from post. Note that maintaining the status quo does not contribute any value. Realist target levels must be set (some are set by directives/laws).</td></tr>
<tr><td>


</td><td>Emissions are those waste products that are released directly into the air, and cannot be isolated and removed from the site. A good example of this (although a disappointing visual) might be smokestacks from a coal power plant, or the exhaust from the fleet of tactical vehicles. These are a particularly worrying byproduct of power generation, as they cannot or are economically unfeasible to collect. Minimizing emissions attributable to current source energy systems can be measured by volume (ft^3).</td></tr>
</table>

Once the importance of each measure was decided based off of the stakeholders needs and weights were assigned, the next phase was setting the values. Each measurement has a zero to ten scale (i.e., maximum stakeholder value). The data for each portfolio was gathered mainly from open source and the NREL report and converted to quantitative and defensible value measures. Once all of the data developed for each candidate portfolio, the value that each portfolio received was multiplied by the weight given to it and summed for a total portfolio score. Exhibit 5 shows the swing weights that were used for both the energy security and Net Zero analysis. Parnell and Trainor (2009) present a discussion on the use of swing weight matrices. This resulted in each portfolio having a score allowing it to be objectively compared to other portfolios. The most common way to compare portfolios using MODA is cost versus value since cost can be a significant reason to pick a portfolio with less value over one with more value. Conversely if there is a portfolio that has more value and is cheaper than another portfolio, there is no reason to choose the "dominated" portfolio.

Exhibit 5. *Swing weight matrix used for energy security and Net Zero MODA analysis*

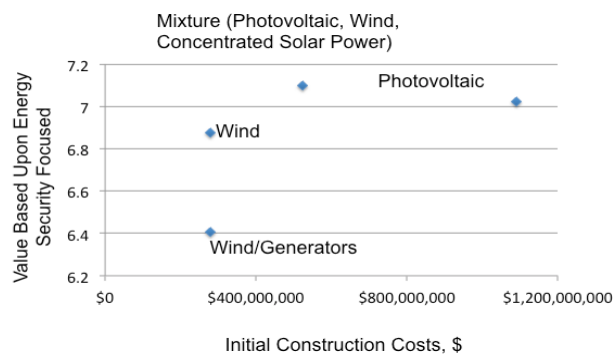
		Importance of the Value Measure to the Decision Makers and Stakeholders for Energy Security		
		High	*Medium*	*Low*
Variation in Measure Ranges	*High*	• Maximize Resiliency • Maximize Renewable Energy Consumption • Maximize Redundancy	• Minimize Energy Use Intensity • Maximize Compliance With Mandates • Minimize Emissions	
	Medium	• Minimize Offsite Energy Consumption	• Minimize Waste Products	
	Low	• Maximize Cyber Security • Maximize Physical Security		

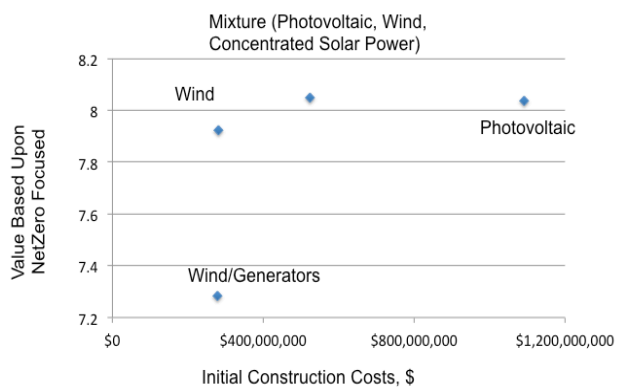
		Importance of the Value Measure to the Decision Makers and Stakeholders for NetZero Investment		
		High	*Medium*	*Low*
Variation in Measure Ranges	*High*	• Maximize Renewable Energy Consumption	• Minimize Energy Use Intensity • Maximize Compliance With Mandates • Minimize Emissions	
	Medium	• Minimize Offsite Energy Consumption	• Minimize Waste Products • Maximize Resiliency • Maximize Redundancy	
	Low	• Maximize Cyber Security • Maximize Physical Security		

DEA will be useful for analyzing energy security and renewable energy sources since there are already set producers, but not necessarily established portfolios that reach all the goals of Net Zero or energy security goals. Data Envelopment Analysis will help indicate which portfolios are efficient and determine the best options for reaching Net Zero and increase energy security. Each portfolio will have strengths that help create an efficiency frontier. This frontier can then also be used to analyze the fallbacks of each portfolio that makes it less efficient.

Exhibit 6 shows both of our cost versus value graphs. From this Exhibit you can gather that photovoltaic is not the best option. The mixed portfolio or possibly the wind portfolio warrants more detailed analysis.

Exhibit 6. *Cost versus value graphs*



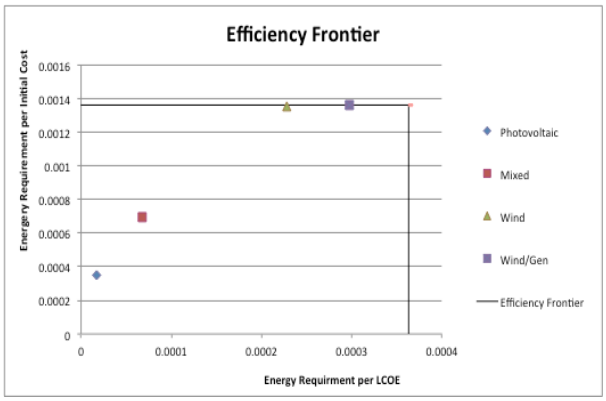


After identifying DMUs for the four example Net Zero portfolios and the equivilent objective energy portfolios, DEA analysis was run on all the models.

DEA is able to consider as many DMUs as available, which would make the efficiency frontier impossible to illustrate. In Exhibit 7, some of the DMUs used were combined in order to be able to provide a two dimensional efficiency frontier. While this graph does not totally match the actual efficiency calculated, it is still helpful to visualize the weaknesses of the less efficient portfolios. Further

analysis can be done to see exactly how much a portfolio would need to improve to reach 100% efficiency. Any point along the ling indicates a virtual portfolio that does not exist, but could theoretically since DMUs from the existing portfolios were able to. Exhibit 8 follows the same conclusion as the efficiency Exhibit. Wind and Wind/Gen are either on, or near, the efficiency frontier.

Exhibit 7. *Efficiency frontier*



The recommendation based off the DEA analysis for this demonstration would support the conclusion of MODA, and recommend the wind portfolio to achieve Net Zero and still have efficient energy security. This demonstration study shows the effectiveness of Data Envelopment Analysis, even with the limited amount of data. DEA could be even more effective in educating decision makers and stakeholders with real portfolios, more DMUs, and allows for more analysis.

Conclusions and Recommendations

Using our models, military installations will be able to evaluate portfolios of renewable/alternative energy sources, and see the benefits that provide beyond just being more secured. Teams of engineers will propose portfolio mixtures of renewable and alternative energies suited to that particular installation, and then they will apply DEA to compare the portfolios to one another. MODA will then be used to present the impacts of these portfolios on select externalities to the decision-maker as a numeric value. A swing-weight matrix, which is a weighting schema, allows MODA to be employed with a different weight for different values at every Army post.

To extend this research and produce a meaningful decision support tool for the Army we need to:

- Conduct a more meaningful case study; we found that we lacked the expertise to fully develop and cost the energy portfolios,
- Involve more stakeholders in developing the swing weight matrix for the MODA analysis,
- Refine value measures to produce better fidelity, and
- Have subject matter experts review our value measures.

Our demonstration study, we are able to see that our two analysis techniques indicate that the portfolio of wind technologies or the portfolio of wind technologies supported by generators would be the most beneficial. The DEA explicitly states this, but the MODA, however, leaves more open to interpretation.

Acknowledgments

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About the Authors

John V. Farr is a Professor of Engineering Management and Director of the Center for Nation Reconstruction and Capacity Development at the United States Military Academy at West Point. He is a former Professor and Associate Dean for Academics in the School of Systems and Enterprises at Stevens Institute of Technology. He was the founding Director of the Department of Systems Engineering and Engineering Management at Stevens. Before coming to Stevens in 2000, he was a Professor of Engineering Management at West Point where he was the first civilian professor in engineering and Director of their Engineering Management Program. He is a former past president and Fellow of American Society for Engineering Management, former member of the Army Science Board and the Air Force Studies Board of the National Research Council.

George H. F. Alsfelder is a Class of 2012 Cadet at the United States Military Academy at West Point. Prior to coming to West Point in 2008 he attended Cincinnati Country Day School in Cincinnati, Ohio. Upon graduation, he will be commissioned as a 2nd Lieutenant in the Field Artillery Branch where he will serve in the 25th Infantry Division.

Timothy Hartong is an Engineering Management major in his fourth year at the United States Military Academy of West Point, New York. Cadet Hartong served as Executive Officer of the Military Academy's Paintball Club. He is originally from Mount Vernon, Ohio, and will commission as a Second Lieutenant into the United States Army Engineer Regiment this coming May. After attending Basic Officer Leader Course, he intends to graduate from Fort Leonard Wood's Sapper Leader Course prior to his first duty assignment with the 555th Engineer Brigade at Fort Riley, Kansas.

Michael D. Rodriguez is a West Point Cadet from Pleasanton, CA. After spending a year at the United States Military Academy Preparatory School in Fort Monmouth, NJ, he studied Systems Engineering at the United States Military Academy, West Point. Cadet Rodriguez was also a leader of the 10 time National Champion Orienteering Team as well as being an active member and small group leader in the Officer Christian Fellowship. After graduation he will move to Fort Benning, GA to begin the Armor Basic Officer Leader Course studying to become a Platoon Leader in the 3rd Infantry Division.