METHODOLOGY FOR PRIORITIZATION OF INVESTMENTS TO SUPPORT THE ARMY ENERGY STRATEGY FOR INSTALLATIONS

by

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ABSTRACT

The current state of the energy grid in the United States is a threat not only to energy production and way of life but also to our national security. Currently the energy infrastructure is extremely vulnerable, not resilient, and susceptible to a host of physical and cyber attacks. In the event of a major attack against the United States, the energy grid would be a vulnerable and important target that might 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 and a means to assess economic and non-economic value of energy investments. Unfortunately, there are insufficient funds for resourcing renewable energy projects focused solely on energy security. This study attempts to use multi objective decision analysis and data envelopment analysis to evaluate value as a function of life cycle costs of different energy security measures and renewable energy for military installations. We used a portfolio approach in an effort to capture both the true costs and to develop technology feasible alternatives. This study will propose methods, processes, and tools for the decision makers to compare the portfolios' value and cost effectiveness. This paper will culminate in a demonstration of the methodology to illustrate its' utility.

Key Words: Energy security, NetZero energy, data envelopment analysis, value focused thinking, multi-objective decision analysis

INTRODUCTION

Currently, the United States (US) is in a state of extreme dependence on fossil fuels to support our economic and social well being. Intertwined with our national policies are the energy concerns, both operational and for facilities, that affect our nation's military complex. As shown in Figure 1, the modern installation manager and commander must navigate a complex environment to ensure that an installation can conduct its mission both in war and peacetime operations.

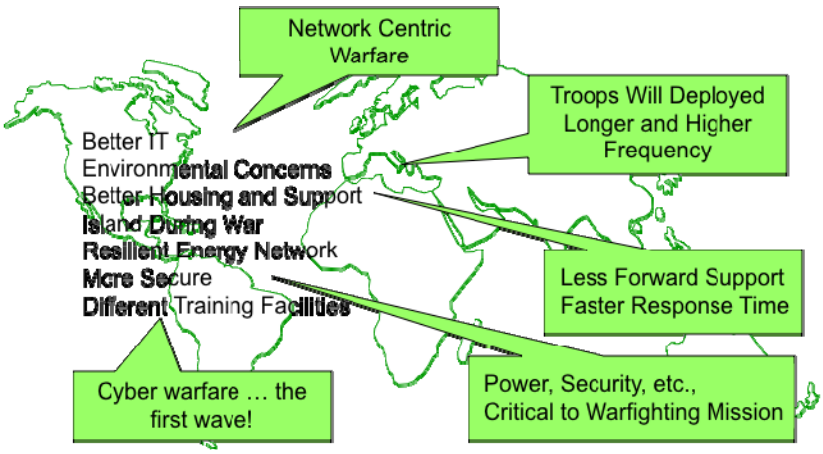


Figure 1. *Issues for the 21st century military installation (1)*

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. It will require coordination between elements of the US government, the military and private corporations. Beyond that, even the societal and economic effects of any proposed solution will need to be understood and quantified.

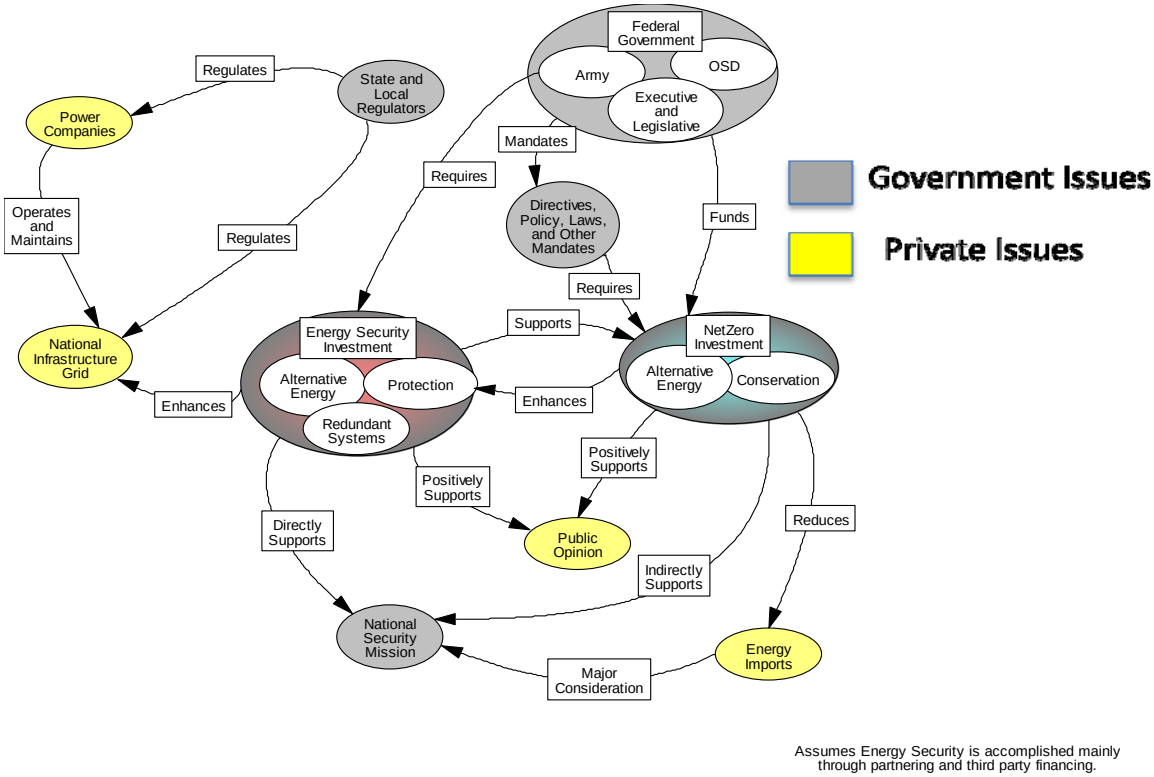


Figure 2. *Systemigram demonstrating energy security dependencies*

The US Army, and the rest of our nation's military, needs a framework that will allow it to quantify the return on investment (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.

If the US were attacked from either a sophisticated enemy or even a disgruntled employee, the energy grid would be an easy target to hit 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 US economy. Figure 3 graphically shows how power is currently distributed to most military installation and installations, and the essential elements of the national energy grid.

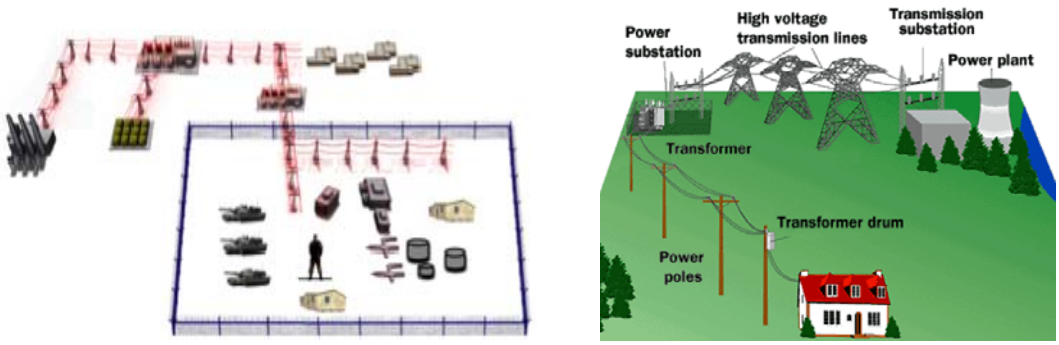


Figure 3. *An installation that is dependent on external sources of power and a representation of the national energy grid*

Military installations should also have the ability to "island" themselves from the power grid in order to support their strategic mission. Ideally a military base can switch off of the energy grid, and still manage to power the essential operations of the installation necessary to conduct their mission. Note that the social implications of islanding will not be addressed but they are profound. This is important in the event of a physical or cyber attack on either the energy grid or our energy resources. Should this happen, the Army, must be able to keep key functions alive until power is reestablished. Currently the military is mainly buying its energy commercially having outsourced most of its power production facilities. However, there is no current plan or funding to harden these outside facilities and the supplying grid. In order to island itself, an installation would almost certainly have to move some kind of energy source onto the installation itself, whether that is solar, wind, biomass, a nuclear generator, or any other kind of renewable energy source. Critical national security and homeland defense missions are at risk of extended outage from failure of the grid. Currently the Army and the Department of Defense have implemented goals and policies to facilitate energy security and other NetZero energy initiatives. 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. To achieve this goal, installations must first implement aggressive conservation and efficiency efforts while benchmarking energy consumption to identify further opportunities. The balance of energy needs then are reduced and

can be met by renewable energy projects. From a solely ROI perspective these alternative energies are not cost efficient when compared to fossil fuels. The argument must be made that the value of alternative energy is directly related to security and environmental stewardship. This is the focus of this research.

METHODOLOGY

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. Note that the Military Operations Research Society or MORS initially investigated the use of MODA to evaluated energy security technologies (2). Also, Hughes (3) 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 similar to Figure 4. 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) (4).

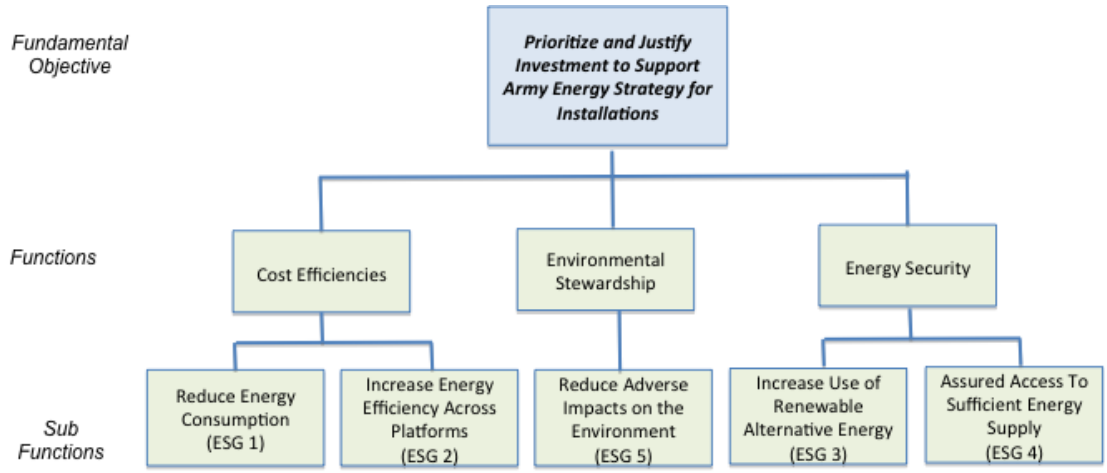


Figure 4. *Fundamental objective and functions for the energy strategy model*

As the evaluation criteria are dependent upon stakeholder analysis, they must be assigned weights 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 which 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 (5). The additive multi criteria function $V(a_i)$ can be expressed as

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

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

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 (6). Unfortunately, the National Renewable Energy Laboratory (NREL) report (6) did not provide all of the components needed to implement a renewable energy solution (i.e., batteries for solar, etc). An example of how value measures are used in MODA was is resiliency which can simply be defined as the ability to bounce back from a disaster. From an energy security perspective, many scholars believe that we cannot protect our strategic resources from a determined threat. Instead our best defense is to build redundant and resilient systems. However, a review of the literature did not product any methodology to quantify resiliency. Thus, we propose the definition presented in Figure 5. This method utilizes the recovery time of different technologies in the aftermath of an attack. To this end, we are proposing that we measure the “Action” performed by these technologies. “Action” is defined as the amount of energy multiplied by the length of time that we will call Resiliency Factor. Note in the figure that two levels of energy needs are presented. The first is the “Typical Daily Requirements.” The second is the “Minimum Amount to Accomplish Mission” which is often referred to as objective energy. Recent experience has shown that in the aftermath of a natural disaster that through energy conservation and other means that the populace requires significantly less to function. For example, Japan cut power consumption by 20 to 25% after the

2011 earthquake. With every military post being different, we suspect the ratio of the minimum divided by the typical to be on the order of 60%.

Figure 5 also contains the value function for resiliency. Note that the units of resiliency are MMBtu*Days. Our notional Fort Carson data required 2,616,402 MMBTu to operate (6). If we assume 60% as the goal we need to return to roughly 1,570,000 MMBTu per year. If you assume that the minimum acceptable time is 30 days then the minimum acceptable amount (value of 0) is 30*1,570,000 or 47,100,000 MMBtu*Days. Note that we used 8 value measures for our MODA analysis in addition to resiliency to include offsite energy consumption, cyber security, physical security, internal energy use, compliance with mandates, emissions, and waste products.

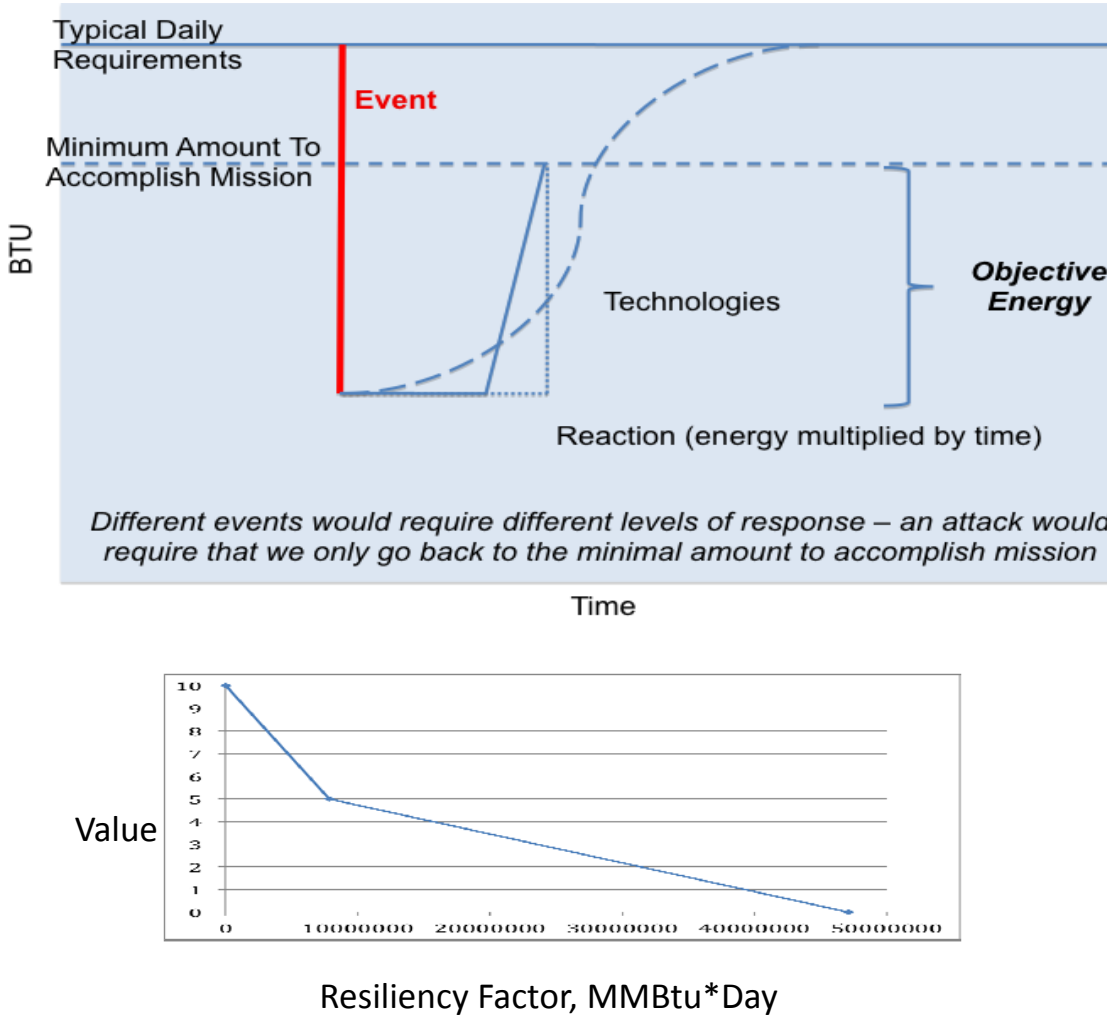


Figure 5. *Graphical representation and value measure for resiliency*

Note that when we discuss energy security (and not NetZero) 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

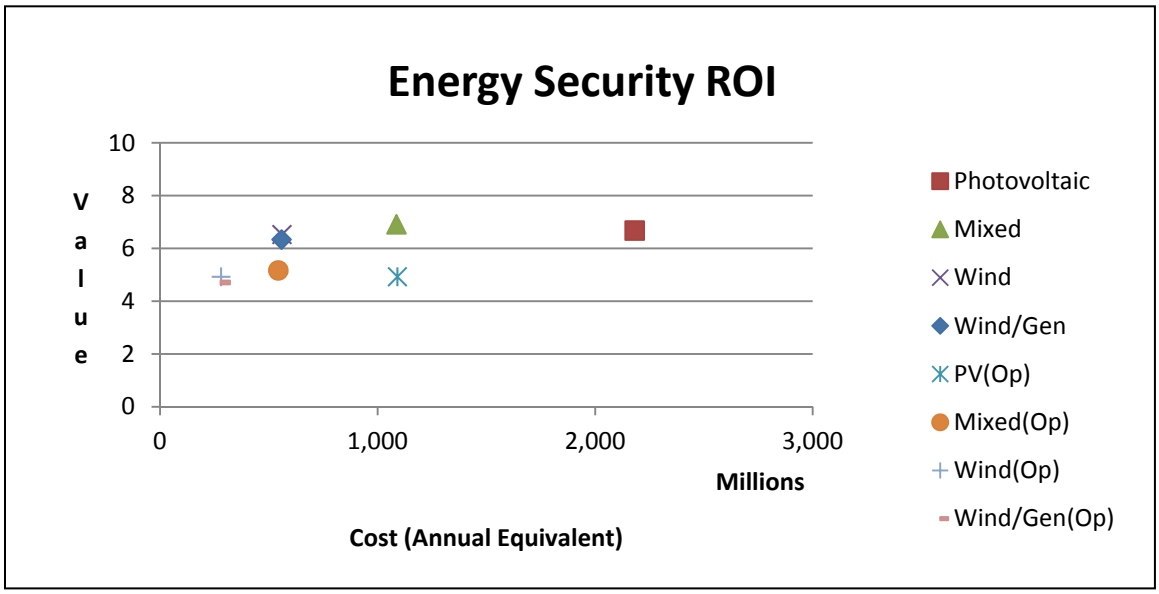
confused with operational energy needed to conduct a military operation in the field (mainly fuel).

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

An increasingly popular way to evaluate performance is Data Envelopment Analysis (DEA) as a quantitative tool. The first major use of the procedure was in Germany to estimate the marginal productivity of research and development (7). 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 (8). 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" (9). 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.

DEA has found a place in product analysis because of it uses fewer assumptions and combines inputs much better than other forms of analysis. DEA also does not use weights like MODA. DEA's ability to make comparisons is why it can now be found in a wide variety of fields. For example, in education, manufacturing, and retail chains it can be used to compare across schools, branches, or departments. DEA is preferred in each field because it assists in identifying deficiencies and strengths in all products, not just providing one solution for all. DEA is a nonparametric method (8). This means that there is no assumption that the structure of the model is fixed. The reason DEA is able to avoid this assumption is mainly due to the fact that the basic concept behind data envelopment is combining the strengths of multiple producers already created. This combination creates a new function referred to as the efficiency frontier. The efficiency frontier consists of all possible hybrids or "virtual" solutions, along with any producer that is 100% efficient. So, in this regard, DEA is able to take multiple inputs and create multiple outputs. Therefore, it is commonly used alongside another form of value modeling that highlights the best solutions from the multiple outputs. Another advantage to DEA is the ability to still work with any form of units. As long as the measures for each product are consistent,

those measures can be any type of units. The frontier would then still maintain the same units in the virtual solutions.



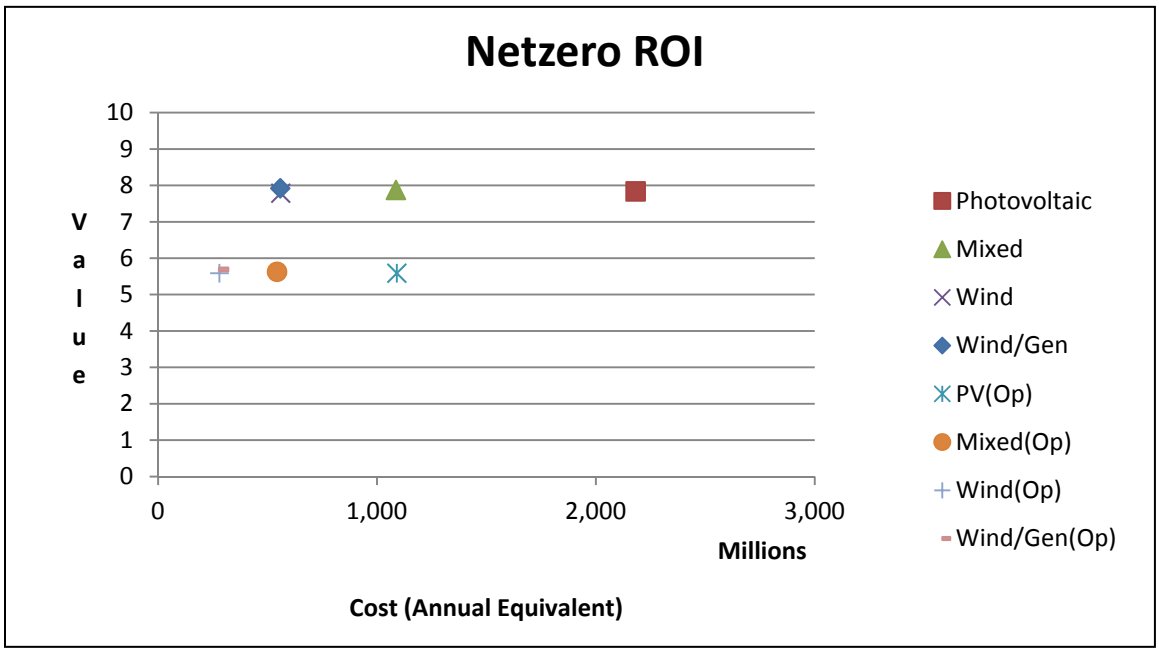


Figure 6. *Cost versus value graphs*

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 NetZero or energy security goals. Data Envelopment Analysis will help indicate which portfolios are efficient and determine the best options for reaching NetZero 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 fall backs of each portfolio that makes it less efficient.
After identifying DMUs for the four example NetZero portfolios and the equivilent objective energy portfolios, DEA analysis was run on all the models.

Figure 7 indicates that the wind and generator combination has an efficiency score is 1. This figure also helps visualize how efficient the rest of the portfolios are. This result varies only slightly from the result of MODA. However, wind by itself is almost completely efficient as well, which lends credibility to the MODA conclusion that wind has the most value.

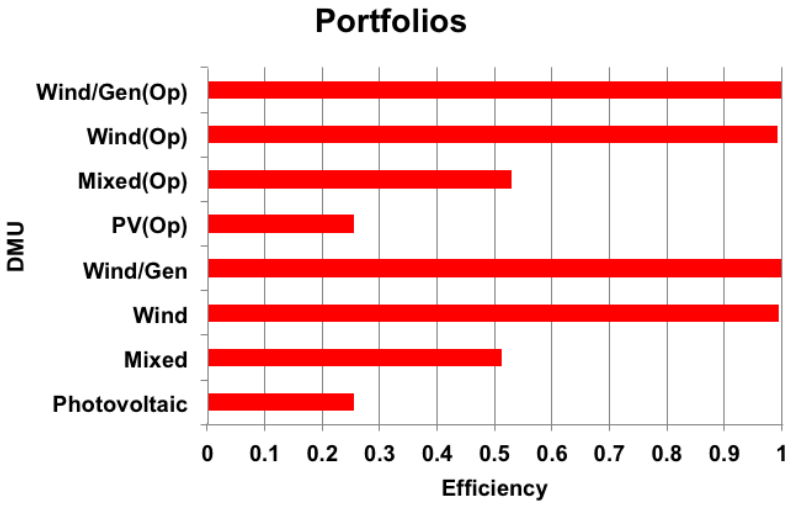


Figure 7. *Efficiency of portfolios*

DEA is able to consider as many DMUs as available, which would make the efficiency frontier impossible to illustrate. In Figure 8, 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. Figure 8 follows the same conclusion as the efficiency figure. Wind and Wind/Gen are either on, or near, the 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 NetZero 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.

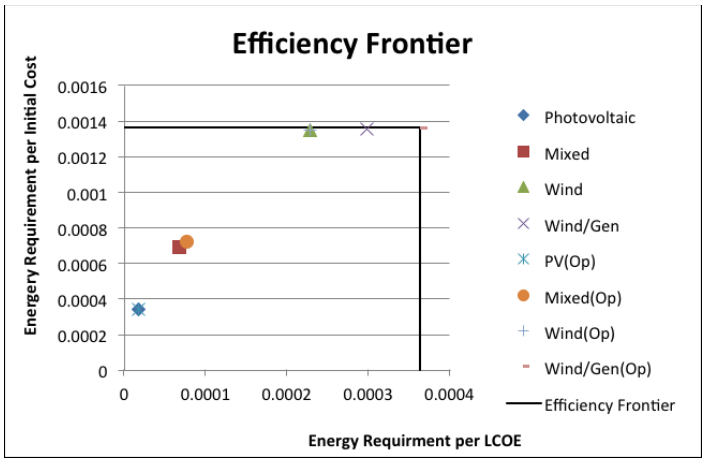


Figure 8. *Efficiency frontier*

RECOMMENDATION

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 secure. 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,
- 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.

ACKONWLEDGEMNTS

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