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Selecting Electricity Generation Sources in Remote Locations

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THESIS

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Abstract

The purpose of this research was to investigate the impact of using a decision analysis technique for the selection of an electrical generation system for remote locations. Specifically, this thesis sought to answer five research questions addressing the types of energy sources used in remote locations, the decision-making processes used to identify these sources, the types of constraints incorporated in such a process, other valued factors, and their level of importance in relation to each other. The research questions were answered through a comprehensive literature review and the 10-Step Value-Focused Thinking Process on a specific case study in the National Park Service. Decision makers comprising of the National Park staff offered their input into the execution of this process. Electrical system manufacturers and distributors were also consulted as subject matter experts. The research identified several electrical alternatives that are currently being used by remote locations around the world. However, decision process used to make such selections were undisclosed. A value-focused thinking model indicated the highest scoring electrical alternative based on constraints and factors provided decision makers. Limitations and assumptions applied to the model further highlighted the significant details.

The culmination of this effort was the introduction of a decision analysis technique to provide valuable information for the selection of electrical systems in remote locations. The implication of this study is the distribution of this technique to inhabitants in other isolated areas for effective decisions.

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To My Family and Fiancé

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Table of Contents

Page

List of Figures

Page

List of Tables

Page

SELECTING ELECTRICITY GENERATION SOURCES IN REMOTE LOCATIONS

Chapter 1. Introduction

1.1 Introduction

Electricity supply and its applications are important commodities for many civilizations worldwide. Many populations rely on electricity to power almost every aspect of their daily routines. Dependence on such a commodity has propelled the significance of electric power to such a degree that civil conflicts have centered upon the continuation of its fuel source (Ross, 2004). The importance of supplying electricity to individuals in rural areas can also cause politicians to win or lose elections (Doig, 1999). Asian countries alone are expected to spend as much as $600 billion in the next decade to supply electricity to its population (Wies, 2006). The simple characteristics of electricity have the potential to save a large amount of time with the incorporation of various household appliances, provide immediate worldwide communication, transport people to any location in the world, and bring accessibility to a demanding society. The importance of electricity supply has been realized by almost every individual in the world. However, the advantages of implementing such a resource do not come without potentially devastating drawbacks.

The demand for commercially viable electric service has led to increased rates of production plants. Most of the electricity supplied in the 1850s was produced by local sources such as firewood and dung. By the 1940s, coal-fired power plants became the dominating source of electricity generation (Compaan, 2006). Large and concentrated demands of electricity service have prompted industries to establish giant factories so that efficiency was maximized. Electrical businesses have determined a way of supplying electricity to many of these people while simultaneously increasing profit in the long-term. By the beginning of the 1960s, the use of conventional power plants to satisfy increasing demands became almost commonplace (Georgopoulou, Lalas, & Papagiannakis, 1997).

However, the evolution of electricity generation plants has resulted in negative impacts. Large population centers became connected to power grids that supplied seemingly limitless amounts of electricity while consuming natural resources at an alarming rate. The utilization of natural resources has led to our dependence on its supply by any means, even from importing fuel. Toxic emissions from these plants have led to the potential demise of the natural environment as well. Negative impacts have become inherent in the quest for supplying electricity to a growing worldwide population.

Even though a large proportion of the world continues to feed on such a precious commodity, there are some locations that do not have the luxury of electricity. It is estimated that there are two billion people in the world who do not have access to grid-connected electricity (Nfah, Ngundam, & Tchinda, 2006). Through the technological evolution of electricity generation, inhabitants such as these are beginning to have access to electrical power while simultaneously avoiding the disadvantages of grid connections. Assistance with electricity decisions for remote areas would be appreciated by the stakeholders involved. Occupants in these remote, off-grid locations can decide on the best method of obtaining electricity while preserving other values as well. Hopefully, the advantages of implementing such decision processes to remote locations can benefit societies that already enjoy commercial power.

1.2 Background

The effects of electricity can easily be recognized by its applications (Eto et al., 2001). The advent of electricity has allowed humans to keep food fresh longer, delay the darkness of night, provide hours of entertainment, and travel to great distances around the world and beyond. There is no doubt that the benefits of electricity have allowed its users to accomplish tasks such as cooking food, communicating messages, and washing clothes more efficiently then ever before. The significance of electricity is certainly realized by practically everyone in the world.

Access to electricity can be divided into two distinct categories. The majority of societies in the world obtain electricity from a general utility provider. Most of these general utility grids use nonrenewable natural resources to create electricity for multiple customers in their jurisdiction. The second category involves isolated locations of the world that are forced to rely on other methods of obtaining their electrical needs. These areas may not have the feasibility to be connected to a large common utility grid. Therefore, these inhabitants must identify means of electrical self-sustainability in order to function with electric power. These differences distinguish the categories of electrical access for human civilizations.

The feasibility of grid connections to remote regions does not exist for various reasons. First, some remote locations include geographical deterrence from public utility providers. Inhabitants of island structures, such as those on Crete Island, do not have grid-connected power from the mainland because they are separated from the mainland by water (Georgopoulou, Lalas, & Papagiannakis, 1997). Other inhabitants, such as those in parts of India, live in areas that are highly inhospitable and mountainous

(Shirodker, 1995). Camp natives at Heelat Ar Rakah, Oman, simply lack grid-connections because of the sheer distance from a supplier (Suleimani & Rao, 2000). Another major reason of infeasibility for grid-connections is the lack of financial support for it. Some people in remote locations do not have the necessary finances to pay for the installation of electric cable supporting towers, the routing of cables, routine billing, and constant maintenance (Byrne, Shen, & Wallace, 1997). There may be other issues as well, such as environmental concerns, which have resulted in the grid-connection deficiency. These reasons have prevented some remote areas of the world from experiencing the benefits of commercial power.

Many remote inhabitants have resorted to other means of electricity generation. A large amount of these remote locations tend to include gasoline or diesel fuel generators for supporting their electrical household needs (Byrne, Shen, & Wallace, 1997). Others depend on renewable energy methods such as solar and wind power. Even though the availability of common electrical service remains impractical, some people in remote areas have become resourceful in identifying alternative methods.

An overwhelming amount of remote sites in the United States are managed by the federal departments. The amount of land owned by the federal government corresponds to “approximately 3.3 billion square feet of facility space” (Renewable, 2004, p. 11). While being recognized as the nation’s single largest energy consumer, efforts have been made to focus on the responsible direction of electricity management in the federal arena (Clinton, 1999). Since federal lands constitute about 29% of the nation’s total surface area, a large potential impact exists for the revolution of electrical systems. The jurisdiction of the National Park Service (NPS), along with three other agencies (Fish and

Wildlife Service, Bureau of Land Management, and the Forest Service), constitutes 96% of these federal lands as well (Renewable, 2004). Therefore, assistance with electricity harvesting would be advantageous for remote locations that are primarily operated under these federal departments.

Analysis of electrical generation schemes in the NPS is warranted for multiple reasons. First, national parks are operated under the premise that environmental preservation outweighs the expansion of natural resource consumption. Therefore, identifying more compatible means of electricity procurement would be advisable. Second, there are many geographical obstructions that prevent an easy approach to grid-based electricity in the NPS. Overcoming such barriers for electricity generating sources would be beneficial. Currently, many remote facilities in the NPS are powered by nonrenewable diesel fuel generators (Green, 2006). The electricity generated from these devices allows tourists to visit areas with more ease. However, emissions from these generators can be dangerous to the environment as well as human health. The NPS would like to convert its power supply to off-grid renewable electrical energy to showcase the functionality of sustainable power as well as its negligible impact on the environment (S. Butterworth, personal communication, December 15, 2006). Based on Executive Order 13123, federal agencies have been directed to “significantly improve its energy management in order to save taxpayer dollars and reduce emissions that contribute to air pollution and global climate change” (Clinton, 1999, p. 30851). Quantifiable analysis for various electrical sources in remote locations can be used to address each reason. However, a common decision methodology that focuses on fundamental objectives has yet to be produced.

Decision methods similar to alternative-focused thinking seem to be a standard practice for many individuals for electricity procurement. Before fully evaluating the values of a decision, many individuals typically choose a solution and evaluate its impacts on generating electricity. Federal authorities also emphasize using life-cycle cost analyses to make decisions about such investments and consider this method to be the primary determination of equipment replacement needs (Clinton, 1999). Even though decision processes are available for electricity decisions, most individuals seem to rely on means objectives. Means objectives are goals that lead to achieving fundamental objectives. They do not encompass the actual reason for accomplishing such actions. A fundamental objective implies the essential reasoning for interest in a problem (Keeney, 1992). In some cases, the decision maker does not realize that "the more that local communities are integrated into the decision making process and the more ownership they develop, the more sustainable the project will be" (Reiche, Covarrubias, & Martinot, 2000, p. 60). Conventional decision processes may not be wholly appropriate to the needs of the decision maker.

Value-focused thinking (VFT) has the potential to rely on the fundamental objectives of electricity decisions in remote locations. This methodology has been applied to a variety of decisions in many contexts. The realm of electricity models in the value-focused thinking arena are not necessarily novel. Models of value-focused thinking have been produced to analyze electrical selection alternatives for the electrical support of military bases (Duke, 2004). Other models have been developed for deciding on a favorable, renewable energy source for backup purposes (Schanding, 2004).

However, the applications of value-focused thinking to remote locations remain scarce in recent literature.

1.3 Problem Statement

The purpose of this research is to identify and focus on the values of a decision context for the selection of power generation sources in off-grid locations. Inhabitants in remote locations should realize that procuring electricity is a concept that is becoming increasingly feasible for them. Worldwide focus on renewable electricity alternatives has propelled the amount and quality of research on this subject. As a result, technology in the electrical production arena has fueled an increase in availability for electric power. Renewable energy hybrid systems are also becoming prevalent around the world. In certain cases, more than one type of solution has the potential to address the electrical needs of individuals in remote areas. A decision process should be introduced in order to assist the decision maker in selecting the best alternative. By using a value-focused thinking model to determine an electrical supply, decision makers will have the potential to satisfy multiple objectives while supplying power to off-grid locations.

1.4 Research Objectives

The benefits of value-focused thinking have been established for many decision contexts. However, the application of its methodology to electricity generation in remote locations remains unknown. This void provides the source for the main research question in this study: How can a value-focused thinking model be applied to remote locations in order to produce a sincere reflection of an electricity generation source decision? The

NPS will be provided with information on the most viable source of electricity to power a remote location using value-focused thinking techniques. However, there are certain investigative questions that need to be specified before research can be completed. First, there are many remote villages and locations that currently operate with off-grid electricity. What types of electrical sources do individuals at remote locations use to typically meet their needs? Addressing this aspect of the research also facilitates the next objective. What decision-making processes have they used to identify and select these sources? A typical methodology for the decision process should be identified if it exists. If there is no status quo among similar situations, this research can be used to introduce a standard of analysis. There are certain constraints that must be satisfied for the decision in any scenario. Third, what types of constraints (legal, political, technical, etc.) must be incorporated in the decision-making process? The selection of an electrical system will not be applicable to any situation if boundaries are not identified and satisfied. Once this aspect is considered, there are various attributes that should be selected as valuable, if not necessary, to the selection process. Fourth, what other types of factors may be important to the decision makers during the selection/decision process? By comparing the importance of these attributes, the decision makers will have an accurate representation of the goals in the problem. Fifth, how much importance should be associated with these various factors? Answering these specific research objectives will provide the decision makers with the confidence that is essential to addressing the problem statement.

1.5 Methodology

The methodology applied in this research is a value-focused thinking model. A value-focused thinking model directs the attention of the decision maker to the philosophy of fundamental objectives. By keeping the focus on such values, the decision maker is able to generate and analyze additional alternatives that may not have been previously identified by other processes. In this model, a value-focused methodology allows the user to concentrate on the actual values of an electrical generation system to be installed on Alcatraz Island. This allows the NPS to identify and highlight important factors of the decision process for the remote location and input them into the model. Value-focused thinking also allows the NPS to distinguish the level of importance for each of these various factors with weight applications. By using this methodology, the decision makers of a remote location are able to provide transparent, quantifiable, and credible support for the selection of an electrical resource for officials at Alcatraz Island.

1.6 Significance of Study

The significance of this research includes the applicability of this technique to many other remote locations of the world. By providing a model, decision makers can use its valuable characteristics to decide on the best way for inhabitants in off-grid locations to produce electricity. Other NPS sites, as well as various federal agencies, can also adopt this decision process for other areas in their jurisdiction as well. Air Force forward-operating bases can use this model to decide on the best method of supplying electricity to its troops while minimizing foreign impacts. Energy specialist, Dr. Alison Doig (1999), states that there are also “under-class” individuals living in urban areas (p.

28). These inhabitants can also implement this model to realize the best alternative for satisfying their electricity needs. In general, the significance of this model is its ability to serve as a more substantive and transparent way for organizations to have more insight into the selection of electricity generation.

1.7 Chapter Previews

Each chapter of this thesis will focus on the particulars involved with an electrical generation decision. Chapter 2 will consist of a literature review that outlines current worldwide situations as well as addresses the specific case study. A methodology will be introduced in Chapter 3 to examine the intricacies involved with a decision between various electrical alternatives. Results will be established in Chapter 4 by quantifying decision maker's values and evaluating measure scores associated with each alternative. The final decision will be presented and precautionary information will be offered for its strengths and vulnerabilities. In Chapter 5, recommendations will be furnished for future implications in this scenario as well as others.

Chapter 2. Literature Review

2.1 Introduction

Literature on electricity generation in remote locations is somewhat limited in scope. In many cases, documents are provided outlining the deficiency of commercial power for such areas (International, 2002). In addition, barriers for commercial power connection have also been realized. However, decision tools used by individuals in remote locations remain limited. Even with the known issues, “not many rural off-grid programs have actually been implemented, so that success stories and lessons learned are still scarce” (Reiche, Covarrubias, & Martinot, 2000, p. 60).

The availability of technological improvements has led to the creation of policies and mandates directing the attention of electricity generation to its negative impacts. Sources such as the Kyoto Protocol have established that many countries around the world are beginning to understand the potential for electrical alternatives. The concept of applying decision methodologies to electricity supplies has spurred the initiation of further research in areas such as United States Air Force bases and grid-feasible locations. These studies provide insight into the characteristics of technological improvements such as renewable energy systems. However, the application of these methods for inhabitants with more restricted means of availability remains insufficient. The following review will aim at summarizing the credibility of a potential contribution to decision methodologies for electricity problems in off-grid locations.

2.2 Remote Locations

Not every part of the world has the feasibility of connecting to commercial electricity grids. Therefore, inhabitants of remote locations usually find alternative ways to procure electricity. There are many instances of remote villages, poor urban households, and undeveloped tourist areas in the world where individuals use other means of electricity procurement. The possibility of supplying power to these areas from distributed power plants becomes practically non-existent for various reasons.

Literature has shown that there may be as many as “1.6 billion people living in rural areas of the poorest regions of the world [who] lack access to modern forms of energy services” (Katti & Khedkar, 2006, para. 1). Table 1 demonstrates a multitude of areas with such deficiencies. There are many groups of individuals who reside in remote places, making their access to public electricity very difficult. The deficiency of a grid-based electric supply is mostly common in areas with lower rates of technological development. Only a handful of sub-Saharan African countries have more than a 20% rural electrification rate. Less than 10% of the populations in those countries have electric service (Doig, 1999). Around 70% of the population of Cameroon lacks the ability to be connected to electric grids from independent generating plants as well (Nfah, Ngundam, & Tchinda, 2006). Even rural areas in Uganda only have 1% of their households with access to electricity (Applewhite, 2002). Other parts of the world also have similar situations. There are estimates that 60% of the households and 70% of the villages in Asia have no access to the electric utility grid (Wies, 2006). Clearly, the reliance on electricity from public generating plants is limited to those inhabitants that are situated in more accessible areas of the community.

Table 1. Countries in 2000 with Low Electrification Rates (International, 2002)

Rank	Country	Electrification Rate %	Population without Electricity (million)	Population with Electricity (million)
1	India	43.0	579.1	436.8
2	Bangladesh	20.4	104.4	26.7
3	Indonesia	53.4	98.0	112.4
4	Nigeria	40.0	76.1	50.8
5	Pakistan	52.9	65.0	73.1
6	Ethiopia	4.7	61.3	3.0
7	D. Rep. of Congo	6.7	47.5	3.4
8	Myanmar	5.0	45.3	2.4
9	Tanzania	10.5	30.2	3.5
10	Kenya	7.9	27.7	2.4
11	Afghanistan	2.0	25.4	0.5
12	Uganda	3.7	22.5	0.9
13	Sudan	30.0	21.8	9.3
14	Nepal	15.4	19.5	3.5
15	Vietnam	75.8	19.0	59.5
16	D. Pop. Rep. of Korea	20.0	17.8	4.5
17	China	98.6	17.6	1244.9
18	Mozambique	7.2	16.4	1.3
19	Middle East	91.1	14.7	150.7
20	South Africa	66.1	14.5	28.3
21	Madagascar	8.0	14.3	1.2

The lack of connectivity to large electric grids also applies to many other situations as well. Some federally owned lands such as those in the National Park Service of the United States also lack connectivity. This includes Alcatraz Island in the Golden Gate National Recreational Area, Crane Flat in Yosemite National Park, and Sunrise in Mount Rainer National Park (S. Butterworth, personal communication, December 15, 2006). Even though these areas are not developed for permanent residency, power is still needed to provide access for tourists. Households and locations in prominently developed countries may also lack grid power. The reasons for such deficiency can be attributed to low incomes, cultural preferences, and environmental considerations from these inhabitants. Communities, such as those of the Old Order Amish, typically do not use modern technology as a personal choice and therefore lack grid power as well (Rheingold, 1999). Some households in urban areas of developed countries also experience limited access to grid power. These individuals live in "informal settlements, often in semi-permanent houses (in other words in slums)" (Doig, 1999, p. 28). In many instances, these individuals rely on other forms of electricity generation.

2.2.1 Reasons for Deficiency

There are various factors that prevent individuals in remote locations from receiving the usual supply of electricity from common utility lines. In many cases, combinations of these factors have led to service exclusion. Reasons for such deficiencies usually include physical constraints to the source (Doig, 1999). In some cases, access to electrical grids is not difficult to achieve in the area but other factors have caused individuals to actually refuse service. In certain areas, cultural traditions have persuaded certain groups of people to reject electric service. Cost burdens can also prevent groups of people from receiving public electricity even though access is physically possible (Stockton, 2004). At times, the reasons for electrical deficiency can be attributed to problems with high population growth and low utility support as well (Nfah, Ngundam, & Tchinda, 2006). These electrical deficiencies can be investigated more thoroughly.

In most cases, physical roadblocks prevent individuals from gaining access to public grid power. One of the most common roadblocks is due to geographical hindrances. Island, desert, and mountainous populations usually have little to no access to public utility grids because these areas incorporate obstacles like water, rugged terrain, and long distances (Doig, 1999). The complications involved with supplying power lines in adverse terrains may include complexities in clearing out areas, installations of power poles, and the ability to reach certain areas for maintenance issues. In some areas, dispersed populations can magnify the effort and cost of supplying commercial power to each household (Nfah, Ngundam, & Tchinda, 2006). Besides the effort involved with installing utility lines, the quality of power supplied through them also decreases as the distance increases (Doig, 1999). The impracticality of commercial utility service is multiplied in certain remote locations that involve more than one of the aforementioned constraints. In addition to physical hindrances, other factors can also be identified.

A lack of grid-based electricity in certain areas of the world can be attributed to high cost characteristics (Stockton, 2004). Financial considerations deter many individuals from obtaining commercial power because large fees are associated with the planning, development, installation, and maintenance of electrical towers and power lines. In remote locations of developing countries such as Uganda, there are people “who can only afford kerosene for lighting their homes and charcoal for cooking [and end up spending] 30% of their income on energy” (Applewhite, 2002, p. 55). This situation is also apparent with families that live near the Mount Shasta region of California. In at least one particular case, a renewable energy system was purchased in place of paying $80,000 for the installation of viable commercial power to a single home (Wigington, 2004). The cost limitations of purchasing commercial power also include families who live in populated areas as well. For example, “Hawaiian electricity users pay the highest rate in the United States at an average retail cost of 13.0 cents/kWh, a premium of 80% over the national average” (Stockton, 2004, p. 950). Some individuals in remote locations such as these choose not to cope with the high costs of local electricity. However, there are individuals who live in areas where cost is not the main concern.

Some groups may not acknowledge the benefits or the necessity for electricity use for societal reasons. Religious people in very conservative communities, such as those of the Old Order Amish, enforce the simplicity of survival without the means of electricity. They are distinguished by “their refusal to allow electricity or telephones in their homes” (Amish, 2007, para. 1). Therefore, the absence of commercial utility lines may be common in certain areas with a large Amish demographic density. Groups of individuals who live in remote locations such as the Amish have formed a traditional way of living for many generations and do not accept innovations lightly. Current events have also triggered more awareness of environmental concerns stemming from emissions of fossil fuel plants (Murthy, Jose, & Singh, 1998). Therefore, households as well as many worldwide companies have converted their reliance on electricity to renewable, on-site generation systems. Sustainable and traditional ways of thinking have led to an independent lifestyle for many communities in remote areas.

Other societal concerns also inhibit access to commercial power. In some areas, the support needed to create and maintain some electrical generation plants is not large enough to handle the growing population needs. Some rural parts of developing countries indicate that “progress in grid extension remains slower than population growth” (Nfah, Ngundam, Tchinda, 2006, p. 833). These areas indicate that another reason for a lack of grid-based electricity is due to the sheer size and density of a remote area that the service must accommodate. Large birth rates, low mortality rates, large-scale migrations of people from rural to urban areas, and dense populations can apply stress to utility grids that are sometimes not designed to handle such loads. Therefore, the lack of grid service for some inhabitants becomes apparent.

2.2.2 Current Status

Currently, the benefits of electricity are being experienced by some individuals in remote areas of the world. Many of them have decided to use more traditional, fossil fuel-powered machines which usually cost less to purchase (Nfah, Ngundam, Tchinda, 2006). Others have elected to rely on alternative methods that provide varying characteristics. Electricity generation alternatives, such as renewable systems can accommodate the demands of inhabitants in remote areas while providing inherent advantages as well. The growing complexities of electrical production alternatives support the need for decision processes in this arena.

Electricity generation in remote locations has not been overlooked. Remote inhabitants may understand that the majority of the responsibility is theirs for providing necessary power for servicing needs. Efforts have been made to find ways of producing electricity on-site. Individuals in many remote locations use traditional methods and equipment such as fossil fuel generators (Nfah, Ngundam, Tchinda, 2006). Diesel generators convert diesel fuel made from crude oil to electricity. This is a popular option in many current remote locations. The cost of owning, maintaining, and fueling these small power sources is somewhat minimal. The largest detraction of diesel generators is the necessary purchase and transportation of the diesel fuel to the remote site. In addition, these traditional power systems emit toxic vapors such as sulfur and particulate matter into the atmosphere (Sydbom, 2001). Examples of remote locations that have been documented to use such generators are listed in Table 2.

Table 2. Remote Locations Using Diesel Generators

Location	Source
Porto Santo, Madeiro, Portugal	(Duic & Carvalho, 2004)
Kenya	(Doig, 1999)
Asia	(Wies, 2006)
Canada	(Kozier, 1992; Spicer, 2006)
Alcatraz Island, California	(S. Butterworth, personal communication, December 15, 2006)
Yosemite National Park, California	(S. Butterworth, personal communication, December 15, 2006)
Mt. Rainer National Park, Washington	(S. Butterworth, personal communication, December 15, 2006)
Alaska	(Wies, 2006)
Thailand	(Wies, 2006)
Hawai'i	(Stockton, 2004)
Arua, Uganda	(Applewhite, 2002)
Cameroon	(Nfah, Ngundam, & Tchinda, 2006)

Other remote inhabitants have determined alternative means of electricity procurement using technology that departs from conventional methods. Renewable energy sources have gained popularity for many remote sites. Research has shown that there are more than 500,000 solar powered systems already installed in rural areas of developing countries (Reiche, Covarrubias, & Martinot, 2000). Many renewable systems incur higher costs upfront. However, these systems allow electricity to be generated from natural resources that are usually free and limitless. The environmental sustainability of renewable energy power has also become attractive to many areas of the world that advocate a stronger co-existence with nature. These individuals have chosen to use alternative fuel sources such as solar panels, wind power generators, and hydropower plants. Table 3 outlines remote areas of the world that contain such techniques. The identification of various electrical generation schemes also alludes to decision-making methodologies that may be apparent.

Table 3. Remote Locations Using Alternative Systems

Location	Fuel Type	Source
Northwest China	Solar	(Hua, Qingshen, Kong, Jianping, 2006)
Joshua Tree National Park, California	Solar	(Sunwize, 2003)
Telephones in India	Solar	(Shirodker, 1995)
Inner Mongolia	Solar	(Byrne, Shen, & Wallace, 1997)
Africa	Solar	(Doig, 1999)
Nepal	Solar	(Khanal, 2003)
Nepal	Micro-Hydro	(Doig, 1999)
Sri Lanka	Micro-Hydro	(Doig, 1999)
Peru	Micro-Hydro	(Doig, 1999)
Southern Africa	Micro-Hydro	(Doig, 1999)
Water Pumping at Heelat Ar Rakah Camp, Oman	Wind Turbine	(Suleimani & Rao, 2000)
Inner Mongolia	Wind Turbine	(Byrne, Shen, & Wallace, 1997)
Turkey	Wind Turbine	(Ozgener & Ozgener, 2006)
Argentina	Wind Turbine	(Reiche, Covarrubias, & Martinot, 2000)

2.3 Decision-Making Processes Used to Identify and Select Sources

The decision-making processes used for the identification and selection of electrical sources in remote locations tend to be very limited. Inhabitants of remote locations in financially burdened countries tend to rely on influences from outside agencies such as the World Bank Group in order to meet electricity needs. In fact, officials at the World Bank Group are “free to choose the technology suited best for a given village” (Reiche, Covarrubias, & Martinot, 2000, p. 55). There are other remote locations that may not be as dependent on outside influences. Federal management personnel in remote locations such as the United States National Park Service are occasionally tasked to identify ideal electrical generation systems. Ideas for energy projects are presented to senior leaders by park personnel as well as outside influences such as the public sector and various agencies. These potential projects are analyzed by applying merits of quality, adherence to guidelines, contributions to mission goals, and cost realizations in order to make a good decision (S. Butterworth, personal communication, December 15, 2006).

The decision processes of individuals such as these most likely correspond to alternative-focused thinking methodologies. However, a review of the literature on this subject did not reveal their decision-making processes. If there are a few alternatives that exist for satisfying an objective, the justification of adopting a long decision process may be considered unnecessary. Decision process innovator, Ralph Keeney, once stated that “the standard ways to address such decision problems [dropped in our laps] use alternative-focused thinking” (Keeney, 1992, p. 47). In the end, the decision maker will most likely choose a source that will satisfy one or two values, such as cost and effort, adequately. The lack of documentation for such decision processes also indicates the need for literature to fill the research gap.

2.4 The United States National Park Service

The cultural values of the NPS evolved from continual awareness of necessity in the preservation of historic lands (Management, 2006). Yellowstone became the United States' first national park in 1872 (Management, 2006). This area was selected by Congress during that year in order to maintain its condition and educate visitors on the importance of historical landmarks. The responsibility of managing the area was handed down to the Secretary of the Interior which, in turn, created the NPS. The NPS was formed to "promote and regulate the use of additional federal areas known as national parks, monuments, and reservations" (Management, 2006, p. 8). Personnel assigned to these areas are responsible for enforcing regulations that protect park resources and values. They are also responsible for educating visitors on the importance of environmental conservation. Since the jurisdiction of the NPS has slowly evolved into a list of nearly 400 different units, management of its lands is crucial for effective sustainment.

NPS senior managers, along with other officials, are responsible for providing broad regulations that usually focus on the overarching vision and goals for the service. This document, called *Management Policies*, is guided by the principles of the "Constitution, public laws, treaties, proclamations, executive orders, regulations, and directives of the Secretary of the Interior and the Assistant Secretary for Fish and Wildlife and Parks" (Management, 2006, p. 4). Within each unit of the NPS, senior officials provide more precise policies and regulations in accordance with the *Management Policies*. The *Golden Gate National Recreation Area General Management Plan* (GGNRA GMP) is an example of the document that "lays the groundwork for more detailed planning and day-to-day decision making that follows" for a specific site (O'Neill, 2006, p. 2). Park managers are directed to refer to the goals of the *General Management Plan* when making decisions affecting areas within their jurisdiction. For example, park utility plans such as electrical service to Alcatraz Island should realistically adhere to the purpose and directives of the GGNRA GMP. Project proposals have to meet approval guidelines specified from district chiefs in various disciplines. Any proposal that is estimated to cost more than a half million dollars must also be approved from the regional director, state historical preservation officer, development advisory board, and a representative from the Secretary of the Interior.

The history of Alcatraz Island includes distinct milestones of occupation before the NPS became involved. It was fortified by the United States Army in 1850 to protect the bay area from foreign invasion due to the great Gold Rush of 1849. As enemy ships grew more powerful throughout the years though, the defensive weapons of Alcatraz Island became obsolete. By 1907, it was converted into the first military prison of the United States. The post-depression era of the United States experienced heightened numbers of crime waves. Alcatraz Island was converted into a federal penitentiary because "a remote site was sought, one that would prohibit constant communication with the outside world by those confined within its walls" (Alcatraz, 2006, para. 3). Rising costs and changing philosophies in Washington D.C. dictated the closure of the federal penitentiary in 1963. In 1969, a political movement involving the rights of all Indian tribes resulted in the back and forth Indian occupation of the island. After two years, the movement ended and the conservation of Alcatraz's history began with the NPS (Alcatraz, 2006). The NPS took jurisdiction of Alcatraz Island in 1972 to preserve natural remnants and historical structures (Alcatraz, 2006). Tours of Alcatraz began and continue to be offered for San Francisco visitors.

2.5 Future Outlook of Electrical Consumption

The future of electricity consumption is promising. The International Energy Agency has indicated that there will be a continued increase in the amount of electrification rates of developing countries through 2030. This is shown in Figure 1. However, certain parameters need to be addressed for a more accurate realization of the situation. The future outlook of energy consumption can be attributed to the fuel needed by each system. Established policies from governmental agencies can also contribute to this scenario. Finally, financial assistance from governmental and non-governmental organizations has the ability to control the future state of electrical consumption.

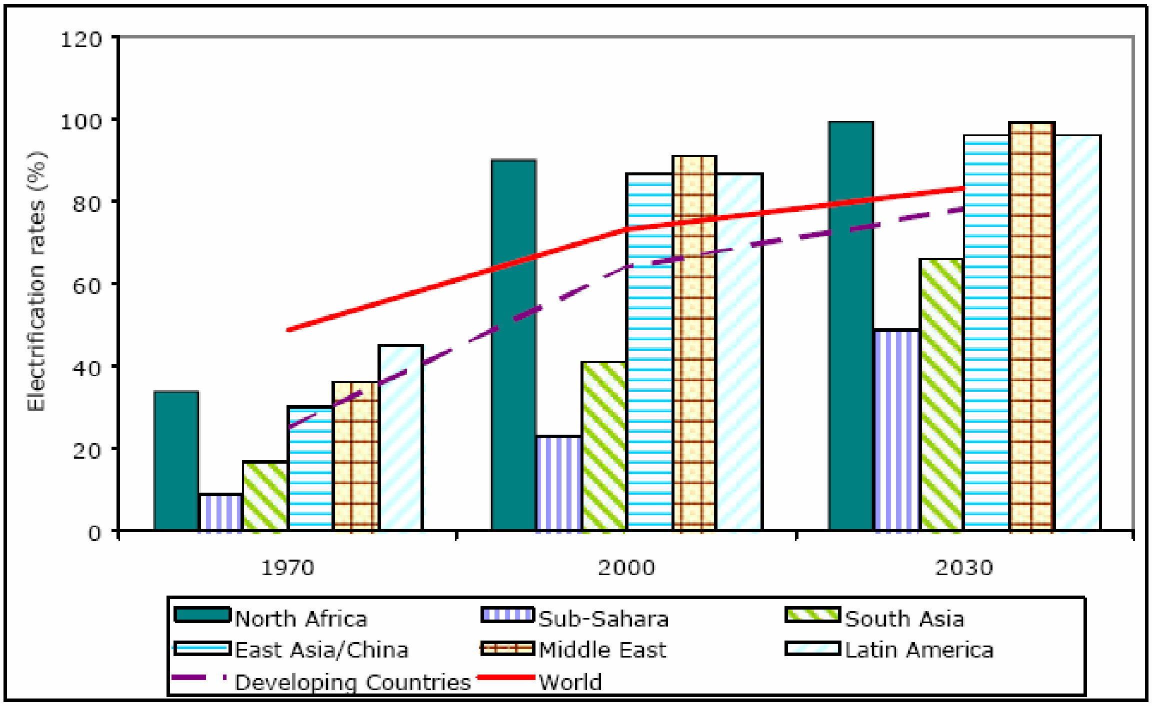

Figure 1. Electrification Rates by Region, 1970-2003 (International, 2002)

The future presence and growth of electrical generation systems will rely heavily on the supply of its energy source. In many off-grid rural areas of the world, electrical power is traditionally provided by fossil fuel generators. Increasing concerns about the status of consumable natural resources and the condition of the atmosphere has drawn attention away from conventional sources. Innovation and advancements in renewable energy generating systems introduce an increasingly popular option. Research has shown that “wind, solar, and other renewable energy sources are widely seen to have great potential for development in the 21st century” (Suleimani & Rao, 2000, p. 339). The advantages of renewable energy systems typically include no emissions, unlimited source of energy, favorable life-cycle costs, and independence from foreign fuel imports. These characteristics are essential for keeping electrical generation system sources viable for remote locations.

Outside organizational influences also dictate the future of electrical consumption. Financial aid from governmental, as well as non-governmental agencies, have increased acceptance in the application of renewable systems. However, some research has shown that government subsidies will only increase the role of renewables to between 6.7% and 12.9% of the world's electrical consumption by 2020 (Goldemberg, 2006). Policies such as the Kyoto Protocol indicate that the future state of electrical consumption will be more adaptive to renewable sources. It is evident that "the continuing challenge is to combine sustainable technology options with the participation of the communities, ensuring a supply system which meets local demands" (Doig, 1999, p. 28). A combination of encouraging characteristics in renewable systems and an increase in sustainability policies signify the future state of electricity schemes in remote locations.

Financial aid for energy assistance can be a large factor for the electrification rates in remote areas, especially those with lower incomes. The World Bank Group (WBG) is dedicated to the assistance of providing power to developing countries which is where most of the remote villages in the world are located. Recent trends in financial support show an increasing support for electrical projects in the world. This is indicated by the Bonn Commitment Curve in Figure 2. The trend of financial support for new renewable energy and energy efficiency in Figure 2 shows how well expectations have been exceeded in 2005 and 2006. The financial aid allocated to such projects indicated by the bars is higher than the Bonn Curve. This is a clue that electrical projects in developing countries may continue to see accelerated support. The establishment of initiatives such as these indicates that the future outlook of energy consumption will remain dedicated to renewable sources.

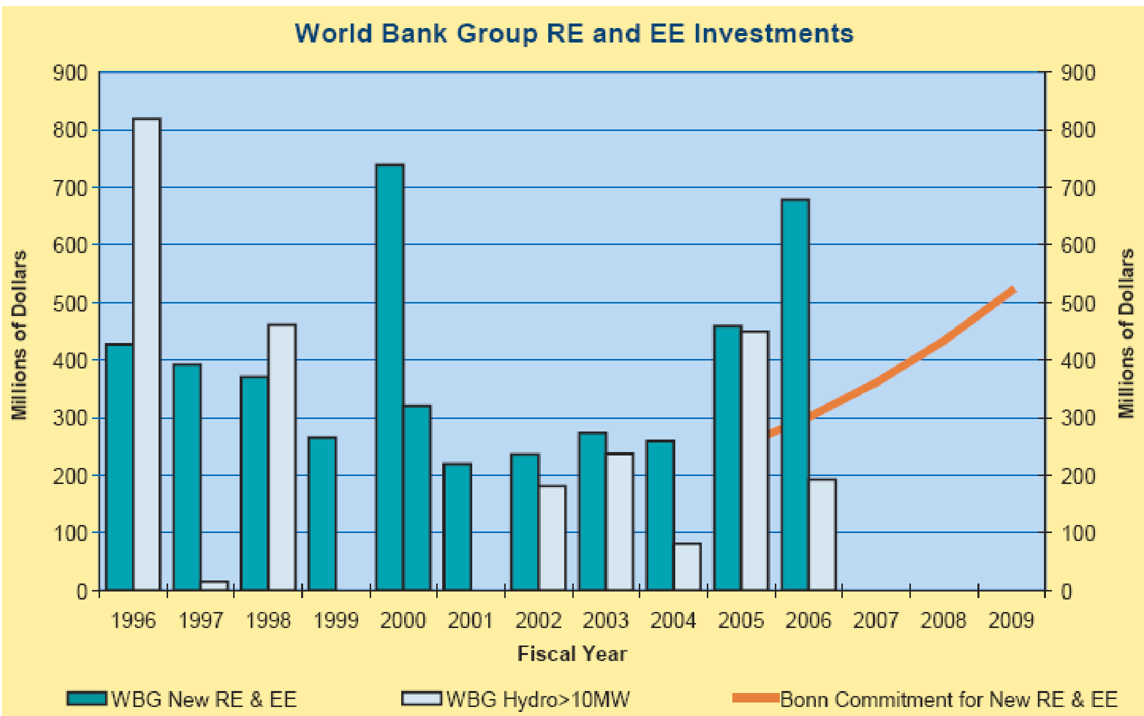

Figure 2. World Bank Group Investments (RE, 2006)

The outlook of electricity consumption for many parts of the world remains partial to renewable sources mostly due to environmentally-focused legislation. The Kyoto Protocol has mandated that the European Union expect to reach a target of 21%

electricity production through renewable sources by 2010. Latin American and Caribbean countries also had established targets of 10% renewable dependency but already achieved that point in 2001 (Goldemberg, 2006). Even though countries such as the United States are not bound to the Kyoto Protocol, many of them have instituted their own Renewable Portfolio Standards (RPS). The RPS dictates how much of the electrical sector is to be provided by renewable sources such as wind, solar, hydro, geothermal, and biomass (Renewable, 2004). By 2001, 13 states in America had already established minimum standards of renewable energy based on the RPS process (Renewable, 2004).

2.5.1 Conventional Sources

Based on a review of literature, the future of conventional electricity sources is expected to be stable. Conventional sources of power generation include systems fueled by coal, natural gas, and oil derivates. Oil production only rose 1% worldwide from 2004 to 2005 (British, 2006(f)). However, some countries experienced dramatic increases and decreases. For example, Azerbaijan oil production rose 42.8% while Uzbekistan dropped 16.9% in 2005 (British, 2006(f)). Worldwide natural gas production rose 2.5% in 2005 even though United States and the European Union reported declines. Dramatic increases in local production occurred in Libya with a 79.5% increase from 2004 to 2005. The Netherlands experienced the steepest decline of 8.4% in natural gas production (British, 2006(c)). Worldwide coal production also indicated an increase of 5% from 2004 as shown in Figure 3. These statistics indicate that the future worldwide outlook of conventional electricity sources remain mostly unvaried even though local changes may be dramatic.

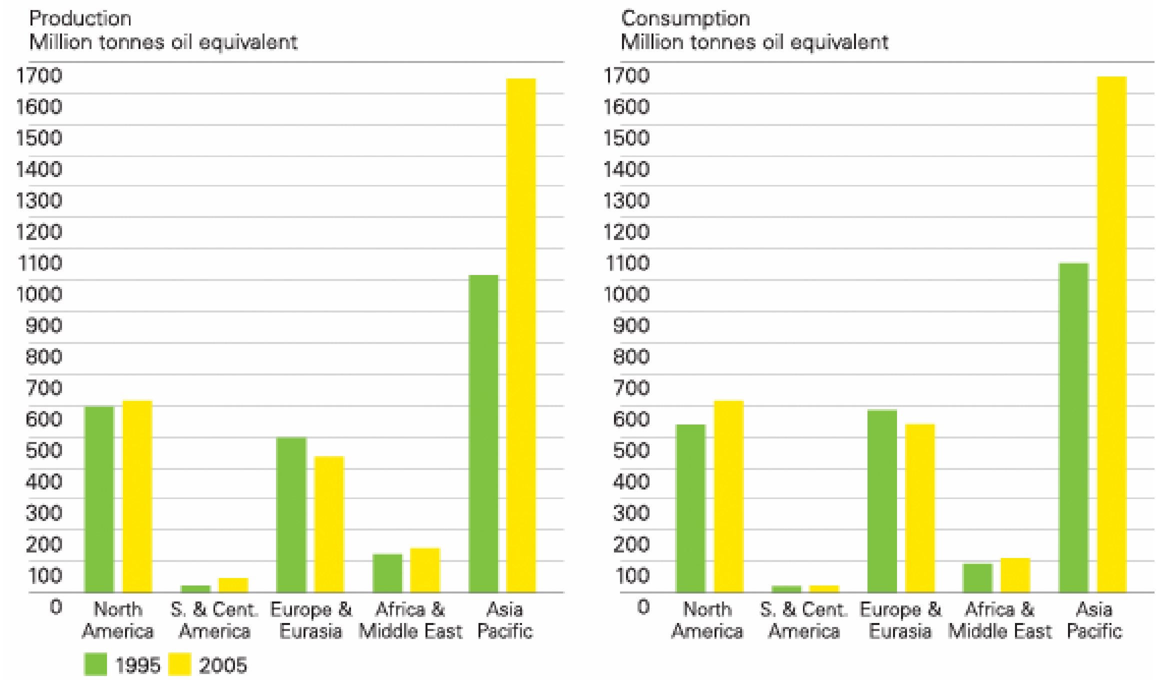

Figure 3. Worldwide Coal Production and Consumption (British, 2006(a))

2.5.2 Wind Power

The future outlook of wind power has strong indications of acceptance for remote locations. Improvements in the technology of wind power have led to the sudden growth in its popularity (Ozerdem, Ozer, & Tosun, 2006). In the past, United States farmers commonly used windmills for pumping water, grinding grain, charging batteries, and providing power for radios, lights, and washing machines (Ozgener & Ozgener, 2006). However, the advent of commercial power had rendered the idea almost obsolete. For the past 20 years, large efforts have been accomplished for the design of wind turbines, control systems, and energy storage systems to enable wind generation to be used in remote applications (Rogers, Manwell, McGowan, & Ellis, 2001). Specific advancements have been made in the areas of “high strength fiber composites, power electronics, and generators” (Ozerdem, Ozer, & Tosun, 2006, p. 726). Research has shown that the potential for renewable energy generated by medium-sized wind turbines in remote locations can be effective as long as support is readily available (Rogers, Manwell, McGowan, & Ellis, 2001). The results in improved efficiency and reduced costs make wind power competitive to conventional sources of electricity (Ozerdem, Ozer, & Tosun, 2006).

The effectiveness of wind power generators also depend on the future outlook of wind density in the area. The United States Department of Energy has documented that “good wind sites are often located in remote locations” (Advantages, 2006, para. 9). Numerous initiatives in many countries have led to a 23.8% increase in global wind power generation from 2004 to 2005 to 59,000 Megawatts (MW) (Danish, 2006). Figure 4 provides a distribution chart of this increase. Research has shown that wind power generation will continue to increase globally. These results also demonstrate that the future outlook of wind technology can have dramatic effects for many individuals in remote locations as well.

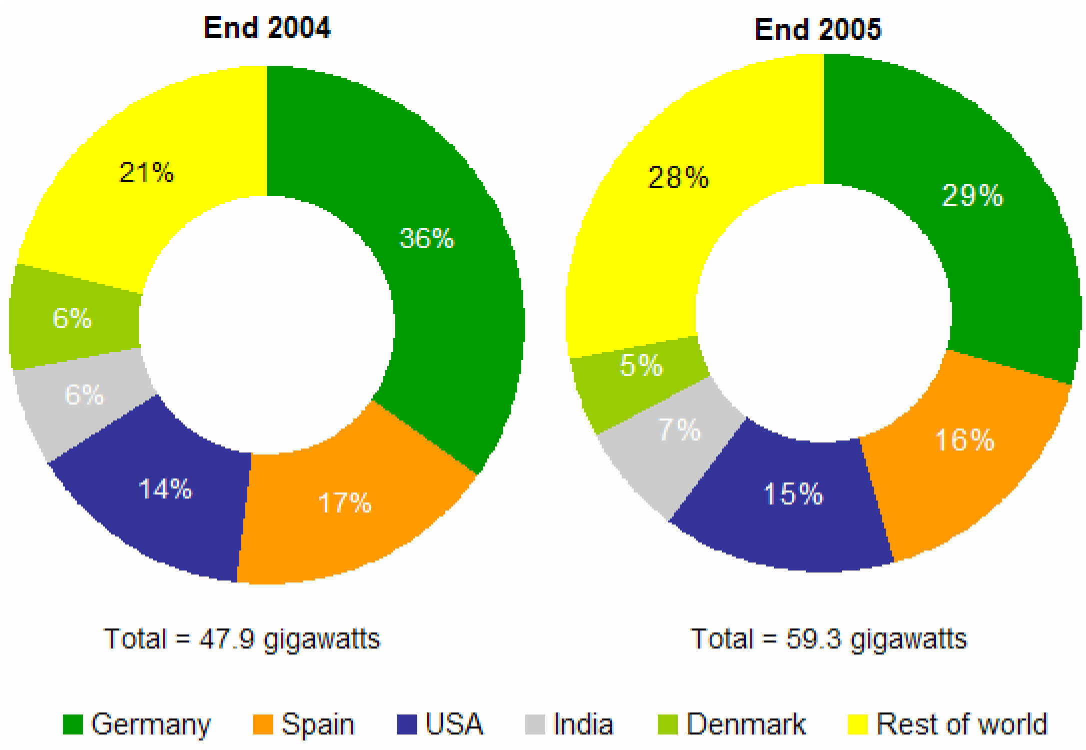

Figure 4. Worldwide Wind Power Generation (British, 2006(e))

2.5.3 Solar Power

The growth of solar power applications is comparable to wind generated power in certain areas of the world. The worldwide electricity generated from photovoltaics has experienced a 30% growth rate since 1997 and expectations are assumed to remain steady through 2020 (Goldemberg, 2006). The Million Solar Roofs Initiative proposed an ambitious plan to facilitate the installation of solar applications on one million buildings in the United States by 2010 (Million, 2006). Based on President Bush's Advanced Energy Initiative and the 2007 budget, an additional $65 million will be allocated to the development of solar electric technologies in the United States. This is an increase of over 78% from the 2006 budget. The goal is to make all solar applications cost-competitive to other forms of renewable energy by 2015 (Solar, 2006(b)). Expectations from the United States Department of Energy show that “there will be more breakthroughs in new materials, cell designs, and novel approaches to product development” (Solar, 2006(a), para. 3). Research also indicates that “within 10 years, photovoltaic power will be competitive in price with traditional sources of electricity” (Solar, 2006(a), para. 6). These facts indicate that the future outlook of solar power in the United States remains theoretically strong for the future. British Petroleum provides increasing expectations for photovoltaic applications for other countries as well. Figure 5 indicates an almost exponential rise in the amount of photovoltaic electricity produced in certain countries. Based on past activity, Japan seems to show the largest growth of solar power applications followed by Germany. Other countries have shown steady growth rates. This indicates that solar power will most likely be favorable for locations such as Japan and Germany in the near future.

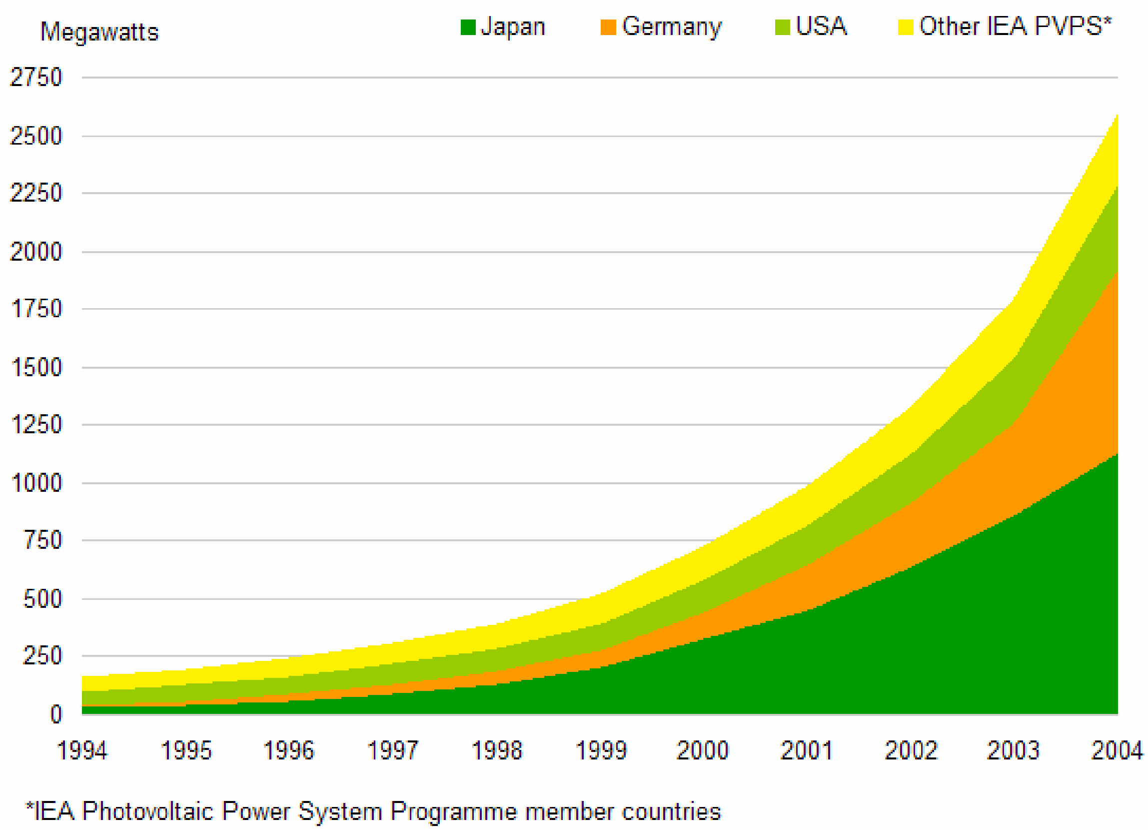

Figure 5. Photovoltaic Power Consumption (British, 2006(d))

2.5.4 Geothermal Power

The future growth of geothermal power remains somewhat questionable for world electrical derivatives. The United States has recently become the most predominant geothermal energy producer of the world at 2,544 MW by the end of 2005 (British, 2006(b)). However, that figure is less than the level of 2,817 MW installed in the United States in 1995. In fact, most countries realized no increase in geothermal power from 2004 to 2005. Figure 6 indicates that the only two countries that have installed additional geothermal systems in 2005 were Guatemala and the United States. Even though Guatemala has realized a 47.3% increase from 2004 to2005, the total capacity generated still remains very small compared to world contribution. Even though geothermal capacities may remain low when compared to global consumption, smaller countries may depend heavily on geothermal power. For example, a quarter of the electricity generated in El Salvador comes from geothermal power (British, 2006(b)). Limits to geothermal expansion include inadequate research and development and high costs associated with installations. Therefore, the near future outlook of geothermal electricity expansion in remote locations remains somewhat grim.

Renewable energy – geothermal

Cumulative installed geothermal power capacit

Megawatts	1990	1995	2000	2003	2004	**2005**	Change from 2004 to 2005	2005 share of total
Argentina	0.7	0.7	0.0	0.0	0.0	**0.0**	n/a	0.0%
Austria	0.0	0.0	0.0	1.3	1.2	**1.2**	0.0%	0.0%
Australia	0.2	0.2	0.2	0.2	0.2	**0.2**	0.0%	0.0%
China	19.2	28.8	29.2	28.2	27.8	**27.8**	0.0%	0.3%
Costa Rica	0.0	55.0	142.5	162.5	162.5	**162.5**	0.0%	1.8%
El Salvador	95.0	105.0	161.0	161.0	151.2	**151.2**	0.0%	1.7%
Ethiopia	0.0	0.0	7.0	7.0	7.0	**7.0**	0.0%	0.1%
France (Guadeloupe)	4.2	4.2	4.2	4.2	14.7	**14.7**	0.0%	0.2%
Germany	0.0	0.0	0.0	0.2	0.2	**0.2**	0.0%	0.0%
Guatemala	0.0	0.0	33.4	33.4	33.6	**49.5**	47.3%	0.6%
Iceland	44.6	50.0	170.0	200.0	202.0	**202.0**	0.0%	2.3%
Indonesia	144.8	309.8	589.5	807.0	807.0	**807.0**	0.0%	9.0%
Italy	545.0	631.7	785.0	790.5	790.5	**790.5**	0.0%	8.8%
Japan	214.6	413.7	546.9	560.9	535.3	**535.3**	0.0%	6.0%
Kenya	45.0	45.0	45.0	121.0	127.0	**127.0**	0.0%	1.4%
Mexico	700.0	753.0	755.0	953.0	953.0	**953.0**	0.0%	10.7%
New Zealand	283.2	286.0	437.0	421.3	435.0	**435.0**	0.0%	4.9%
Nicaragua	35.0	70.0	70.0	77.5	77.5	**77.5**	0.0%	0.9%
Papua New Guinea	0.0	0.0	0.0	6.0	5.5	**5.5**	0.0%	0.1%
Philippines	891.0	1227.0	1909.0	1931.0	1930.9	**1930.9**	0.0%	21.6%
Portugal (The Azores)	3.0	5.0	16.0	16.0	16.0	**16.0**	0.0%	0.2%
Russia (Kamchatka)	11.0	11.0	23.0	73.0	79.0	**79.0**	0.0%	0.9%
Thailand	0.3	0.3	0.3	0.3	0.3	**0.3**	0.0%	0.0%
Turkey	20.6	20.4	20.4	20.4	20.4	**20.4**	0.0%	0.2%
USA	2775	2817	2228.0	2020.0	2534.0	**2544.0**	0.4%	28.5%
TOTAL WORLD	**5832.0**	**6833**	**7972.6**	**8402.3**	**8911.8**	**8937.7**	**0.3%**	**100.0%**

* End of year. Source: International Geothermal Association, conference papers presented at the World Geothermal Congress, 2005.
n/a not available.
Note: Because of rounding, some totals may not agree exactly with the sum of their component parts.

Figure 6. World Geothermal Power Consumption (British, 2006(b))

2.6 Value-Focused Thinking

The value-focused thinking concept analyzes the fundamental objectives of the decision maker and theoretically provides ideal solutions for each problem situation. The process of value-focused thinking is to quantify the decision maker's values in order to produce a final score that reflects the amount of total satisfaction for each alternative. Ralph Keeney (1992) stresses that values should be "the driving force for our decision making" (p. 537). He feels that focusing on values allows the decision maker to identify more desirable outcomes because that is the basis of the time and effort involved in finding a solution (Keeney, 1992). Figure 7 indicates all of the attributes that value-focused thinking can provide to the decision maker. These benefits can be realized by implementing VFT for any decision problem with multiple alternatives because it allows the decision maker to incorporate their objectives more efficiently.

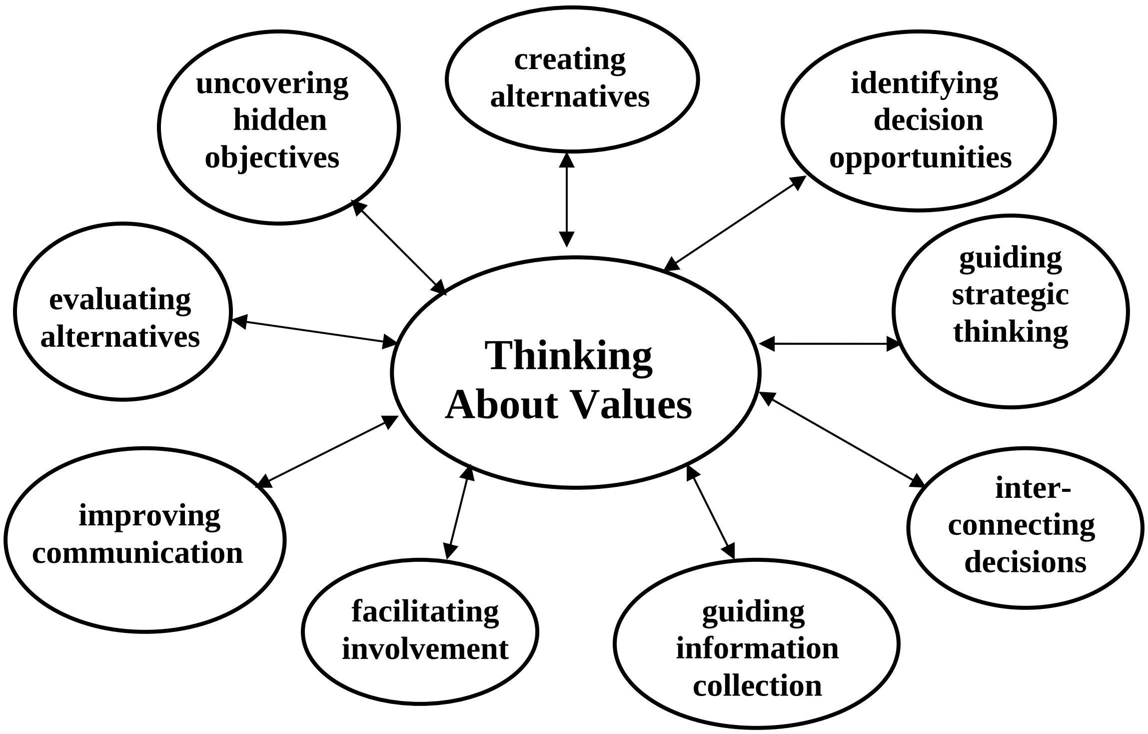

Figure 7. Benefits of Value-Focused Thinking (Keeney, 1992)

2.6.1 Value-Focused Thinking versus Alternative-Focused Thinking

The idea of using VFT for this situation is more suitable than using Alternative-Focused Thinking (AFT) for various reasons. Alternative-focused thinking dedicates the attention of the problem to the solutions that fit instead of the required objectives. By allowing the decision maker to concentrate on the possibilities instead of the objectives, the consequences of an action may seem undesirable (Keeney, 1992). Using VFT guides the decision maker to uncover more opportunities for efficient solutions than may have been developed using AFT. Lastly, VFT improves communication between all audiences and is easily interchangeable with other decision makers. The VFT process should be regarded over AFT because concentration on objectives, uncovering hidden opportunities, and improving communication can lead to a stronger justification for choosing an electrical system in a remote location.

When faced with many problems, most decision makers are apt to find prompt solutions without fully recognizing the consequences of their actions. This way of thinking is common among the human species. The same principles apply to electrical generation scenarios. Simply choosing a diesel generator for an alternative may seem to bring heuristic value. However, after evaluating other objectives by way of VFT, another solution may be more adequate.

By analyzing the main objectives of a decision problem, more alternatives can be realized than with alternative-focused thinking. Focusing on the objectives allows the decision maker to maintain his/her attention on the basic goals of a problem. By rewinding the thought process back to the basic fundamental objectives, the decision maker will be able to understand the more inherent situation and all the possible solutions.

The VFT process provides a detailed map of the decision process to others that alternative-focused thinking cannot. The steps used to complete a VFT methodology require a specific layout to the decision at hand. In addition, applying the 10-step VFT (as cited in Schanding, 2004) process will further define all the components of a decision. The 10-step VFT process was developed by modifying the procedures introduced by Keeney (1996) and Kirkwood (1997). Outlining an organized and operable methodology is very beneficial to the communication standards of all the stakeholders in every problem. Therefore, the VFT process is preferred to alternative-focused thinking because others can follow the decision process easily.

2.6.2 Value-Focused Thinking in Electricity Generation Problems

Value-focused thinking can offer an effective way of deciding what type of electrical system should be used to power remote locations. The concepts of multi-criteria decision methods have been proven to be useful for electricity problems (Haralambopoulos & Polatidis, 2003). Growing technology in the area of renewable energy has provided unique and various alternatives for sustainable electrical production. The number of partnerships for renewable energy policies has increased, dedicating more attention to efficient solutions as well (Climate, 2000). In many remote locations, the feasibility of more than one type is possible. For instance, the mid-west areas of the United States usually experience a large amount of wind and sunlight in its climate. Therefore, a combination of solar panels and wind turbines seem ideal for electricity generation. Other parameters, such as additional electronics-based technological innovations and modifications in decision maker values dictate the need for a simpler justification process. A value-focused thinking process can be the solution to choosing the best way of providing electricity for remote inhabitants.

2.6.2.1 Multi-Criteria Tools for Electricity Generation Problems

The idea of using some form of decision making to determine a justifiable renewable energy source is not entirely innovative. Tools such as “multi-criteria decision aid (MCDA) techniques [have had] a long history in energy projects” (Haralambopoulos

& Polatidis, 2003, p. 962). The technique of value-focused thinking has also been applied to a couple scenarios on energy production in the United States Air Force. A VFT model was constructed to determine ideal renewable energy sources for Air Force bases as a replacement for on-grid public utility dependence (Duke, 2004). Another model was completed to find potential renewable energy backup sources for Air Force bases. This was completed with the assumption that terrorist activities or natural disasters would have the possibility of destroying public utility grids (Schanding, 2004). Strategic objectives were developed at British Columbia Hydro using value-focused thinking to "develop additional resources to generate electricity" as well (Keeney, 1992, p. 538).

Other federal departments have also adopted toolkits for solving such complex electrical problems. The United States National Renewable Energy Laboratory has developed four models to "analyze the performance and reliability of designs for renewable energy systems and their post-maintenance costs and performance" (Technology, 2006, para. 1). One of the models, Village Power Optimization Model for Renewables (ViPOR), is used for the design of a totally autonomous renewable energy system with the lowest cost for village electrification. However, ViPOR only uses a single criterion to determine the best type of renewable energy source. Past research (Duke, 2004; Schanding, 2004) has shown that multi-criteria decision methods like VFT can offer the transparent tools needed for solving electricity issues.

Published reports address issues concerned with decision making tools for the implementation of renewable energy sources. However, the idea of using Value-Focused Thinking to decide on favorable renewable energy sources in remote locations tends to be undiscovered. Theses published by Schanding (2004) and Duke (2004) focused on areas that rely on public utility grids for main power generation. Multi-criteria decision making tools were implemented in the island of Chios, Greece, to determine the best exploitation of land, including geothermal resources. Although the idea of analyzing an island location may seem similar to the analysis of this study, the alternatives were only tailored to a specific situation. Other forms of renewable energy were not evaluated. Other decision making tools such as PROMETHEE have been applied to a rural community in Northern Greece. Another evaluation method, called Electre, has been carried out for the evaluation of the most suitable innovative technologies in the energy sector at the island of Sardinia (Linares, 2002). Other tools have been applied to help determine the planning models dealing with uncertainty and formulations of policies (Linares, 2002; Greening & Bernow, 2004). Ecological footprint tools have also been presented to show whether sustainability principles are followed in various levels of electricity planning (Stoglehner, 2003). These research areas can be vital to the overall applicability of decision making tools to renewable energy. However, the idea of using value focused thinking in order to provide assistance in determining favorable renewable energy sources in remote locations should be addressed.

2.6.2.2 Growing Complications with Electricity Generation Options

Options for supplying electricity to remote locations are numerous. Innovations in technology have provided varying methods of generating electricity (Electric, 2007). The alternatives of producing electricity can be divided between renewable and non-renewable sources. Non-renewable sources include electricity mainly generated from fossil fuels such as coal and oil, as well as natural gas. Within each of those categories, various manufacturers can offer their services for installation. Many areas in the world also have the potential to pursue renewable technologies such as solar power, wind power, geothermal power, and hydropower, as well as combinations of systems called hybrids. Within some arenas of renewable power, various options exist for practical uses. For example, solar power can be used to heat air and water as well as provide electricity (Solar, n.d.(b)). Solar panels can be mounted on roofs as shingles or set in other areas as well (Solar, n.d.(a)). There are also many manufacturers that offer their services for installation in any of these combinations. In order to recognize the ideal alternative of producing electricity, the fundamental objectives of the decision maker need to be realized and factored into the problem. Once the model is completed and analyzed, viable options for generating electricity will not seem so overwhelming.

Chapter 3. Methodology

3.1 Introduction

Value-focused thinking is a method of applying decision analysis principles for gaining more information to solve a problem. A final value score is associated with each alternative that is analyzed in the model. This provides a preliminary solution to the problem along with additional information. The effect of following the steps to a value-focused thinking problem is the application of the additive value function for determining the final value score:

$$\upsilon(x) = \sum_{i=1}^{n} \omega_i \upsilon_i(x_i) \tag{1}$$

where $\upsilon(x)$ is the *final value score* of an alternative, ω_i represents the *weight* associated with the i^{th} measure, n is the *number of measures,* and $\upsilon_i(x_i)$ is the *value function score* of an alternative for the i^{th} measure. All alternatives are quantified using same the values, identified for evaluation. The result is a score that reflects the distance, in a value sense, of how well each alternative meets the values of the decision maker from the hypothetically worst possible alternative to the best possible alternative. The final value score closest to 1, or “ideal”, is preferred by the decision maker.

The 10-step Value-Focused Thinking (VFT) process has an operable sequence of directions. The mathematical purpose of this methodology is to implement the additive value function for analysis. Figure 8 shows a visual representation of how each step contributes to developing an effective hierarchy and analysis for a final recommendation. The first six steps of the process will be discussed in this chapter. The remaining steps will be covered in Chapter 4, which summarizes the results and presents recommendations.

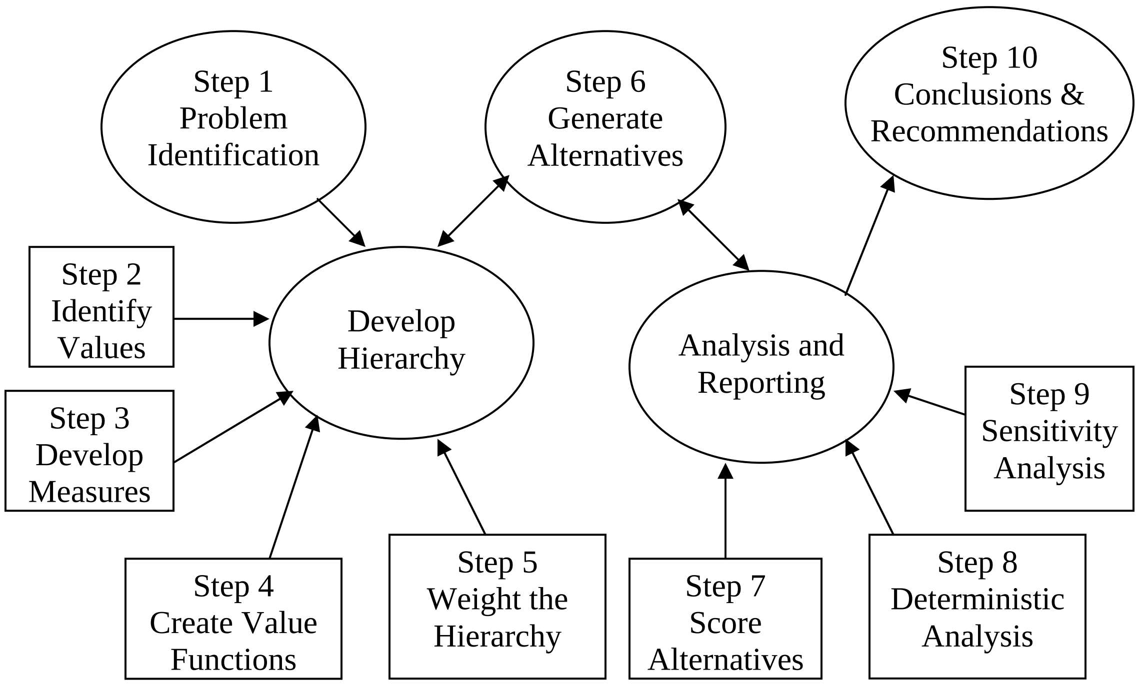

Figure 8. 10-Step VFT Process (Schanding, 2004)

3.2 10-Step VFT Process

The 10-step VFT process allows the decision maker to gain information about the problem by following a predetermined sequence. First, the fundamental objective of the problem is identified by investigating the purpose behind the model in step 1. Then, values associated with the problem are listed and grouped into a value hierarchy. In step

3, measures are correlated to each value on the lowest level of the hierarchy so that measurement tools can be identified. Step 4 involves creating value functions that define the value score associated with each measure range. Next, weights are applied to the model so that the degree of importance for each value can be established for analysis. Step 6 involves generating alternatives for review. These alternatives are scored for each measure so that a final value score can be presented. Step 8 includes the assessment of the final value score along with possible cost considerations. Next, sensitivity analysis is used to determine the vulnerability of the rank order. Finally, conclusions and recommendations are made based on the input gained from the model. These steps allow the decision maker to gain more understanding for the objectives and alternatives under consideration.

3.3 Step 1-Problem Identification

Currently, electrical demands at Alcatraz Island are met using diesel fuel generators. These generators supply power to various visitor facilities such as visitor services, care and upkeep of maintenance, and nighttime lights. Areas of visitor services that require electricity include sewage pumps, water pumps, bathroom lights, and the radio tower. Maintenance areas also need electricity for telephones, refrigerators, computers, and lights for office spaces. At night, Alcatraz runs regular lights and a lighthouse to prevent boat collisions and provide aesthetic appeal from surrounding areas. The amount of power supplied by these diesel generators provides Alcatraz with the necessary 100 kW of electricity demand every day.

Golden Gate National Recreation Area (GGNRA) management and personnel realize that there may be other methods of supplying electricity to replace the aging equipment. There has been an increase in demand for Alcatraz Island to become self-sustaining and environmentally compatible in accordance with the GGNRA General Management Plan (GMP). Therefore, a decision model would be beneficial to determine more information for an ideal electrical source based on values from park engineers and managers. The fundamental objective of this model is to identify an electrical generation source that would be best suited for Alcatraz Island in accordance with the GGNRA GMP. The decision makers of this VFT model were composed of an energy coordinator/park manager and a site-specific support team. At the conclusion of this model, an electrical alternative with the highest final-value score was identified for this remote location.

3.4 Step 2-Identify Values

The values, as determined by the decision makers in this problem, include those aspects that would generally relate to electrical system objectives as well as environmental preservation. The top-tier values of site appropriateness, operation, public education, and environmental impact were determined by applying the platinum standard of elicitation. The platinum standard of elicitation is the process of building a model based on input from both senior level managers and authoritative documents (Weir, 2006). The decision makers were identified as authoritative representations of the GGNRA GMP. Site appropriateness captures the characteristics of the system that may or may not be in accordance with multiple parameters of the specific site location.

Operation refers to the performance of an alternative based on its own characteristics and fuel requirements. Public education is the interpretation conveyed by an alternative that can be positively linked to the NPS values. Environmental impact encompasses compatibility ratings of each system alternative to the preservation of the natural surroundings. The top-tier values of the decision model shown in Figure 9 reflect the main objectives of the electrical system for selection of the best way of powering Alcatraz.

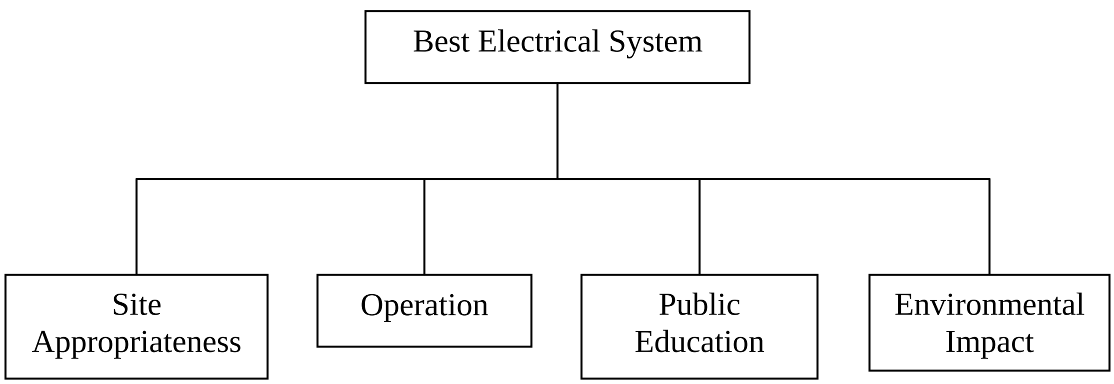

Figure 9. Top-Tier Values

3.4.1 Values-Site Appropriateness

The site appropriateness top-tier value is characterized by the five second-tier values shown in Figure 10. This tier was determined by grouping values that characterized the specific location of analysis. The noise value encompasses the level of audible distractions that an alternative may produce. This value is further specified into the third-tier values of peak and mean decibel levels since both aspects must be taken into consideration. Aesthetics is an indication of how visually stimulating an alternative is based on the setting of Alcatraz Island. Construction resources indicates the amount of work that will be necessary to install the alternative as well as the resources that will be available to facilitate it. Area occupied is a measure of how well the alternative will physically be able to fit into the designated area on the island. If a preliminary system will not easily fit, further accommodations will have to be considered. Finally, compliance burden designates the amount of paperwork and processes that will be necessary to permit the construction of such an alternative on Alcatraz.

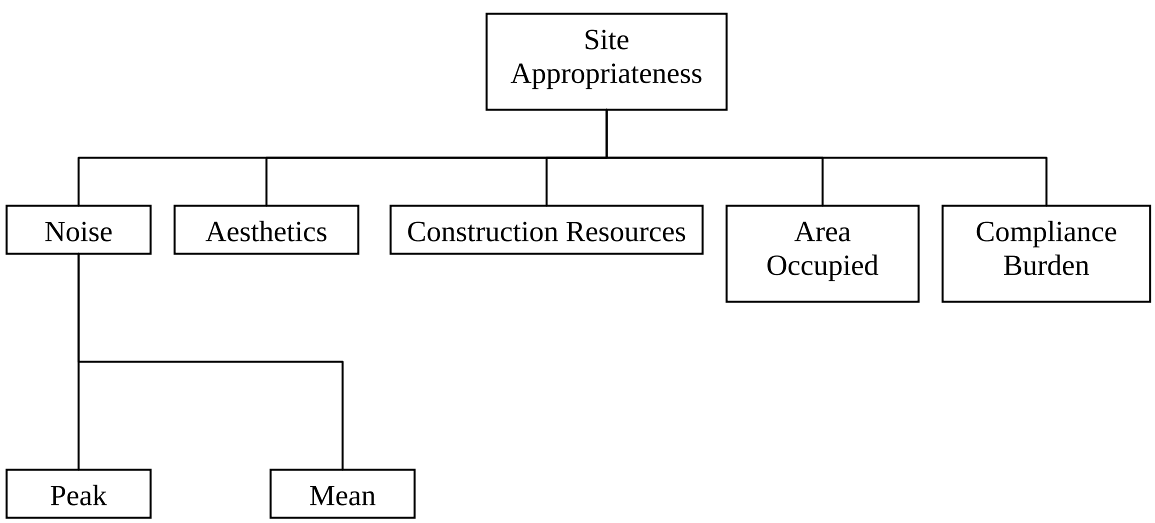

Figure 10. Site Appropriateness Tier

3.4.2 Values-Operation

The operation top-tier value is divided into the second-tier values shown in Figure 11. This tier was determined by grouping values that seem to apply towards the general operation of each alternative. Reliability indicates how long the electrical alternative is estimated to operate based on manufacturer inputs. Maintenance determines how often an alternative system needs to be serviced for routine upkeep. Technical support availability is the degree of how quickly support can be established for frequent questions or maintenance issues on the island. Energy source encompasses all of the aspects necessary for the supply that the alternative needs for electrical conversion.

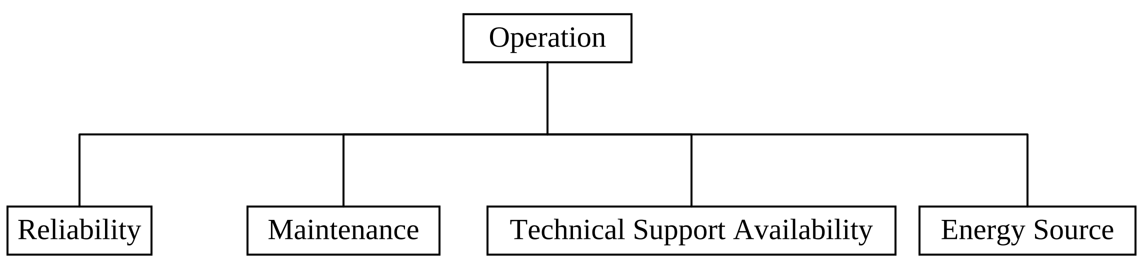

Figure 11. Operation Tier

The value of energy source contains many lower level values in order to fully represent its importance. Energy source is determined by the third-tier values shown in Figure 12. Efficiency refers to the amount of energy provided based on the amount of energy input into the system. Availability constitutes the amount of the energy source provided on an average day. Storage indicates the amount of effort and precautionary steps required for providing an energy source to each particular alternative. Storage is divided into the fourth-tier values of reserve ability, capacity, and safety. Reserve ability is the criteria that measures whether or not an energy resource is allowed to be stored for future consumption. Capacity is a depiction of how much energy can be stored per cubic foot. Safety is determined by the fifth-tier values of flammability, health, reactivity, and special category labels for each resource required.

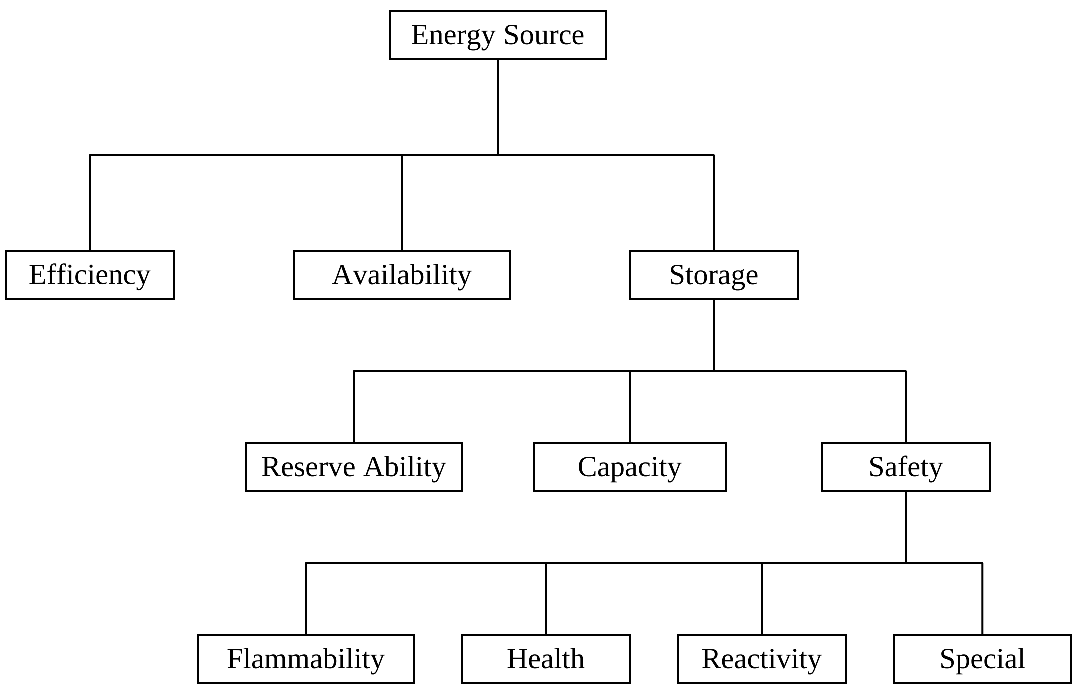

Figure 12. Energy Source Tier

3.4.3 Values-Public Education

The public education first-tier value demonstrates the ability of each alternative to contribute to the knowledge consumption of all observers. These observers include park visitors, park management and employees, as well as other agencies. The nature of this value did not necessitate the need for lower level values. By implementing the public education first-tier value, the objective of portraying the importance of public awareness in National Park Service (NPS) standards was depicted.

3.4.4 Values-Environmental Impact

Environmental impact summarizes the effect that each alternative will have on the natural aspects of Alcatraz Island and its immediate surroundings. This tier was determined by grouping values on the basis of providing environmental awareness. This first-tier value is divided into second-tier values shown in Figure 13. Preservation is the objective of the NPS in maintaining national park regulations. The preservation of the park is considered from a cultural and historical viewpoint as well as natural resource concerns in the fourth-tier level. The emissions criterion is provided in the hierarchy in order to determine how an alternative affects emission limits established by local district standards. Finally, the environmental group must also indicate their satisfaction in preserving the quality of land, water, and air creatures based on each electrical alternative.

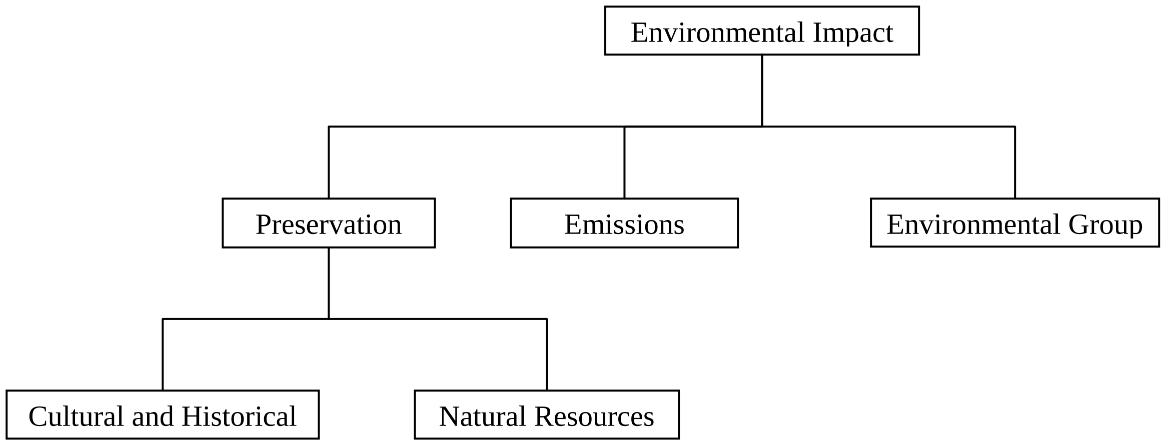

Figure 13. Environmental Impact Tier

3.5 Step 3-Develop Measures

Measures were constructed for each bottom tier value to implement a quantitative means of scoring each alternative. Measures are specific means used to identify how each bottom-tier value will be scored. These measures can be categorized into one of four combinations of measure types as shown with some examples in Table 4. Natural measures are those that can naturally be counted, gathered, measured, or recorded. Constructed measures are those applications that can only be defined by subjective scale. Direct measures are those measures that present the closest definition of the value by directly relating to it. Proxy measures may not directly be associated with the value but can its relationship can be inferred. By identifying these measures, the scoring of values for each alternative will be able to contribute to the overall additive function score.

Table 4. Measure Categories with Examples (Knighton, 2006)

	Natural	Constructed
Direct	Net Present Value Time to Remediate Cost to Remediate System Reliability Bandwidth Per Sec Revisit Time	Olympic Diving Scoring Weather Prediction Categories Project Funding Categories R & D Project Categories
Proxy	Gross National Product (Economic Growth) Site Cleanup (Time to Remediate) Number of Subsystems (System Reliability)	Performance Evaluation Categories (Promotion Potential) Instructor Evaluation Scales (Instructor Quality) Student Grades (Student Learning)

3.5.1 Measures-Site Appropriateness

The bottom tier values for site appropriateness consist of five measures. Peak noise can be measured using the highest decibel level of sound expected from each alternative. Similarly, mean noise can also be measured using the average decibel level. Aesthetics will be measured using a subjective scale from the park committee by determining how visually distracting each alternative is to the island. Construction resources will be measured using a subjective scale provided by the committee in accordance with the amount of tools and level of effort needed to install an alternative. The area occupied value will be measured using a fit/does not fit criteria. This determines if further renovations will have to be accomplished for an ideal alternative. The categorization of an alternative to a ‘does not fit’ score does not imply that it will not be considered. The compliance burden value will be measured using a subjective scale given by the park committee to reflect the amount of time, effort, and processes that will be necessary for the implementation of an alternative. The measures encompassed in the site appropriateness tier in Table 5 consist of various types that are expected to quantitatively define the values accurately.

Table 5. Measures-Site Appropriateness

Values	**Measures**	**Type of Evaluation**	**Lowest Score**	**Highest Score**	**Units**
Peak	Peak db Level	Natural, Direct	90	0	Decibels
Mean	Mean db Level	Natural, Direct	70	0	Decibels
Aesthetics	Aesthetics Rating	Constructed, Direct	0	10	Rating
Construction Resources	Construction Rating	Constructed, Direct	0	10	Rating
Area Occupied	Area Fit	Natural, Proxy	Does Not Fit	Fits	Go/No-Go
Compliance Burden	Compliance Rating	Constructed, Direct	0	10	Rating

3.5.2 Measures-Operation

The many values depicting the operation tier correlate to a high amount and variety of measures. In this situation, reliability is measured by obtaining the expected lifetime operating hours until failure by the manufacturer of each alternative. Maintenance is quantified by the expected hours between routine services. The cost of routine services is not considered because its effects are assumed to be minimal in comparison to supply costs. Technical support availability is measured by the number of hours expected for the manufacturer to be on the site. Telephone and online support will not be considered because the assumption is that assistance can easily be achieved in this manner for all alternatives. Efficiency is measured by the electrical energy effectiveness provided from each alternative using a common efficiency ratio. Availability is a measure of the proportion of a typical day that the electricity can be provided by each alternative based on the energy source. Reserve ability is a go/no-go measure that indicates whether or not the electrical energy source is allowed to be kept on the island. Capacity is synonymous with the storage capacity of the energy produced by each alternative. This is measured by Mega British Thermal Units (MBTU) per cubic feet in order to provide a quantifiable reflection of energy density in the source. Flammability, health, reactivity, and special are measured using a categorical fire diamond definition as used for many chemical containers by the United States National Fire Protection Association (Shearer, 2006). All of these measures in Table 6 demonstrate the most efficient way of scoring the operation tier of the hierarchy.

Table 6. Measures-Operation

Values	Measures	Type of Evaluation	Lowest Score	Highest Score	Units
Reliability	Expected Lifetime	Natural, Proxy	10	30	Years
Maintenance	Hours Between Services	Natural, Proxy	250	2000	Hours
Availability of Technical Assistance	Hours Until Arrival	Natural, Proxy	2	24	Hours
Efficiency	Efficiency Ratio	Natural, Proxy	0	0.6	Ratio
Availability	Daily Portion	Constructed, Direct	Never	Continuous	Kilowatts
Reserve Ability	Reserve Allowance	Constructed, Direct	Not Allowed	Allowed	Go/No-Go
Capacity	MBTU Per Cub Ft	Natural, Proxy	0.5	1.5	MBTU/ Cubic Foot
Flammability	Flammability Rating	Constructed, Direct	0	4	Level
Health	Health Rating	Constructed, Direct	0	4	Level
Reactivity	Reactivity Rating	Constructed, Direct	0	4	Level
Special	Special Rating	Constructed, Direct	Anything Besides Corrosive	None	Category

3.5.3 Measures-Public Education

Public education consists of one measure since this value does not need to be specified any further. A subjective rating will be associated with this value since this is the most practical way of measuring such an impact. This was defined by the park committee's interpretation of how well each alternative would contribute to the overall representation of the NPS standards. A subjective rating scale was chosen because it is easily understandable by the subject matter expert.

3.5.4 Measures-Environmental Impact

Environmental impact contains all the measures needed to comply with certain criteria that are devoted to reducing the ecological impact and preserving the historical qualities of the island. The preservation of historical qualities includes the prevention of any object or action that may be harmful to the prison structure. The cultural and historical value will be measured using a subjective scale by park officials in charge of corresponding areas. This was defined by the park historical officer in recognition of how each alternative can impact the island artifacts. Natural resources will also be measured by a subjective scale by the natural resource official assigned to the island. The emissions value will be determined by taking the marginal percentage of the Bay Area Air Quality Management District (BAAQMD) Limits that is distributed by each alternative. Each alternative will be measured by how closely its expected air emissions approach the limit provided by this regulation. A small margin between the limit and the emission level would receive a low value score. Conversely, a high margin of compliance would receive a high value score. Environmental group is measured by a subjective rating from the environmental group that is tasked to identify such effects. These measures given in Table 7 will be able to adequately determine how much each alternative contributes to the overall additive value score.

Table 7. Measures-Environmental Impact

Values	Measures	Type of Evaluation	Lowest Score	Highest Score	Units
Cultural and Historical	Cult and Hist Rating	Constructed, Direct	0	10	Rating
Natural Resources	Natural Rating	Constructed, Direct	0	10	Rating
Emissions	BAAQMD Limit Margin	Natural, Direct	0	60	%
Environmental Group	Environmental Rating	Constructed, Direct	0	10	Rating

3.6 Step 4-Create Value Functions

The fundamental purpose of single-dimensional value functions is to graphically represent the decision maker's value in relation to a measure score. These functions allow the analyst to assign quantitative value scores for the possible range of each measure under consideration. By retrieving these scores for each alternative, the analyst will be able to distinguish how well they meet individual values established by the decision maker. Value functions can be composed of linear, exponential, categorical, or even custom functions. The shape of each curve was determined by soliciting the decision makers' preference for lower and upper bounds that correspond to value scores of 0 and 1, respectively. Then, the midpoint of the value function was determined by asking the decision makers which measure score would provide a value score of 0.5. The result of this process is a determination of how the single-dimensional value function behaves. Measures and corresponding value functions scored using a subjective rating scale are explained in more detail throughout Appendix A. There were no exponential or custom value functions in this model.

3.6.1 Value Functions-Linear Ascending

Linear ascending functions are those that increase in value score as the measure score increases; these functions demonstrate a positive linear slope. Most of the value functions in the model comprise of subjective ratings from zero to ten. In these cases, a zero measure score is assigned a zero value score. A measure score of ten is captured with a value score of one. This type of single-dimensional value function was applicable to the measure of aesthetics in the model as shown in Figure 14. Functions similar to these for other measures are provided in Appendix A. The red dot in Figure 14 refers to the midpoint of the value function. This value function is assigned in a continuous manner in order to address the possibility of ratings that may lie between whole numbers. Using linear ascending single-dimensional value functions to address certain measures retains simplicity as well as practicality for the scoring of the model.

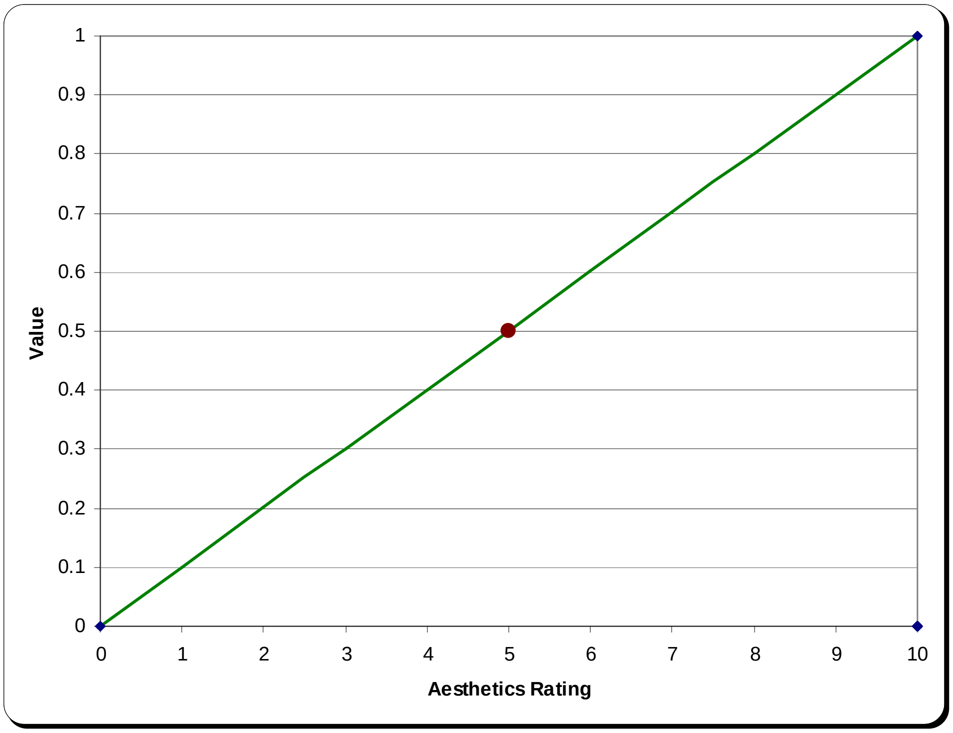

Figure 14. Value Functions-Aesthetics Rating

3.6.2 Value Functions-Linear Descending

Linear descending value functions reflect the negativity of an increasing measure score. As an alternative's measure score increases throughout the range, the value score decreases. Measures with single-dimensional value functions similar to that shown in Figure 15 for peak decibel level demonstrate the increased value assigned to smaller measure scores. Other functions such as these are provided in Appendix A. As the peak decibel level increases from 0 to 90, the correlating value score decreases. This makes sense because an ideal alternative should not transmit a large amount of noise that would impair the efficiency of tourist operations as well as degrade the habitat of the island. A continuous line is used to capture the possibility of decibel levels in between whole numbers as well.

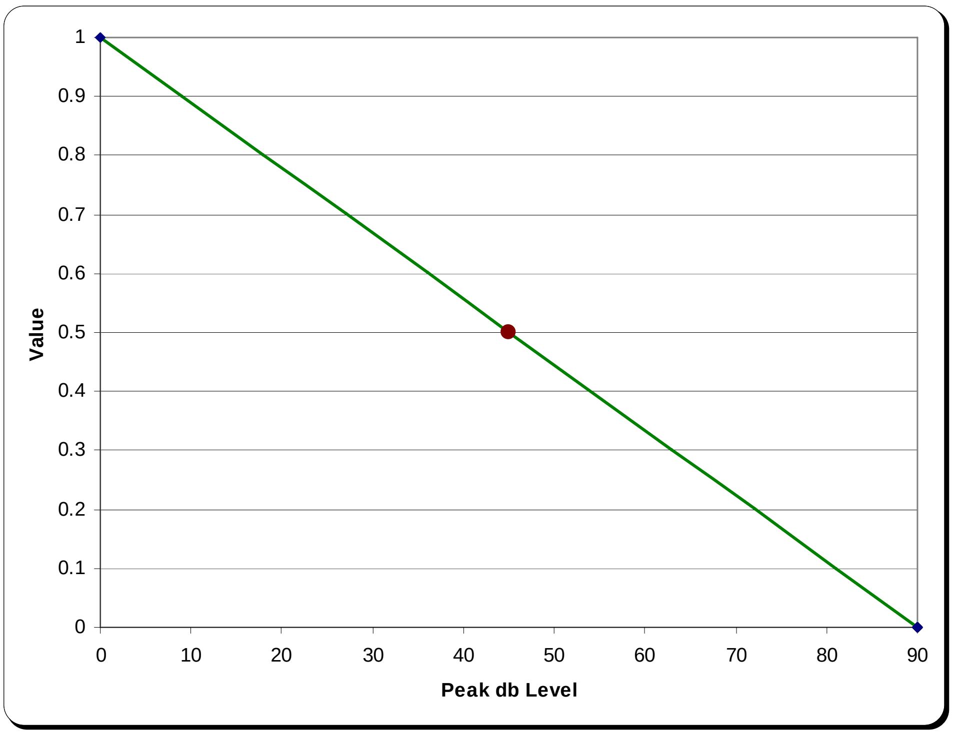

Figure 15. Value Functions-Peak Decibel Level

3.6.3 Value Functions-Categorical

Categorical value functions are useful in assigning value scores to alternatives that only have discrete possibilities. Each alternative can be assigned any value score of zero to one depending on the category that reflects its characteristics. For example, the flammability rating of an energy source used for electrical alternatives in Figure 16 has five discrete ratings. Other measures with value functions similar to this are provided in Appendix A.   Based on the flammability level of the "fire diamond," the necessary energy source for each alternative is assigned its respective value score. Categorical value functions allow the analyst to specifically address measures whose ranges are not continuous for the scoring of each alternative.

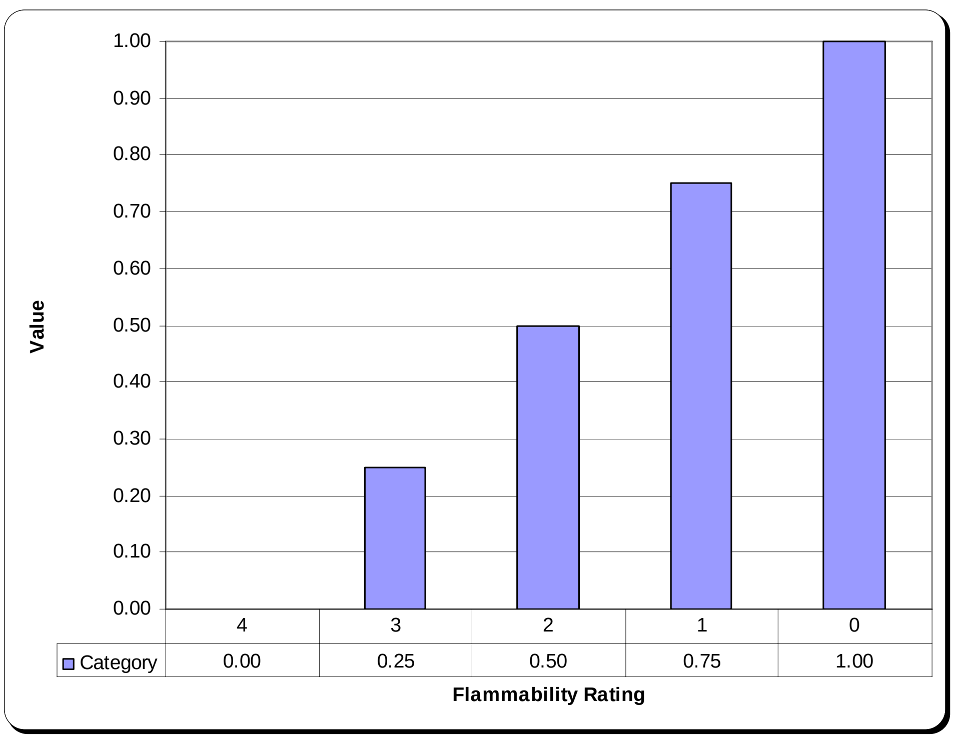

Figure 16. Value Functions-Flammability

3.7 Step 5-Weight the Hierarchy

Weights are implemented in the value hierarchy to represent the decision makers' level of importance associated with each measure. There are two main methods to implementing weights in a value hierarchy using the "marble" method. The use of either method depends on the size, complexity, and effort of the decision problem. Local weighting is used when a value model has many measures separated by many tiers and branches. Each group of values that are in the same tier and stem from the same value immediately above it is analyzed sequentially. A proportion of weights are distributed to values in each local group symbolizing how important that value is to the decision maker. If each value in a group is allocated with the same proportions, then each value infers the same level of importance to the decision maker. Variations from equal proportions symbolize a variance in the level of importance for each value. The global weighting method is usually used for smaller hierarchies because all lowest-tier values are evaluated in relation to one another instead of one group at a time. Theoretically, both methods should produce the same results of overall global weights for each lowest-tier value. This is because the global weights can still be determined from the local method by multiplying the local weight of each value by the local weight of each value above it until the overall objective is reached. Application of either weighting method quantifies the level of importance of each value in order to accurately reflect the views of the decision maker.

The weights applied in this model were determined by using the local weighting method in order to minimize the complexity of dealing with numerous measures. Local weights were assigned to the values of site appropriateness, operation, public education, and environmental impact as seen in Figure 17. Then, the second-tier values of noise, aesthetics, construction resources, area occupied, and compliance burden are allocated with a proportion of the weights as shown in Figure 18. This pattern is repeated until all values are assigned their local weights. Figures 19 and 20 show the local weights assigned to the rest of the hierarchy with lower-tier values. Afterwards, global weights were calculated from assigned local weights in order to compare values with one another.

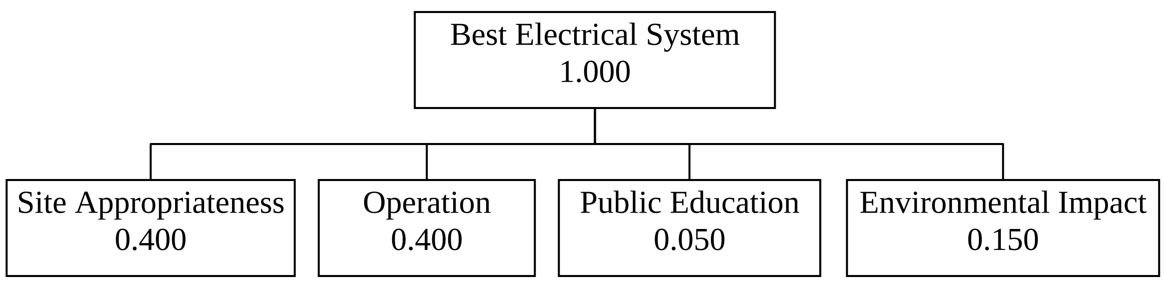

Figure 17. Local Weights-First Tier

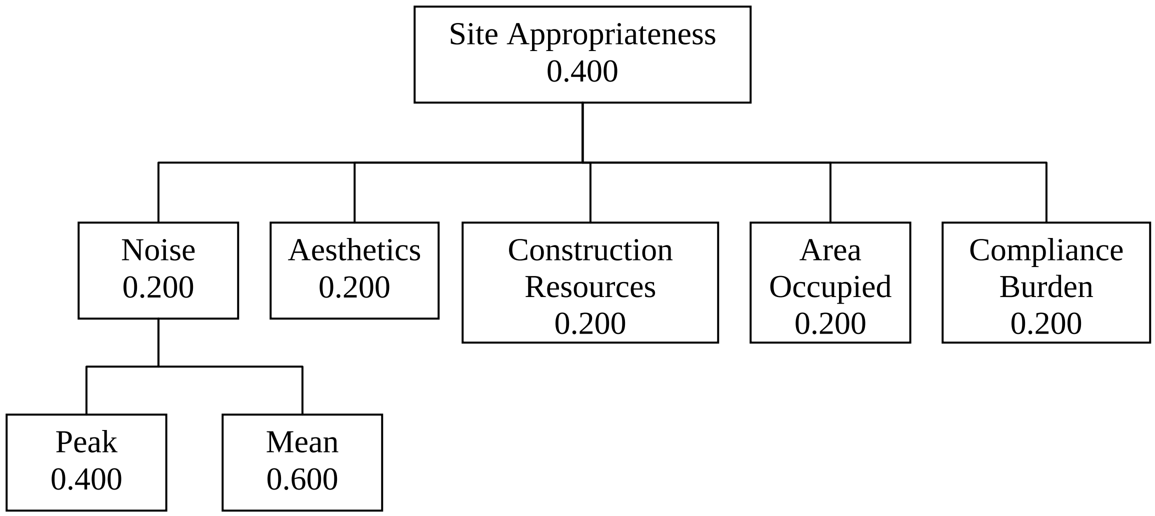

Figure 18. Local Weights-Site Appropriateness

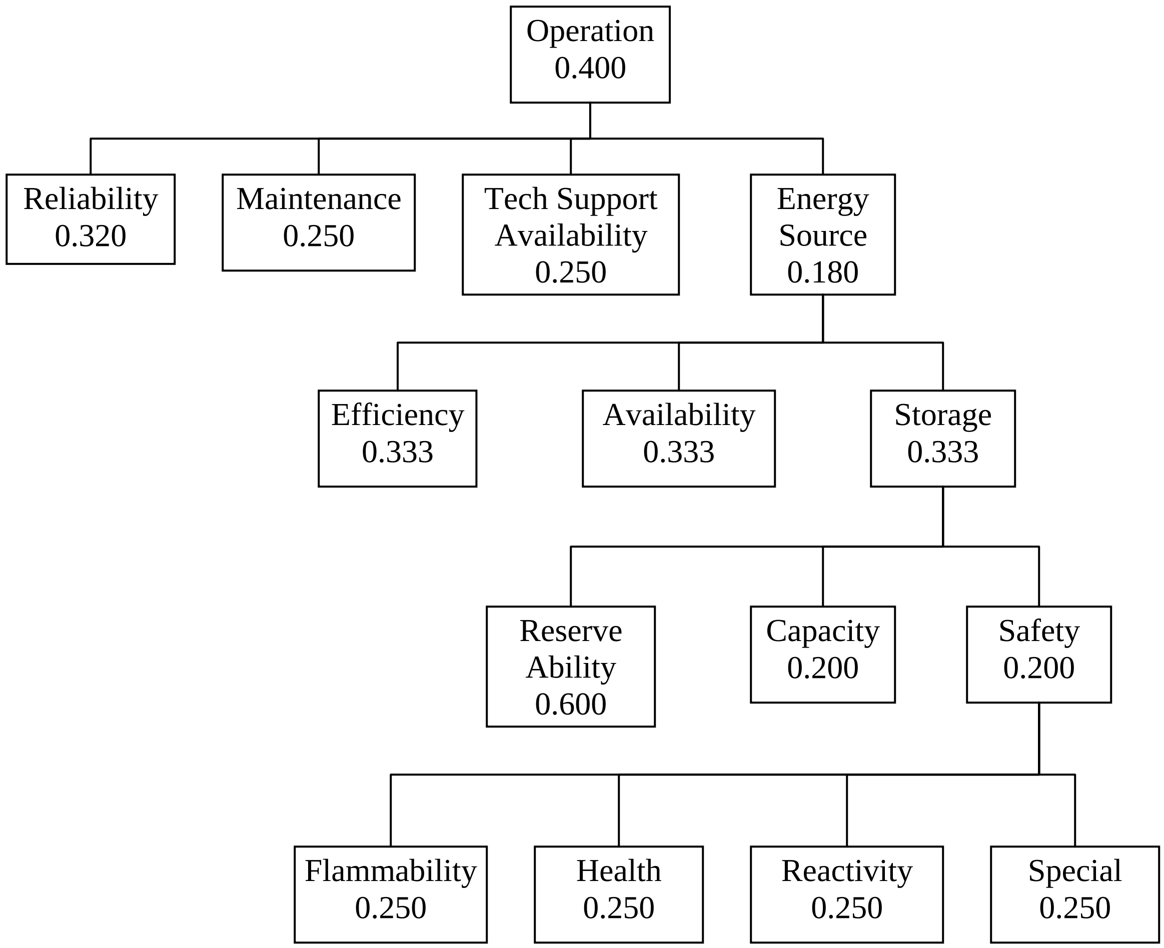

Figure 19. Local Weights-Operation

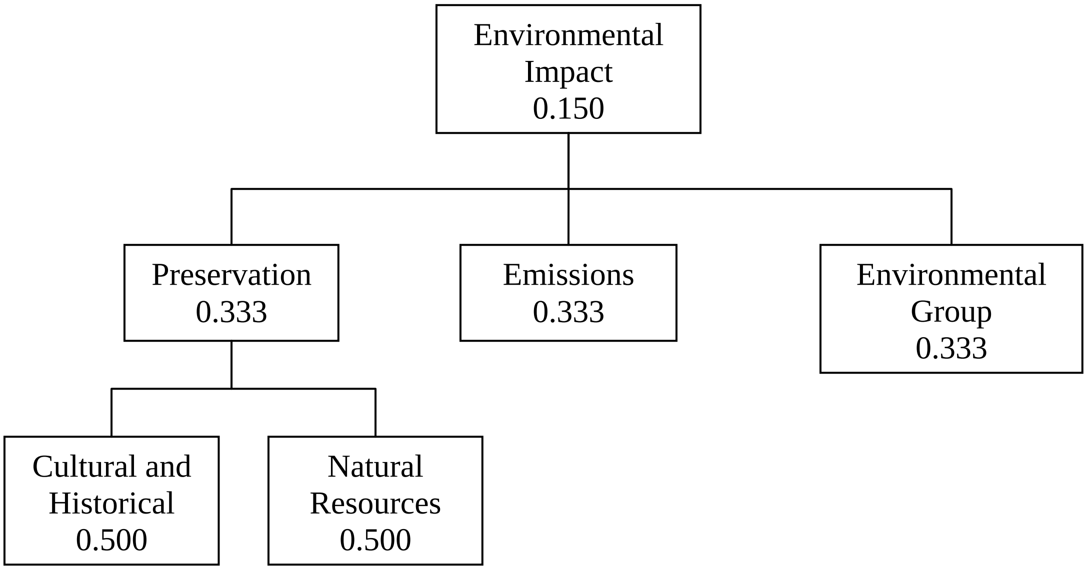

Figure 20. Local Weights-Environmental Impact

Table 8 is a representation of the applied global weights sorted in order of rank of importance. The benefit of rank-ordering the measures by weight is the ability to recognize the most and least important measures of the decision efficiently. Based on the weights applied to each measure, reliability is the most important value in this decision. The least important values are associated with the safety features of flammability, health, reactivity, and special category. The allocation of these weights reflects the amount of consideration that the decision makers have in deciding on the best electrical generation system.

Table 8. Global Weights-Rank

Rank	Measure	Global Weight
1	Reliability	0.128
2	Maintenance	0.100
3	Technical Support Availability	0.100
4	Aesthetics	0.080
5	Construction Resources	0.080
6	Area Occupied	0.080
7	Compliance Burden	0.080
8	Public Education	0.050
9	Emissions	0.050
10	Environmental Group	0.050
11	Mean	0.048
12	Peak	0.032
13	Cultural and Historical	0.025
14	Natural Resources	0.025
15	Efficiency	0.024
16	Availability	0.024
17	Reserve Ability	0.014
18	Capacity	0.005
19	Flammability	0.001
20	Health	0.001
21	Reactivity	0.001
22	Special	0.001
	Total	**1.000**

3.8 Step 6-Generate Alternatives

After the hierarchy is completed, alternatives can be identified for analysis. Decision problems exist which may have numerous alternatives for evaluation even when value-focused thinking is applied. Analyzing all of these alternatives would be difficult and time consuming. Additionally, the decision makers may realize that not all alternatives are even feasible.

In this problem, the decision makers have identified several alternatives that can be scored with value-focused thinking. Screening criteria for this decision context include the availability of an alternative for purchase, the ability to physically fit on the island, and the capacity to provide adequate power to the island. Federal, state, local, and NPS specific regulations must also be followed as well as approval from senior management personnel. After the screening criteria were implemented, attention was given to high-ranked measures. The alternative of establishing an underground cable from a commercial grid system to the island would score well with the values of reliability, maintenance, technical support availability, aesthetics, construction resources, emissions, and environmental group. Renewable energy technologies such as wind turbines and solar panels encompass various alternatives that would score well in the values of reliability, emissions, and noise levels. The decision-makers indicated that a diesel generator would be installed as a secondary source of power for each of these alternatives because this system would not have to rely on renewable sources. This is reasonable since some days may not experience high levels of sunlight or wind. After consideration of these filters, six alternatives were identified for analysis as depicted in Table 9.

Table 9. Alternatives

Alternative	Primary	Secondary
1	Solar Panels	Diesel Generator
2	Wind Turbine	Diesel Generator
3	Submarine Cable	Diesel Generator
4	Diesel Generator	Diesel Generator
5	Solar Panels/Wind Turbine	Diesel Generator
6	2 Wind Turbines	Diesel Generator

The process of selecting these alternatives is considered sensitive to the specific situation. The decision makers have justified these alternatives for analysis because they pass the screening criteria and highlight the importance of many values. All alternatives are meant to provide the primary means for electricity on the island. However, a diesel generator will be used as a backup source of electricity during times of contingency operations. Secondary diesel generators will not be included in scoring values since they are only used during infrequent times.

Many of these alternatives identified for analysis encompass unique characteristics and methods of supplying power. For solar panels, the roof of the main prison system is an adequate area for installation. The solar radiation provided by the sun in that area can then be converted to electricity for the island. A wind turbine could also be mounted near the highest elevation on the island in order to experience more wind speed. The power produced by rotating blades is proportional to the wind speed experienced (A. Walker, personal communication, January 15, 2007). A submarine cable can be used to connect the island to a commercial utility grid on the mainland. The cable would be installed under water and is estimated to require 2 miles of length for connectivity. The status quo in this problem is replacing the existing diesel generators with new ones. The characteristics of the replacement generators are similar to the current system. The fifth alternative involves installing the same wind turbine as alternative 2. However, solar panels with lower power ratings will operate in conjunction with it. The last alternative includes analyzing the installment of two wind turbines to understand the effects of multiple systems to the model. Each of these alternatives provides a multitude of positive and negative distinctions for producing electricity.

Chapter 4. Results

4.1 Introduction

The final portions of the 10-step Value-Focused Thinking (VFT) process include scoring alternatives, deterministic analysis, and sensitivity analysis. Each of the alternatives identified in Chapter 3 were evaluated based on the measure scores affiliated with each value. For each alternative, only the primary supply system was analyzed; the supplemental generator included in all alternatives was ignored. Using the additive value function, final value scores can be calculated and a solution is determined. The result of this score produces a solution to the decision problem that is closest to the overall value of the decision makers. Cost implications can be addressed by instituting a cost-value ratio for each alternative. However, quantitative calculations were not performed for this ratio because there are various methods and considerations for computing cost for each alternative. Finally, uncertainty with weighting schemes can be addressed using sensitivity analysis. In sensitivity analysis, the global weights of any value can be altered individually to identify vulnerabilities with a preliminary solution. This section of the VFT process contains the calculations involved with discovering a preliminary answer for supplying power to Alcatraz Island.

4.2 Step 7-Score Alternatives

Each of the six alternatives under consideration was scored based on information gathered from subject matter experts and manufacturers. The National Park Service (NPS) contracts projects with manufacturers and distributors for electrical work in their jurisdiction. In order to get accurate scores for each alternative, contact was established with these commercial industries. Scores for values dealing with rating dimensions were obtained within the NPS since these personnel represent the ultimate authority for using such objectives in the model. The following paragraphs provide further details into the scoring system.

4.2.1 Alternative 1 (Solar Panels)

Solar panels incorporate some of the characteristics represented in the value hierarchy. The ideal setting for this alternative is on the roof of the main prison block because it is the highest point on the island and devoid of obstruction. The main prison roof provides approximately 5000 square meters for solar panel installation. The maintenance for these panels would include cleaning them of avian excrement, dirt, and salt water on a monthly basis. The expected lifetime, hours between services, hours until arrival, and efficiency ratio was provided by the manufacturer. Table 10 depicts the scoring of solar panels on Alcatraz Island for this model.

Table 10. Scoring Alternatives-Solar Panels

Values	Measures	Solar Panels	Dimensions
Peak Noise	Peak db Level	0	Decibels
Mean Noise	Mean db Level	0	Decibels
Aesthetics	Aesthetics Rating	3	Rating
Construction Resources	Construction Rating	10	Rating
Area Occupied	Area Fit	Fits	Go/No-Go
Compliance Burden	Compliance Rating	2	Rating
Reliability	Expected Lifetime	25	Years
Maintenance	Hours Between Services	720	Hours
Tech Support Availability	Hours Until Arrival	2	Hours
Efficiency	Efficiency Ratio	0.2	Ratio
Availability	Daily Portion	Half	Category
Reserve Ability	Reserve Allowance	Not Allowed	Go/No-Go
Capacity	MBTU Per Cub Ft	0	MBTU/Cubic Foot
Flammability	Flammability Rating	0	Level
Health	Health Rating	0	Level
Reactivity	Reactivity Rating	0	Level
Special	Special Rating	None	Category
Public Education	Education Rating	10	Rating
Cultural and Historical	Cult and Hist Rating	3	Rating
Natural Resources	Natural Resources Rating	9	Rating
Emissions	BAAQMD Limit Margin	100	% Margin
Environmental Group	Environmental Rating	10	Rating

4.2.2 Alternative 2 (Wind Turbine)

Wind turbines have characteristics similar to solar panels. The main differences between the two involve the noise levels generated, maintenance intervals, and technical support availability. A diesel generator will have to be used to supplement this alternative with power in times of low wind velocities. This is in addition to the other supplemental diesel generator that will only be used in times of contingency. As stated previously though, only the characteristics of the primary supply system, the wind turbine, will be analyzed for this alternative. Wind turbines are highly visible due to the sheer heights of the nacelles and large sweeping areas of the turbine blades. This characteristic results in low scores for aesthetics, cultural and historical preservation, and environmental group ratings. The noise levels, expected lifetime, hours between services, hours until arrival, and efficiency ratio value scores were provided by the manufacturer. Table 11 shows the scores obtained for the wind turbine alternative.

Table 11. Scoring Alternatives-Wind Turbine

Values	Measures	Wind Turbine	Dimensions
Peak Noise	Peak db Level	98	Decibels
Mean Noise	Mean db Level	75	Decibels
Aesthetics	Aesthetics Rating	0	Rating
Construction Resources	Construction Rating	9	Rating
Area Occupied	Area Fit	Fits	Go/No-Go
Compliance Burden	Compliance Rating	10	Rating
Reliability	Expected Lifetime	22.5	Years
Maintenance	Hours Between Services	30,240	Hours
Tech Support Availability	Hours Until Arrival	24	Hours
Efficiency	Efficiency Ratio	0.25	Ratio
Availability	Daily Portion	>Half	Category
Reserve Ability	Reserve Allowance	Not Allowed	Go/No-Go
Capacity	MBTU Per Cub Ft	0	MBTU/Cubic Foot
Flammability	Flammability Rating	0	Level
Health	Health Rating	0	Level
Reactivity	Reactivity Rating	0	Level
Special	Special Rating	None	Category
Public Education	Education Rating	10	Rating
Cultural and Historical	Cult and Hist Rating	1	Rating
Natural Resources	Natural Resources Rating	3	Rating
Emissions	BAAQMD Limit Margin	100	% Margin
Environmental Group	Environmental Rating	3.5	Rating

4.2.3 Alternative 3 (Submarine Cable)

Connecting an underwater cable from an electrical generation substation near San Francisco to Alcatraz presents unique characteristics. The manufacturer of these cables had indicated that reliability for these is very high. Routine maintenance is not expected to occur with this alternative until replacement is warranted. The only cause for repairs on the cable would be due to random mishaps from ship anchors. The efficiency of a submarine cable is limited to the steam generation plant from the distribution source. Line loss will not be significant in this case because the distance of the cable would only be 2 miles at the most. Technical support is only dependent on routine transportation ferry schedules since the manufacturer resides in the bay area. Since emissions are directed to another source, there is no effect to immediate surroundings. The decision makers emphasized that the focus of this alternative's characteristics be directed towards the island itself and not the distribution source. This will inherently provide the submarine cable alternative with better results. Preservation levels and compliance burden also reflect high marks since effects to natural surroundings are mitigated. Table 12 depicts all the value scores for the submarine cable.

Table 12. Scoring Alternatives-Submarine Cable

Values	Measures	Sub Cable	Dimensions
Peak Noise	Peak db Level	0	Decibels
Mean Noise	Mean db Level	0	Decibels
Aesthetics	Aesthetics Rating	10	Rating
Construction Resources	Construction Rating	10	Rating
Area Occupied	Area Fit	Fits	Go/No-Go
Compliance Burden	Compliance Rating	10	Rating
Reliability	Expected Lifetime	50	Years
Maintenance	Hours Between Services	438,000	Hours
Tech Support Availability	Hours Until Arrival	2	Hours
Efficiency	Efficiency Ratio	0.55	Ratio
Availability	Daily Portion	Continuous	Category
Reserve Ability	Reserve Allowance	Not Allowed	Go/No-Go
Capacity	MBTU Per Cub Ft	0	MBTU/Cubic Foot
Flammability	Flammability Rating	0	Level
Health	Health Rating	0	Level
Reactivity	Reactivity Rating	0	Level
Special	Special Rating	None	Category
Public Education	Education Rating	0	Rating
Cultural and Historical	Cult and Hist Rating	10	Rating
Natural Resources	Natural Resources Rating	10	Rating
Emissions	BAAQMD Limit Margin	100	% Margin
Environmental Group	Environmental Rating	9.5	Rating

4.2.4 Alternative 4 (Diesel Generator)

The status quo of replacing the current diesel generator with another one of the same model was also evaluated. The advantages of keeping the same electrical source include the ability to store the primary energy source on the island as well as reliability standards. The manufacturer of these generators had indicated that these systems can last up to 50 years when routine maintenance is upheld. However, routine maintenance on this alternative consists of frequent oil changes once a week. Technical support and efficiency scores also rated very well for this system. The capacity for the diesel generators is calculated by determining the amount of energy in a cubic foot of diesel fuel. This calculation is provided in Appendix B. Noise levels, expected lifetime, hours between services, hours until arrival, efficiency ratio, and daily portion scores are determined by manufacturer specifications. This alternative also contains the only nonzero score on the safety tier with a flammability rating of 2, due to the characteristics of diesel fuel. Table 13 reflects the value scores of a diesel generator.

Table 13. Scoring Alternatives-Diesel Generator

Values	Measures	Diesel Gen	Dimensions
Peak Noise	Peak db Level	87	Decibels
Mean Noise	Mean db Level	84	Decibels
Aesthetics	Aesthetics Rating	5	Rating
Construction Resources	Construction Rating	10	Rating
Area Occupied	Area Fit	Fits	Go/No-Go
Compliance Burden	Compliance Rating	5	Rating
Reliability	Expected Lifetime	50	Years
Maintenance	Hours Between Services	250	Hours
Tech Support Availability	Hours Until Arrival	2	Hours
Efficiency	Efficiency Ratio	0.32	Ratio
Availability	Daily Portion	Continuous	Category
Reserve Ability	Reserve Allowance	Allowed	Go/No-Go
Capacity	MBTU Per Cub Ft	0.978	MBTU/Cubic Foot
Flammability	Flammability Rating	2	Level
Health	Health Rating	0	Level
Reactivity	Reactivity Rating	0	Level
Special	Special Rating	None	Category
Public Education	Education Rating	0	Rating
Cultural and Historical	Cult and Hist Rating	10	Rating
Natural Resources	Natural Resources Rating	5.5	Rating
Emissions	BAAQMD Limit Margin	94	% Margin
Environmental Group	Environmental Rating	5	Rating

4.2.5 Alternative 5 (Solar Panels/Wind Turbine)

Combining the alternatives of solar panels with a wind turbine can present some unique characteristics. The sum of power produced on average with this alternative would be enough to continuously sustain Alcatraz Island. Calculations are provided in Appendix B. This sufficiency will allow NPS to be independent from yearly fueling costs as well. However, there are detriments to this combination. Noise levels, aesthetics, preservation, maintenance, and environmental group scores will be anchored by the lowest score of the two. The final value score for this alternative will most likely be negatively affected as well. The construction rating and efficiency ratio was obtained by averaging the corresponding scores of both alternatives because the amount of resources used for installing both systems will still be favorable for the solar panels. The efficiency ratio was also averaged because the amount of power provided by each system is equal. Therefore, the efficiency ratio should depict the alternative as a whole. This is demonstrated in Appendix B. Table 14 depicts the value scores for installing solar panels along with a wind turbine on Alcatraz Island.

Table 14. Scoring Alternatives-Solar Panels/Wind Turbine

Values	Measures	Solar/Wind	Dimensions
Peak Noise	Peak db Level	98	Decibels
Mean Noise	Mean db Level	75	Decibels
Aesthetics	Aesthetics Rating	0	Rating
Construction Resources	Construction Rating	9.5	Rating
Area Occupied	Area Fit	Fits	Go/No-Go
Compliance Burden	Compliance Rating	2	Rating
Reliability	Expected Lifetime	22.5	Years
Maintenance	Hours Between Services	720	Hours
Tech Support Availability	Hours Until Arrival	24	Hours
Efficiency	Efficiency Ratio	0.225	Ratio
Availability	Daily Portion	>Half	Category
Reserve Ability	Reserve Allowance	Not Allowed	Go/No-Go
Capacity	MBTU Per Cub Ft	0	MBTU/Cubic Foot
Flammability	Flammability Rating	0	Level
Health	Health Rating	0	Level
Reactivity	Reactivity Rating	0	Level
Special	Special Rating	None	Category
Public Education	Education Rating	10	Rating
Cultural and Historical	Cult and Hist Rating	1	Rating
Natural Resources	Natural Resources Rating	3	Rating
Emissions	BAAQMD Limit Margin	100	% Margin
Environmental Group	Environmental Rating	3.5	Rating

4.2.6 Alternative 6 (2 Wind Turbines)

The final alternative involved the installation of two wind turbines on Alcatraz Island. This alternative was formed from the basis of each wind turbine only being able to produce half the necessary power demand. With this alternative, a supplementary diesel fuel generator will not be required, and cost flows will be minimized. However, certain disadvantages were escalated by this alternative. Construction burden and preservation experienced large declines in value scores. This is because the 30 meter wind sweep diameter of each turbine produces a large detraction from the island presence. Additionally, the threat to avian organisms is significantly magnified. Table 15 contains the value scores for this alternative as well.

Table 15. Scoring Alternatives-2 Wind Turbines

Values	**Measures**	**2 Wind Turbines**	**Dimensions**
Peak Noise	Peak db Level	98	Decibels
Mean Noise	Mean db Level	75	Decibels
Aesthetics	Aesthetics Rating	0	Rating
Construction Resources	Construction Rating	8	Rating
Area Occupied	Area Fit	Fits	Go/No-Go
Compliance Burden	Compliance Rating	5	Rating
Reliability	Expected Lifetime	22.5	Years
Maintenance	Hours Between Services	30,240	Hours
Tech Support Availability	Hours Until Arrival	24	Hours
Efficiency	Efficiency Ratio	0.25	Ratio
Availability	Daily Portion	>Half	Category
Reserve Ability	Reserve Allowance	Not Allowed	Go/No-Go
Capacity	MBTU Per Cub Ft	0	MBTU/Cubic Foot
Flammability	Flammability Rating	0	Level
Health	Health Rating	0	Level
Reactivity	Reactivity Rating	0	Level
Special	Special Rating	None	Category
Public Education	Education Rating	10	Rating
Cultural and Historical	Cult and Hist Rating	0	Rating
Natural Resources	Natural Resources Rating	0	Rating
Emissions	BAAQMD Limit Margin	100	% Margin
Environmental Group	Environmental Rating	0	Rating

4.3 Step 8-Deterministic Analysis

Final score values and decisions were assessed using the additive value function. Preliminary scores taken from each alternative were aligned and multiplied with predetermined weights to calculate the final value scores. Figure 21 depicts the final score values for each alternative along with visual representations of each criteria score contribution. Plots of first-tier value scores are provided in Appendix C. Based on the final value score and figure, installing a submarine cable is the preliminary solution for powering Alcatraz. The largest contributions to the submarine cable's final score come from the reliability, noise levels, compliance rating, and maintenance characteristics; this alternative scored the maximum value for these measures. These advantages overwhelmed the drawbacks of public education and reserve ability for this alternative. The diesel generator alternative score suffered dramatically from routine maintenance issues. The advantages of installing solar panels with a wind turbine included very low noise levels, high aesthetics ratings, and maximum technical support availability scores. However, the negative impacts of certain values in this alternative contributed to a lower final value score. The final score value of 0.926 for the submarine cable alternative demonstrates that this system contained 92.6% of the total possible value for the decision makers. Therefore, a high degree of certainty for value satisfaction can be gained by choosing this alternative.

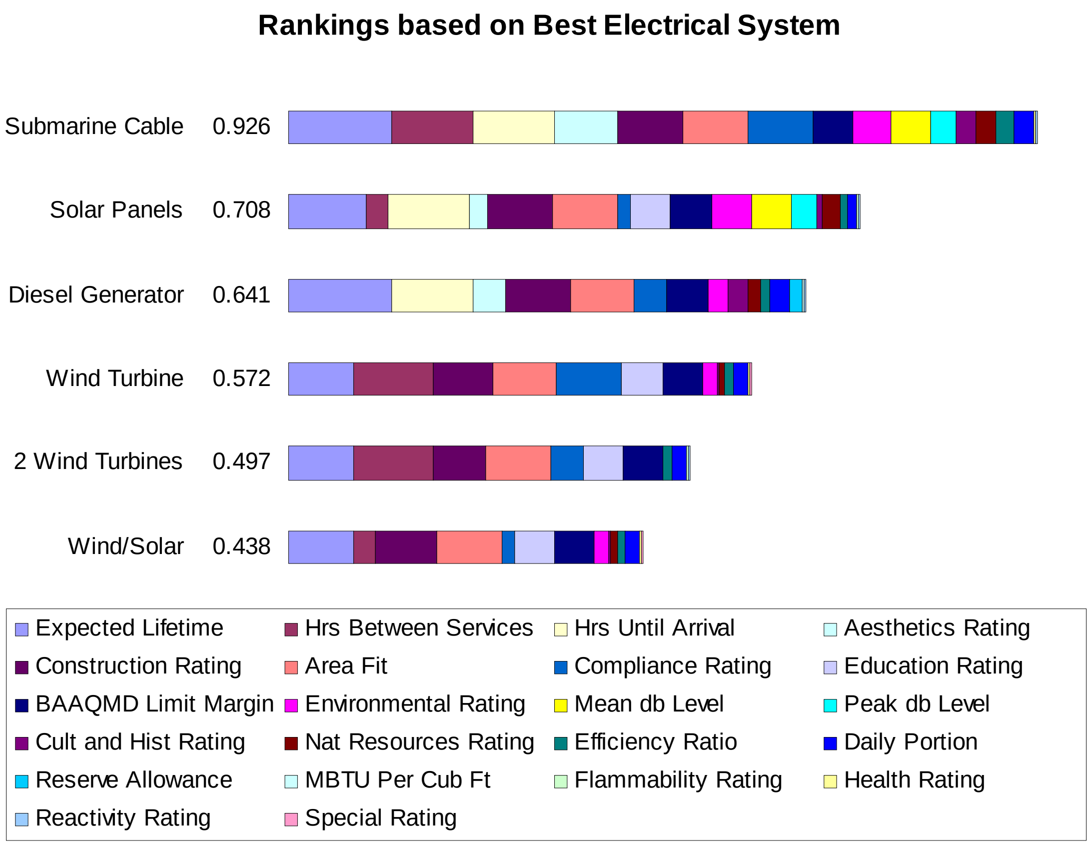

Figure 21. Deterministic Analysis

In order to adequately address the reality of the situation, cost should also be considered. A cost criterion was not implemented into the model to avert potential independence issues. Theoretically, any drawbacks to each alternative can be averted by an increase in cost flows to that alternative. The effect of financial considerations to so many values demonstrates dependence on cost. This issue can be nullified by applying cost outside of the decision model. A simple calculation can reflect a more realistic outcome by using cost as a common baseline when the model provides final value scores. The formula for calculating a cost-value ratio is shown as:

$$\textit{Cost-Value Ratio}(x) = \textit{Final Value Score}(x)/\textit{Cost}(x) \tag{2}$$

where *Cost-Value Ratio(x)* is the score given to alternative *x* based on the additive value function and *Cost(x)* is the cost of alternative *x*. Actual cost data were not generated because various types of cost considerations are beyond the scope of this research. However, it is necessary to understand the implications of applying common cost estimations to the final value score. A cost-value ratio calculation can easily challenge the notion that the best solution for powering Alcatraz is connecting a submarine cable to the mainland power supply.

4.4 Step 9-Sensitivity Analysis

Sensitivity analysis allows the analyst to consider various combinations of the weighting scheme in the decision process. The fundamental purpose of this analysis is to determine the possibility of changes in the alternative ranking. Each sensitivity plot indicates how every alternative behaves with respect to varying global weights for that value. The rank order of different weighting scenarios can be evaluated by these graphs.

Sensitivity analysis can be performed on the first-tier values in order to gain a fundamental understanding of the overall sensitivity of the model. Decisions such as these can be susceptible to variations in weighting criteria. Sensitivity analysis affords the decision maker an opportunity to understand this effect before implementing it in the situation.

4.4.1 Site Appropriateness

Site appropriateness consists of 40% of the global weight for the model. The weights associated with the sub-values of site appropriateness are evenly distributed between noise, aesthetics, construction resources, area occupied, and compliance burden. Therefore, all sub-values have a potential impact on the sensitivity of site appropriateness. Figure 22 demonstrates the dominant nature of the submarine cable compared to the other alternatives. This indicates that varying the weight of site appropriateness will not have any impact on the preliminary solution. The lack of any crossing lines signifies that the entire rank order of all five alternatives is insensitive to variations in the site appropriateness weight. Sensitivity analysis of bottom-tier values under site appropriateness did not display any change in the preliminary choice from varying weighting schemes. Noise levels, aesthetics, construction resources, area occupied, and compliance burden values further support the preliminary solution of installing a submarine cable.

The final value score of the submarine cable increases as the global weight for site appropriateness increases. This behavior is apparent because the submarine cable received higher value scores for site appropriateness then in other areas. In fact, the submarine cable received the highest value scores for each value in this portion of the hierarchy. This explains the final value score of 1 for this alternative if the global weight is increased to 1. This analysis can also be applied to the other alternatives as well. The value score received for each alternative in this portion of the hierarchy is reflected in Figure 22 by referring to the point where the global weight is 1. A decreasing final value score function correlates to that alternative scoring better in other portions of the model. The degree of difference in value scores received by site appropriateness is reflected in the slope of each line.

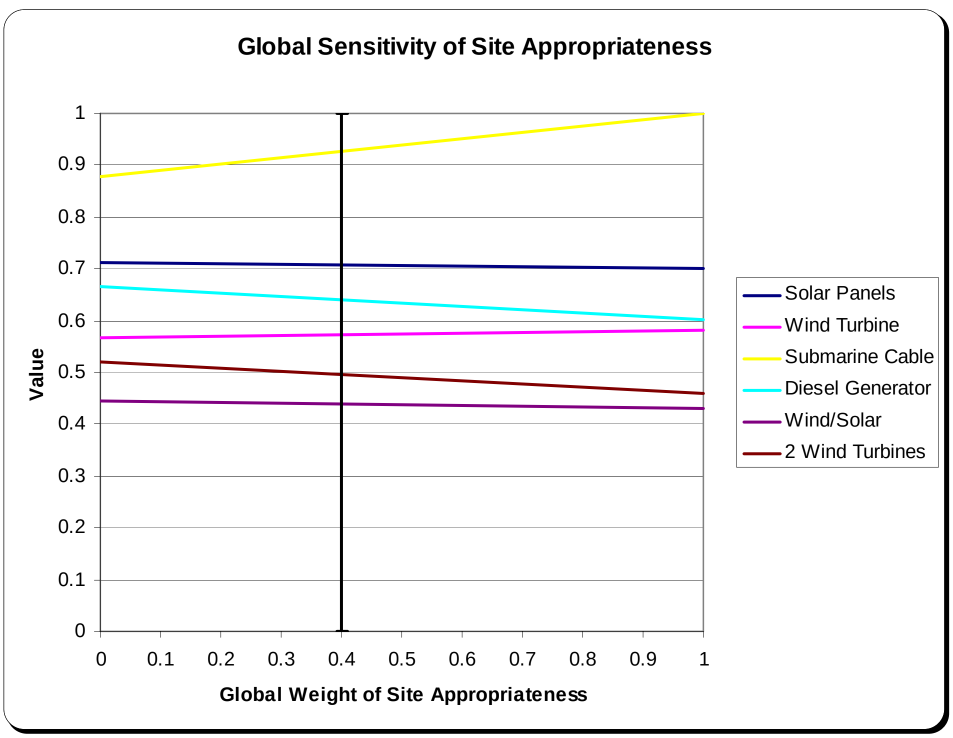

Figure 22. Sensitivity Analysis-Site Appropriateness

4.4.2 Operation

The global sensitivity of operation also indicates that the submarine cable option is dominant to all other alternatives throughout the range of possible weights. The final value score for submarine cable, diesel generator, and 2 wind turbines increases as the operation weight increases. This is because these alternatives scored higher for the operation portion of the hierarchy. The rate of increase for the diesel generator alternative is greater than the rate of increase for any other alternative. This behavior is due to the diesel generator alternative receiving a much higher value score difference for operation than in other parts of the model. However, the best rank that the diesel generator can receive is second if the weight of operation is approximately 0.7 or more. The other alternatives decrease in final value scores as global weight is increased because they received higher scores in other portions of the model. An increase in global weight to this first-tier value will cause the final value scores for these alternatives to drop. The lack of possibility for the submarine cable to become dominated in Figure 23 indicates that operation is highly insensitive for the highest scoring alternative.

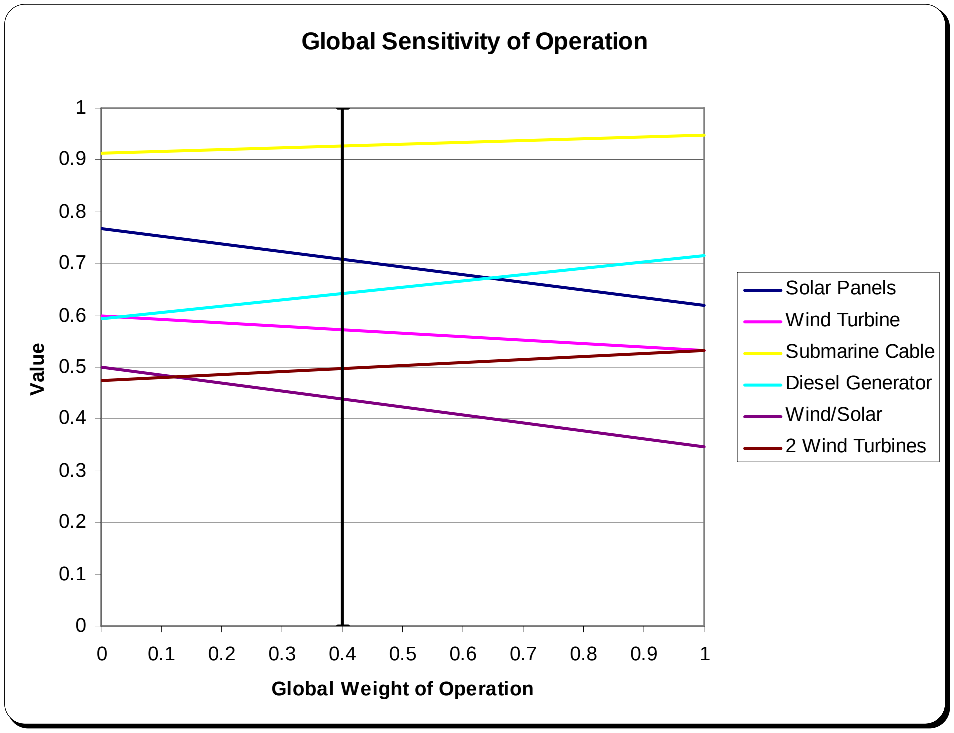

Figure 23. Sensitivity Analysis-Operation

Some values in this portion of the hierarchy also exhibited a level of sensitivity in final value scores. Reserve ability provided change in the best alternative within its global weight range. The current global weight for reserve ability is 0.0144. If this weight was increased to approximately 0.2 as shown in Figure 24, the viable solution would be replaced by the installation of solar panels on the island. However, a 14-fold increase in the weight assigned to reserve ability is considered unlikely; therefore, the measure is considered strongly insensitive. This remains evident for higher reserve ability global weights as well. The diesel generator was the only alternative to be given a value score of 1 for this measure because this system's energy source was the only one that is allowed to be kept on the island. This explains the nature of convergence to a final value score of 1 as the global weight reaches 1. The bottom-tier values of reliability, maintenance, technical support availability, efficiency, availability, flammability, health, reactivity, and special were completely insensitive to weight changes.

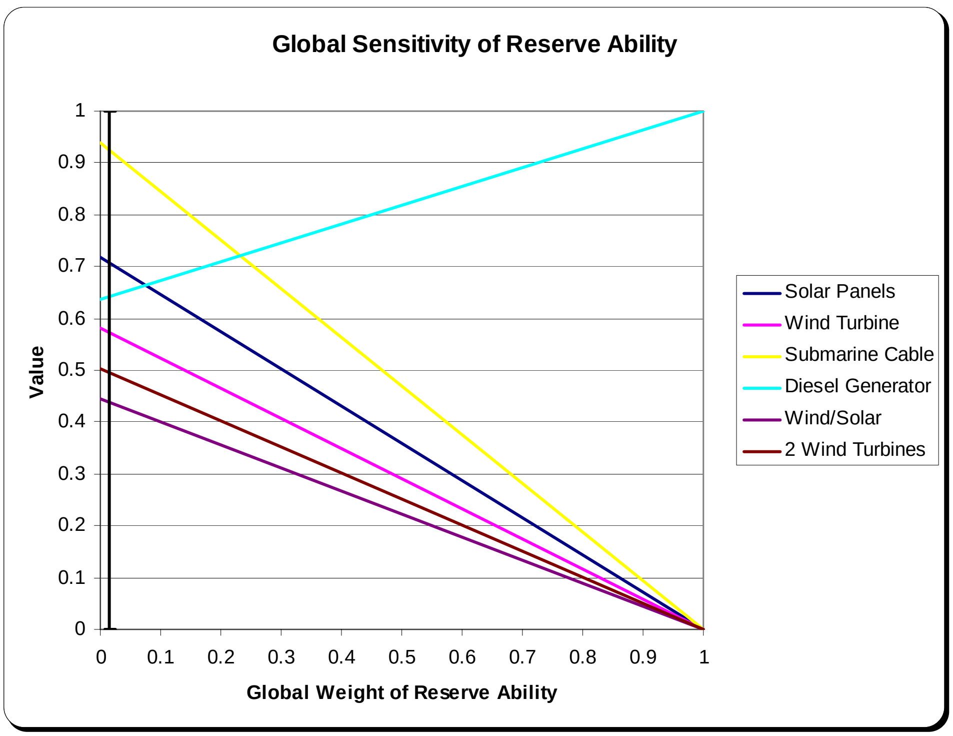

Figure 24. Sensitivity Analysis-Reserve Ability

The sensitivity graph of capacity shown in Figure 25 indicates that the submarine cable would be dominated by the diesel generator alternative if the global weight was increased to approximately 0.35 or more. This behavior is due to the diesel generator alternative receiving the only value score from this measure. This also explains why every alternative's final value score goes to 0 as the global weight for capacity is increased.

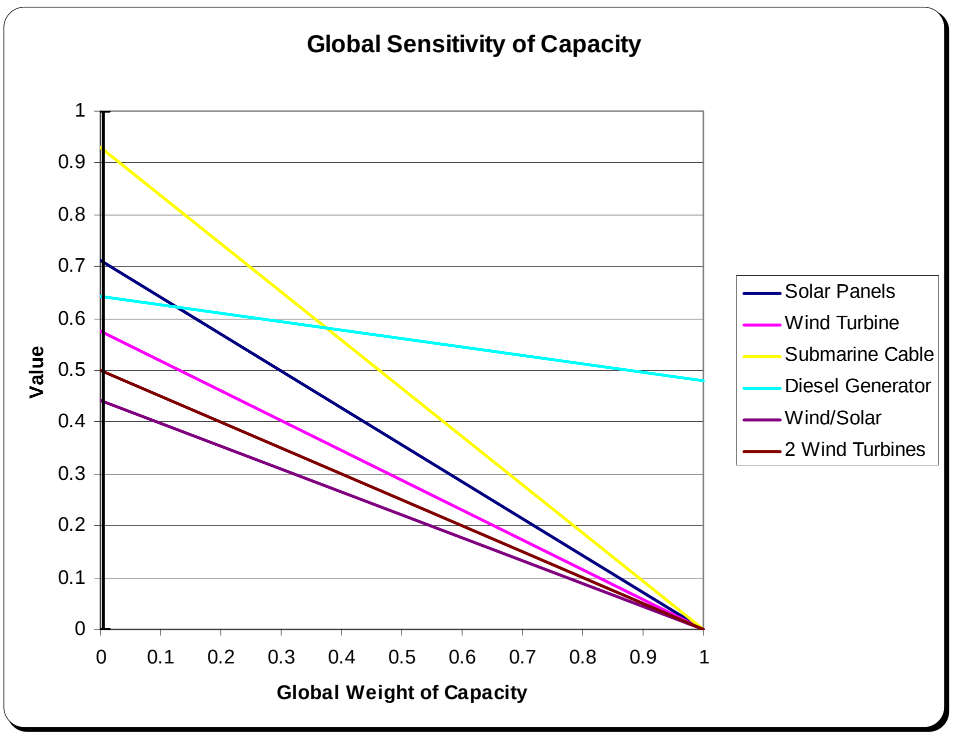

Figure 25. Sensitivity Analysis-Capacity

4.4.3 Public Education

Public Education is the only first-tier value to produce a minimal degree of sensitivity for the model. Sensitivity analysis for this value in Figure 26 demonstrates that the final value score for the submarine cable will remain dominant unless the weight on public education grows beyond approximately 0.2. Further increase in the public education weight will result in solar panels becoming the most favorable alternative. The decision makers would have to increase the public education weight by 300% of its current weight in order for this result to be sensitive. This is not considered very likely; thus, the measure is considered moderately insensitive. Incidentally, the best alternative becomes tied for the worst alternative if the decision makers assigned full weight to public education. Each of the alternatives either go to 0 or 1 depending on what they scored for this measure. Measure scores of either 10 or 0 were distributed to all alternatives. Therefore, each alternative's final value score converges to its respective final value score as the global weight reaches 1. Since the margin for the public education weight needs to be large to have any effect, the option of installing the submarine cable on Alcatraz based on this value would be considered insensitive.

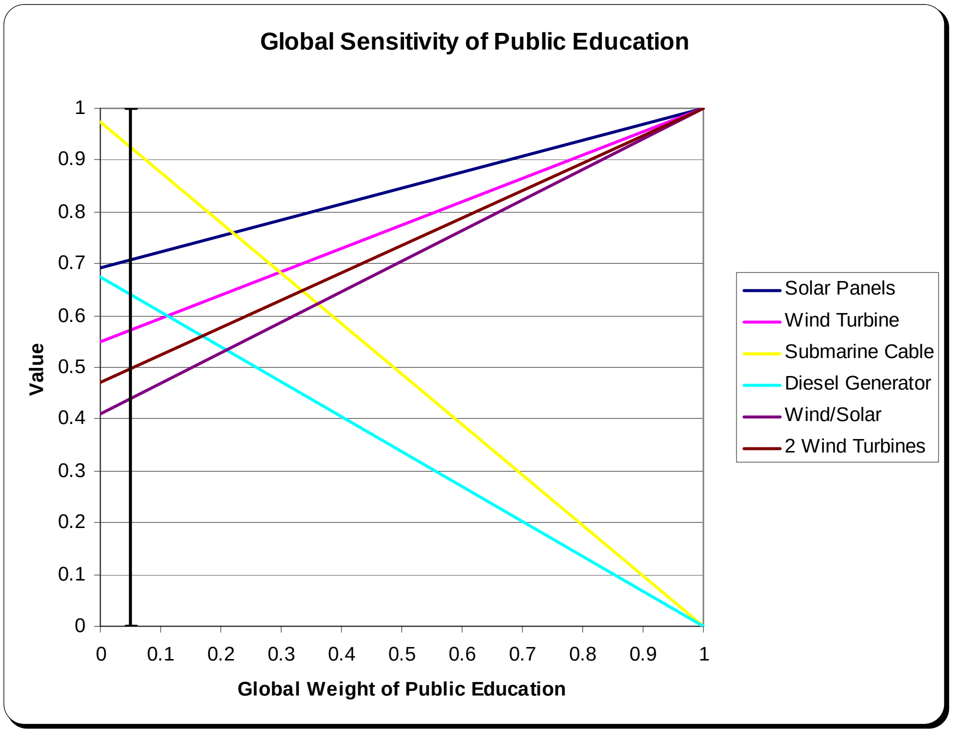

Figure 26. Sensitivity Analysis-Public Education

4.4.4 Environmental Impact

The results of sensitivity analysis for environmental impact show that this value is highly insensitive to changes in weights for the highest ranking alternative. The submarine cable option is dominant throughout the range of environmental impact weight assignment and actually increases in the final value score as the global weight is increased. This behavior is due to the submarine cable receiving higher value scores in this portion of the model. Solar panels, wind/solar, and diesel generator also experience increases for the same reason. The other alternatives have decreasing slopes because they scored better in other portions. The bottom three alternative ranks vary among themselves as the weight is increased. However, 2 wind turbines, wind, and solar/wind remain in the bottom part of the final value scores throughout the weight range. The placement of solar panels as second in the ranking is also insensitive to changes in environmental impact weighing. This behavior can be observed in Figure 27.

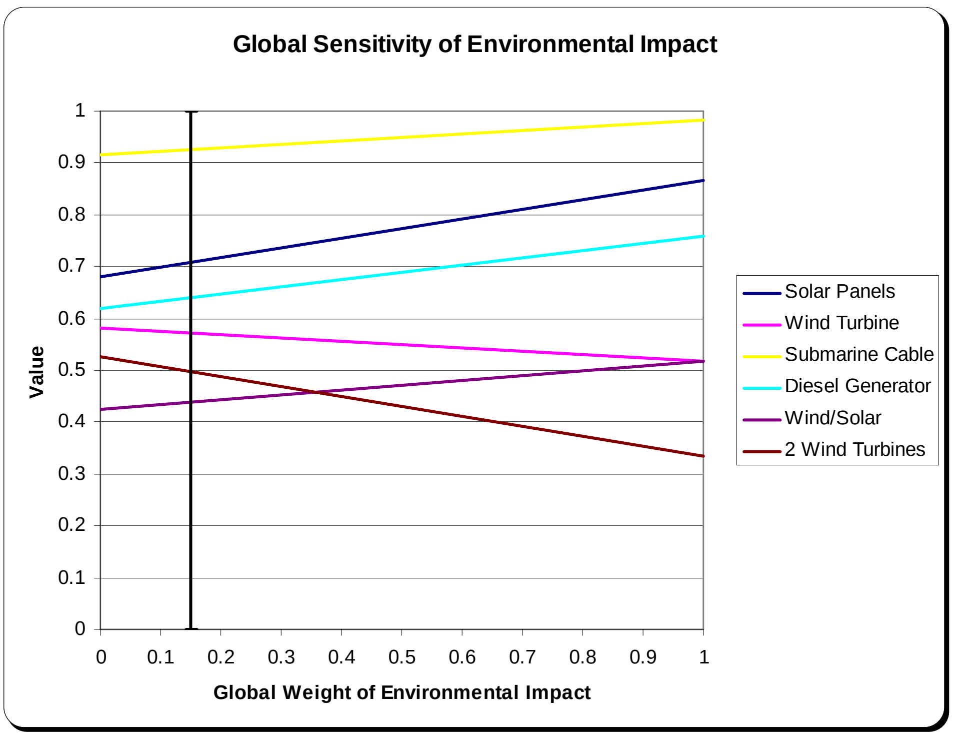

Figure 27. Sensitivity Analysis-Environmental Impact

The environmental group value is the only sub-value that produced any level of sensitivity for the environmental impact tier. The sensitivity graph for environmental group in Figure 28 shows that the viable solution would change to solar panels if the global weight was increased to approximately 0.8. Since the current global weight for environmental group is at 0.05, the probability of this occurring is very low. Therefore, even this sub-value is considered strongly insensitive. The submarine cable increases only slightly as the global weight is increased because the value score received from this measure was similar to the sum of all value scores received in other areas. Therefore, an increase in global weight for environmental group does not affect the final value score as much. The solar panel function increases dramatically because the value score for environmental group was much more than the value scores received from other measures. Similar analysis can be performed for the other alternatives. The direction and slope of each function indicate the value score and the degree of difference in value scores for all other measures compared to environmental group, respectively. The 2 wind turbines alternative goes to 0 because it received the lowest value score possible for this measure. Cultural and historical, natural resources, and emissions sub-values did not provide any level of sensitivity for the environmental impact tier.

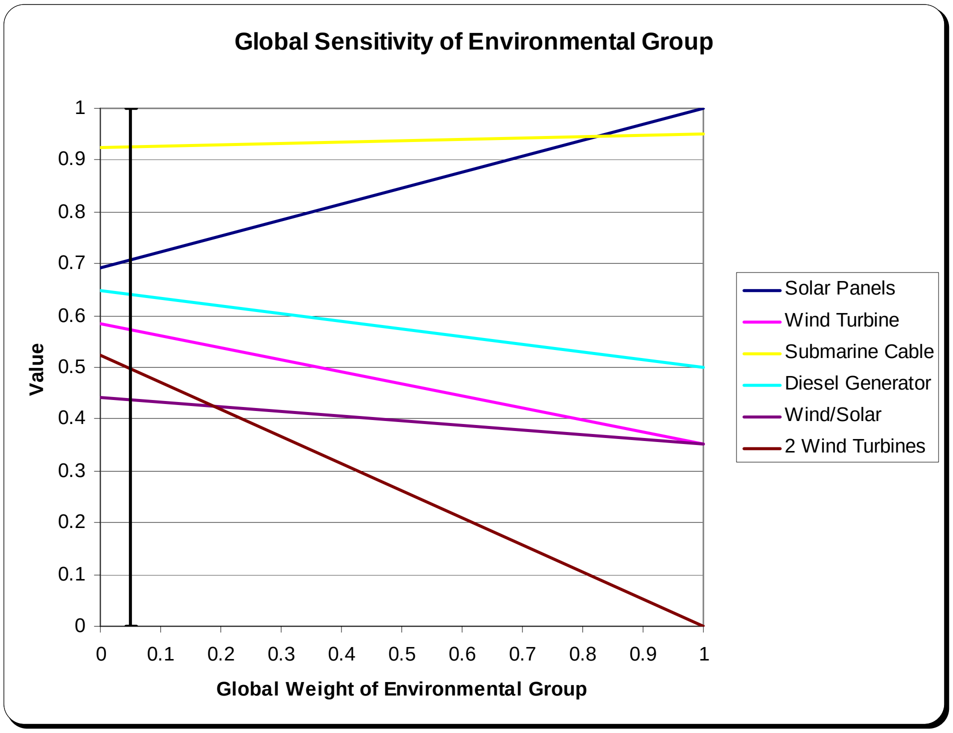

Figure 28. Sensitivity Analysis-Environmental Group

Chapter 5. Conclusion

5.1 Introduction

This chapter highlights an informative solution for the case study as well implications for other remote areas. The last step of the 10-step Value-Focused Thinking (VFT) process involves making a final recommendation based on the results of the previous steps of the model. This data has indicated that the installation of a submarine cable should be highly considered. However, there are certain assumptions and limitations that must be realized. Considering these facts will lead the decision makers to a more confident understanding of the solution application. Supplementary research into this field may also be crucial for the expansion of knowledge to related areas in other parts of the world. Additionally, the application of investigative work and decision analysis has revealed answers to this study’s research objectives. The identification of such a productive decision technique can be useful for many other decision makers in the same predicament.

5.2 Step 10-Conclusion and Recommendations

The value-focused thinking methodology applied in this scenario presented useful information for decision makers at the NPS. The decision analysis tool initially indicated that installing a submarine cable from the island to the mainland would represent the highest degree of value satisfaction in supplying power to Alcatraz Island. However, a cost-value calculation will help the decision makers to determine if installing a submarine cable would overwhelmingly be the best solution. Even though the location of this evaluation was considered to be remote, the highest scoring alternative of procuring electricity involved negating the features of isolation by connecting to the mainland power source. The consideration of renewable energy technologies in support of the NPS' environmental stewardship was also negated by the high value scores of normally nonrenewable dependence. The irony of the result serves to demonstrate the level of complications involved with such a decision. The recommendation of this model implies further investigative actions towards the feasibility of installing a submarine cable. However, the application of the model cannot be substantiated without identifying certain assumptions and limitations.

5.3 Assumptions and Limitations

There are a few assumptions that were considered during the development of this research. First, inputs provided by the decision makers are assumed to be the ultimate authority of electricity procurement for Alcatraz Island. These choices are also assumed to be steady throughout the modeling process. Second, the characteristics of each alternative and its associated scores are held constant. For example, electricity production of an alternative will not fluctuate. Based on this assumption, environmental aspects associated with Alcatraz Island are assumed to be ultimate. For example, the climate and average currents associated with Alcatraz Island will not change. Park officials at Alcatraz Island must also have the means to procure the chosen system. In addition, value scoring effects of the supplemental generator were ignored so that the fundamental problem can be focused on the primary source even though it may not independently meet demand. Finally, noise, emission, and environmental group effects for the submarine cable were assumed to be discounted since scores were site specific. These assumptions demonstrate the evaluation considerations used to provide adequate knowledge of the situation context.

The limitations of this research may provide potential drawbacks to the model. First, value-focused thinking merely serves as a guide for any decision problem. Certain parameters may not have the practicality of quantification by this methodology. Therefore, this model can only assist the decision maker for the selection of an ideal electrical generation source. Another limitation incorporated in this research is a lack of evidence for value-focused thinking processes associated with other remote sites. This concept suggests that a lack of familiarity may be present in the model. Third, the application of this model to other remote locations is limited to the general methodology. Decision makers in other remote locations may have varying values as well as alternatives. For example, the National Park Service (NPS) is endowed with a fairly high amount of environmental and preservation restrictions. However, inhabitants in other remote locations may not experience the same pressures. Therefore, the decision maker's level of importance for such areas may differ dramatically. The fourth limitation includes the fact that there are no permanent inhabitants on Alcatraz Island. This model did not reflect the values that may be associated with residential purposes since Alcatraz Island is only open to tourists. Lastly, value-focused thinking only allots a distribution of importance by weights for comparison of values within the hierarchy. Constraints such as authoritative sanctions can only be satisfied in the beginning or end of the model by using screening criteria. These limitations allow other decision makers to decide on the applicability of this model to their particular situation.

5.4 Further Research

Research recommendations can be formulated from additional insights gained throughout the development of this study. The issues described in the previous section provide avenues for future work. First, this study focused on using a fairly popular remote location without any inhabitants. The analysis of value-focused thinking to other remote sites may create peripheral knowledge in this field. Second, other manufacturers and alternative methods of electrical generation were not considered in this study. The reason for such deficiency is that the availability of newer technologies is limited and procurement can be costly or unavailable. However, innovative methods of today can become the common denominator of electricity generation for the future. Sources of power drawn from the submarine cable, such as renewable energy, can be evaluated for its effects on the model. More research can be developed by including such systems in value-focused thinking. Third, the element of remoteness in this study's location was not a factor since the best solution involved a brute method of connecting to a commercial power grid. Further studies can be allocated in order to examine if locations with higher degrees of isolation behave similarly. Fourth, financial considerations such as monetary incentives delivered by governmental and non-governmental entities are popular in many parts of the world for renewable energy applications. Additional research can be directed towards identifying these credits and understanding its impacts on such a decision process. The application of this study served to initiate opportunities for further research in the arena of electricity for remote areas.

5.5 Final Thoughts

A combination of investigative research and decision analysis applications revealed answers to the research objectives presented in the beginning of the study. Individuals in some remote areas of the world have learned to procure electricity by means of conventional and innovative systems. The majority of inhabitants at these locations rely on fossil fuel-powered generators. Others have adopted renewable methods such as solar panels, wind turbines, and hydropower for electricity dependence. However, the lack of literature explaining the decision processes for these choices signify a void in the realm of electricity generation. Constraints involved with choosing an electrical source highly depend on the specifics of remoteness. The case study investigated in this research highlighted the regulatory hurdles such as the Golden Gate National Recreation Area General Management Plan, the National Park Service *Management Policies*, and other governmental regulations necessary for implementation. Besides certain procedural parameters, other types of factors were also identified in the decision analysis model. The application of weight distributions strictly correlated to the amount of importance associated with each factor. The effect of applying value-focused thinking to a remote location was the ability to represent a sincere reflection of the values in a problem such as this. Understanding the global ramifications of such a process can assist in providing the best solutions for all remote inhabitants.

Rapid changes occurring in the electrical industry and lack of power for many inhabitants warrants an effective solution. Studies in the decision analysis realm can be utilized for situations such as these. Environmental damages and growing trends in alternative methods of electricity production have spurred the need to utilize helpful tools for effective decision-making. Millions of people in remote locations continue to lack the resources for electrical generation based on many reasons. Value-focused thinking can be applied to these locations to alleviate the situation or understand all the components necessary for such a deficiency. The results of this methodology allow the decision maker to comprehend the effects of each alternative on all of the objectives that were identified. Additional policy restrictions were also considered outside of the model. Further progress and knowledge distribution in this area can continue to assist many more in other remote locations of the world.

Appendix A. Single-Dimensional Value Functions

A.1 Site Appropriateness

Peak db Level

Peak decibel level measures the degree of a potential audible distraction that is predicted for output based on manufacturer specifications. It is measured using decibel levels since this is a standard measuring technique for sound. Zero decibels refer to an electrical system that does not provide any audible sound. Ninety decibels was chosen for a minimum value score cutoff because that audible level is comparable to the sound level produced by a kitchen blender. The decision makers did not place anymore value in a system that would contribute that amplitude of sound or more. Even though the peak decibel level measure may refer to an instantaneous output, 90 decibels or more would not be valued at all.

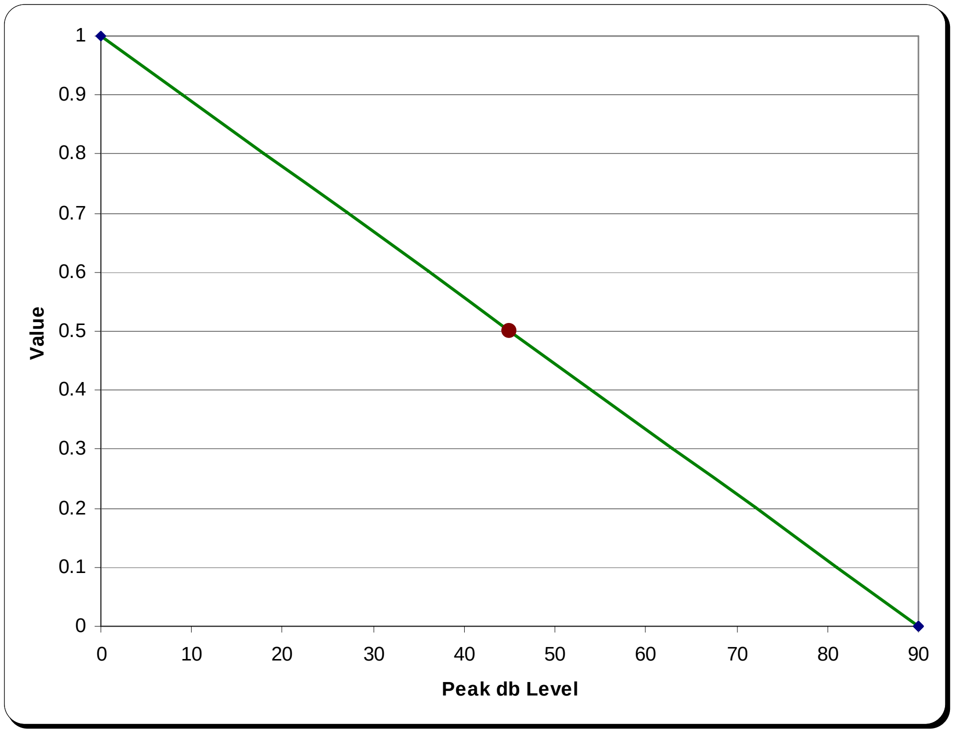

Figure 29. Value Functions-Peak db Level

Mean db Level

Mean decibel level involves similar aspects as the peak decibel level. Both measures refer to the amount of sound that is produced from an electrical system. However, the maximum allowable output is 70 decibels for the mean decibel level measure. This is because an average output of 70 decibels is comparable to busy road traffic and the decision makers felt as if a system produced that level or more, it would impair the ability for others to speak amongst themselves in the immediate area.

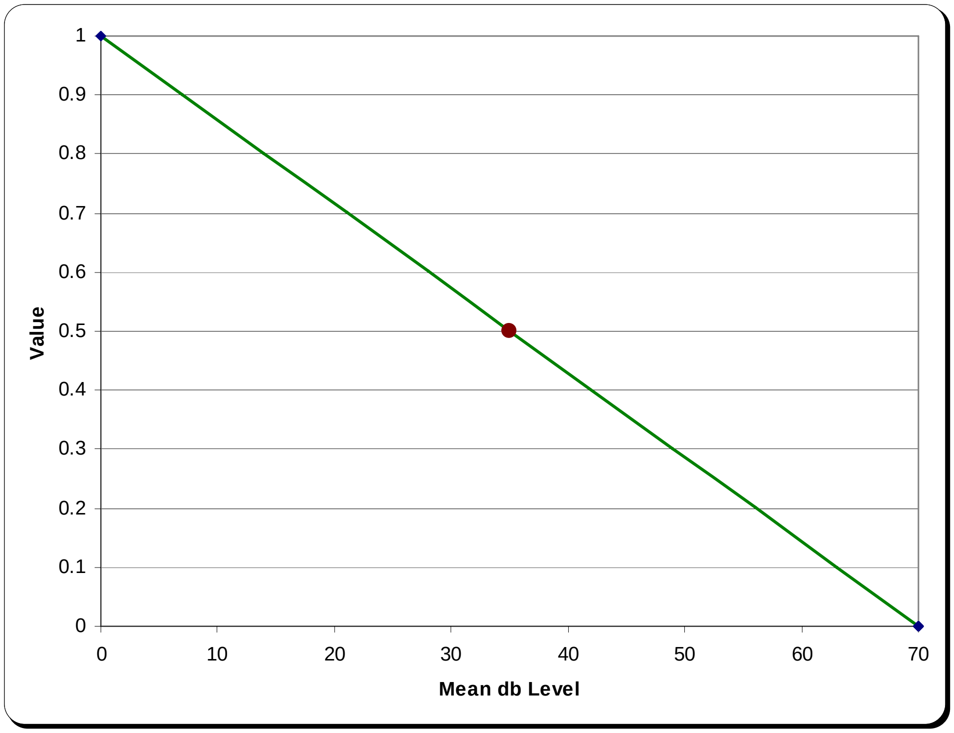

Figure 30. Value Functions-Mean db Level

Aesthetics

Aesthetics provides the decision makers with a representation of visual quality in an electrical generation system. Since visual quality can sensibly be measured using subjective inputs, the value function for aesthetics is scored with a 0-10 rating scale. The more visually pleasing an alternative is, the higher the rating score it gets. This would correspond to a higher value score as well. Ratings were provided by the decision makers since they would be most familiar with the visual aspects of the surrounding area. If an alternative does not devalue the visual attractiveness of the surrounding area, it receives an aesthetics rating score of 1. An aesthetics rating score of 0 would indicate the most severe impact of aesthetics quality from that alternative. Any rating in between these extremes signify a proportion of visual impairment from the largest (0) to the smallest (10).

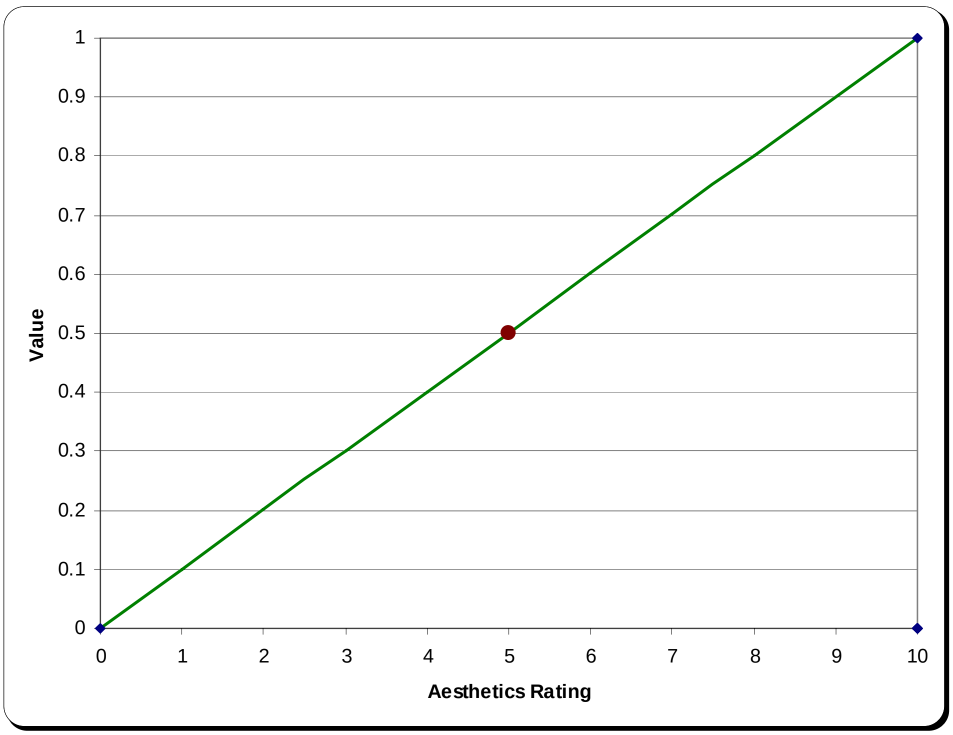

Figure 31. Value Functions-Aesthetics

Construction Resources

Construction resources refer to the amount of equipment, tools, and manpower required for the introduction of each alternative. The amount that is required can vary greatly and is subject to personnel opinion. Therefore, a rating scale of 0-10 is also implemented in this measure. A rating score of 0 would mean that the resources necessary to install the system would be very large. Conversely, a rating score of 10 would signify that additional resources required would be very minimal or negligible. Any rating score in between these extremes indicate the proportion of the resources required from the highest (0) to the lowest (10). The score for each alternative was elicited by the decision makers since they realize what resources they already have on the island.

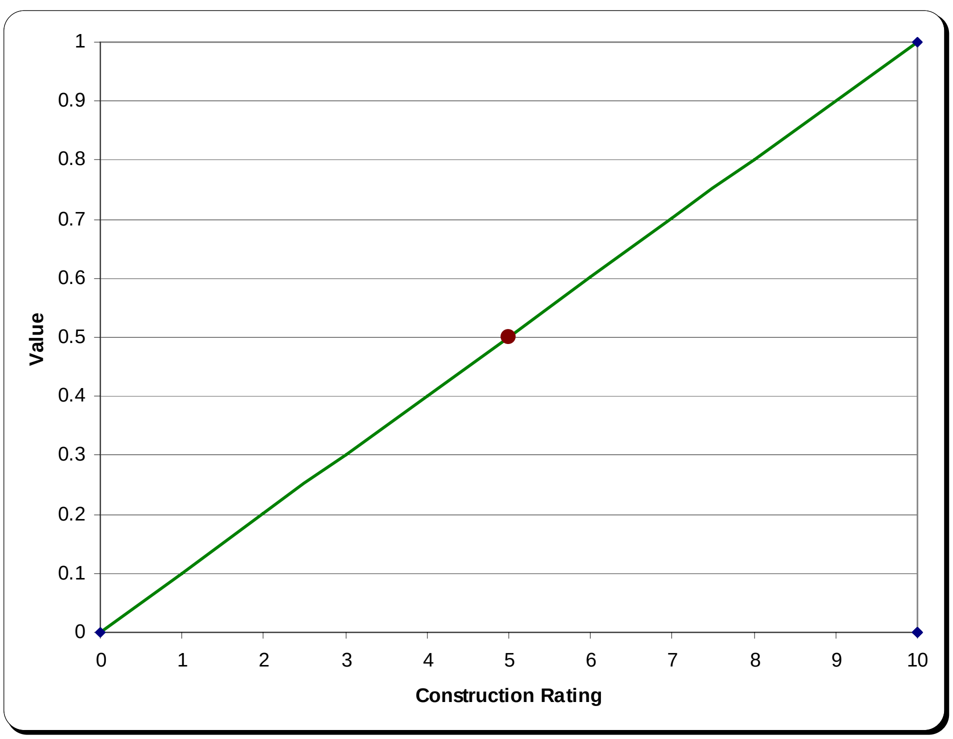

Figure 32. Value Functions-Construction Resources

Area Occupied

The area occupied measure is a representation of whether or not an alternative would be able to operate within the allotted space on the island. If an alternative requires more room on the island, the decision makers has indicated that it would be of no value in this category. However, the potential exists for expansion of an electrical generation area occupied on Alcatraz if it is deemed necessary.

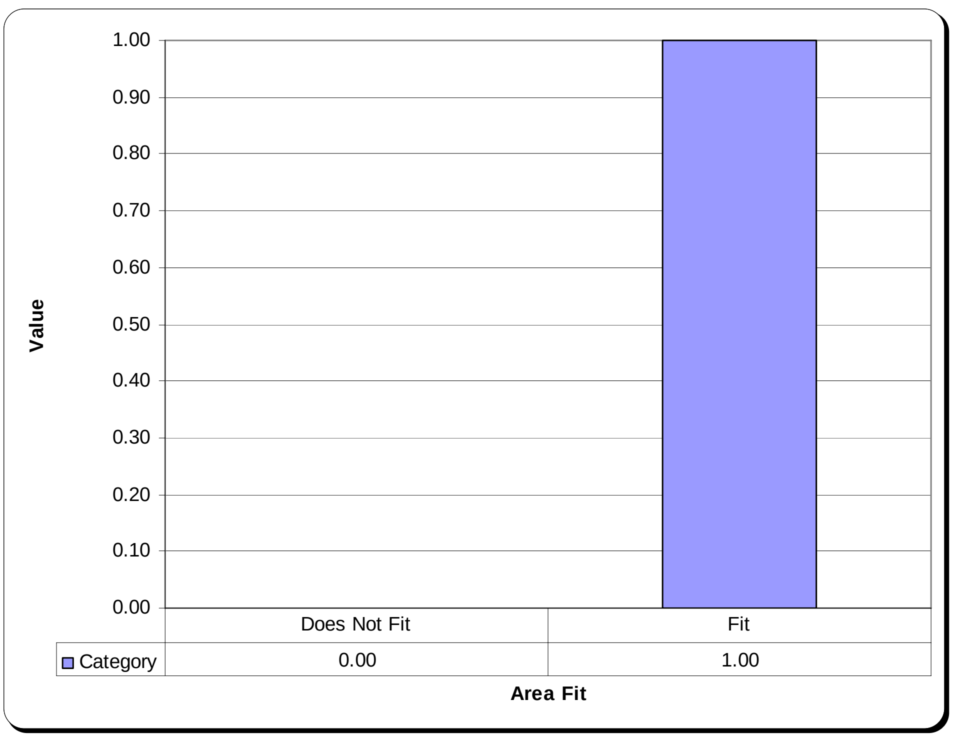

Figure 33. Value Functions-Area Occupied

Compliance Burden

Compliance burden measures how complicated it would be for each alternative to be instilled on the island. For each alternative, time and effort exists for bureaucratic processes to be completed for approval. More atypical changes would require more time and effort for implementation approval. Measuring the specifics of such a burden is provided by a 0-10 rating score. A rating score of 0 signifies an almost impossible amount of time and effort required for implementation. A rating score of 10 correlates to almost no compliance burden necessary. A typical example of an alternative with a rating score of 10 would be keeping the status quo. Any rating score in between these extremes would signify the proportion of how much of a burden that alternative inflicts from the most (0) to the least (10). The decision makers have been elicited for value scoring since they are most familiar with the project processing requirements.

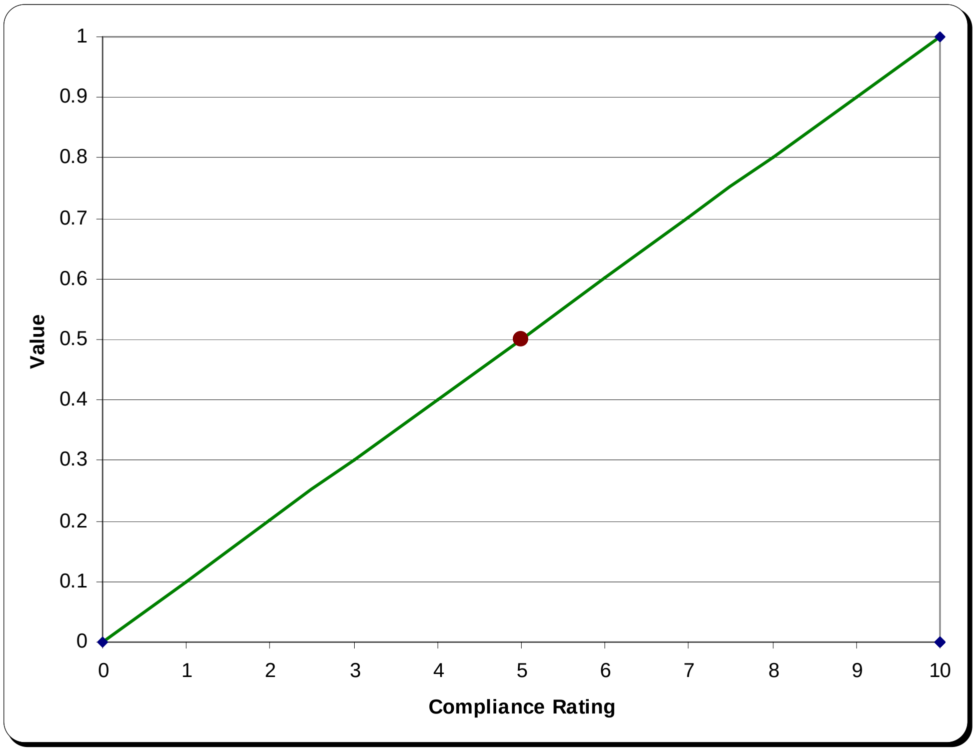

Figure 34. Value Functions-Compliance Burden

A.2 Operation

Reliability

Reliability can be measured using alternative techniques. One method of scoring reliability can be in the form of a subjective rating based on the decision makers' opinion. Another may involve analyzing the history of the manufacturer of each alternative. The decision makers felt as if using the expected lifetime operating hours as provided by the manufacturer would be the most accurate indication of reliability. The longer the system is expected to last, the more value is devoted to the alternative in this category.

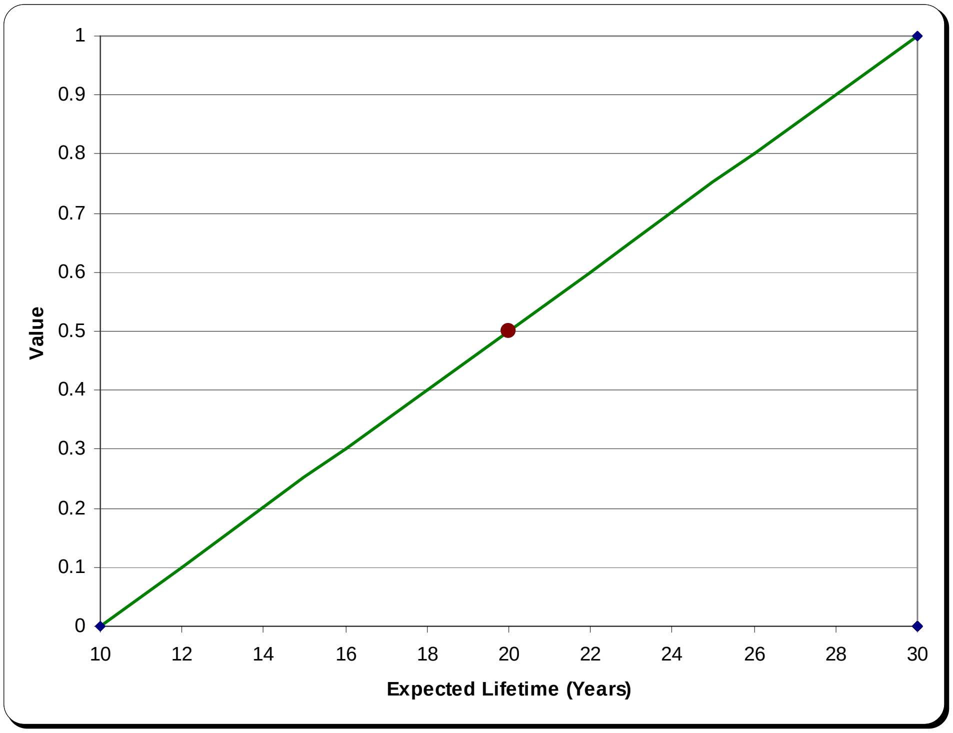

Figure 35. Value Functions-Reliability

Maintenance

The maintenance measure is used to define the number of operating hours expected between each routine service. An indication of the best alternative in this category refers to a system that would only require servicing no less than every 2000 hours. Any alternative that requires servicing more often than every 250 hours would be given a zero score.

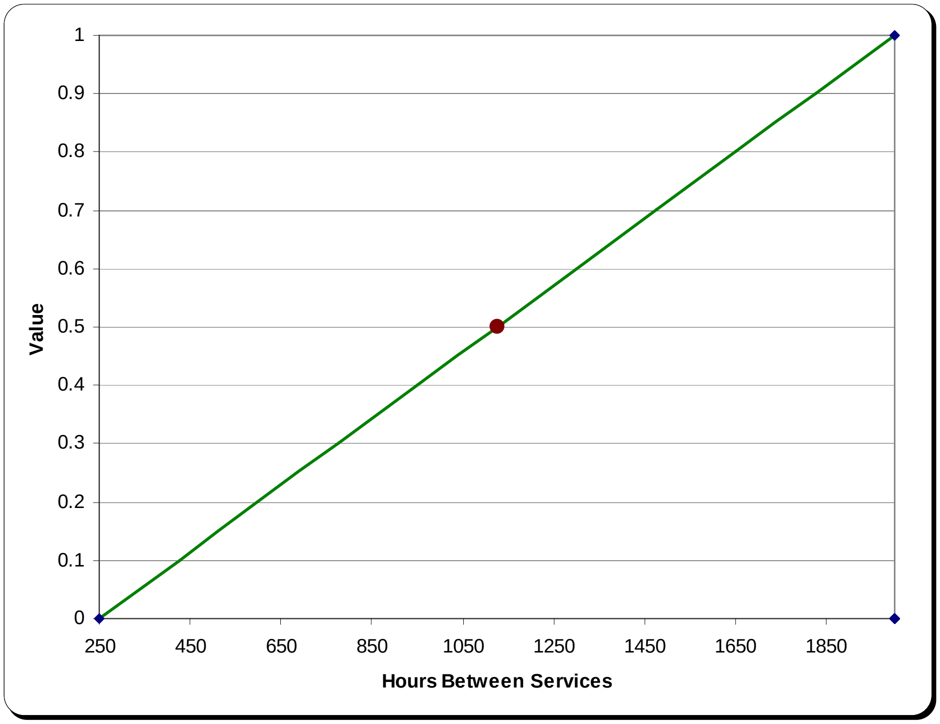

Figure 36. Value Functions-Maintenance

Technical Support Availability

Technical support availability is an indication of the how quickly the manufacturer's support group can arrive on site to handle any complication involved with an electrical generation system. If the personnel necessary is expected to take more than 24 hours, the alternative would score a zero in this category. Any time less than two hours represents the best value score.

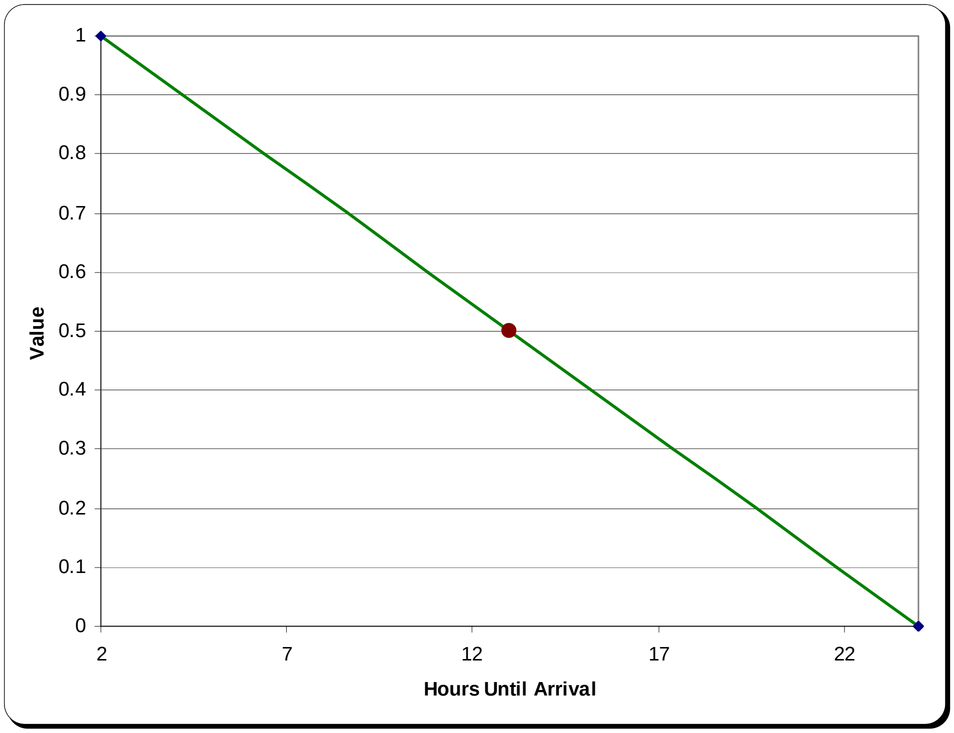

Figure 37. Value Functions-Technical Support Availability

Efficiency

Efficiency is a representation of how well the system is expected to produce electricity based on the amount of energy given to it. This measure is accomplished using a ratio of the energy given to the system over the energy produced by the system. The higher the system efficiency ratio, the more valuable the alternative is in this category. The best value is devoted to an efficiency ratio of 60% since no current electrical alternative exists with characteristics higher than that.

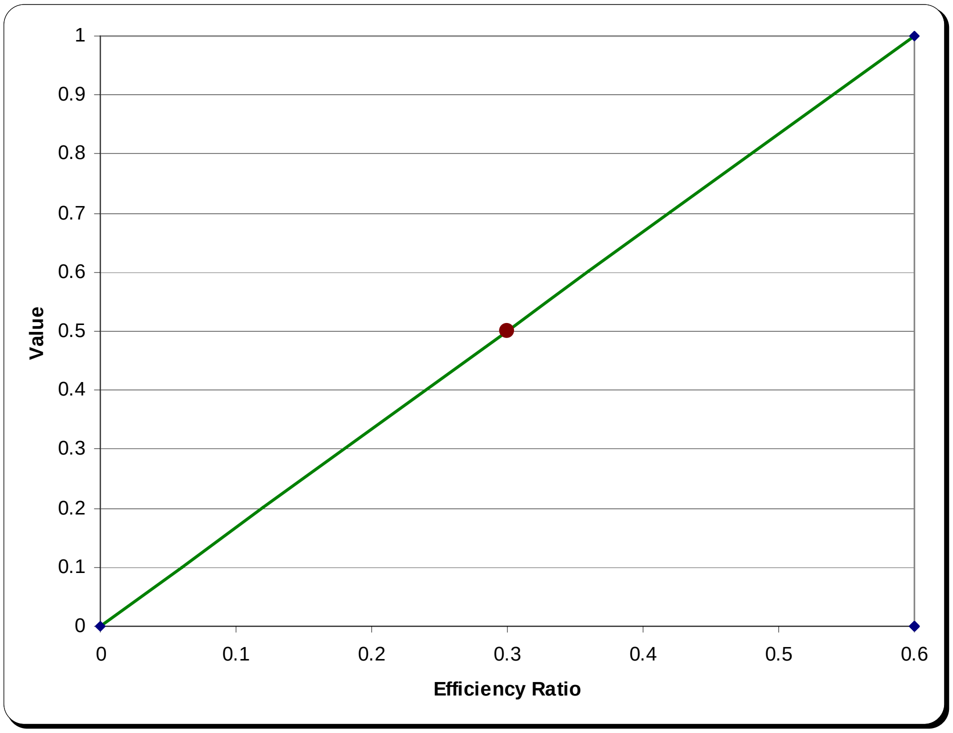

Figure 38. Value Functions-Efficiency

Availability

Availability is used to determine how often the energy source would be available for each alternative to convert into electricity. This is defined by a categorical measure which corresponds to the portion of the day that the energy source is available. If the energy source is predicted to be available all day, it scores a "continuous" rating. Energy sources that only work well with sunlight will only receive a "half" rating. Wind energy is expected to be available at least half a day. Figure 39 indicates the value function for availability.

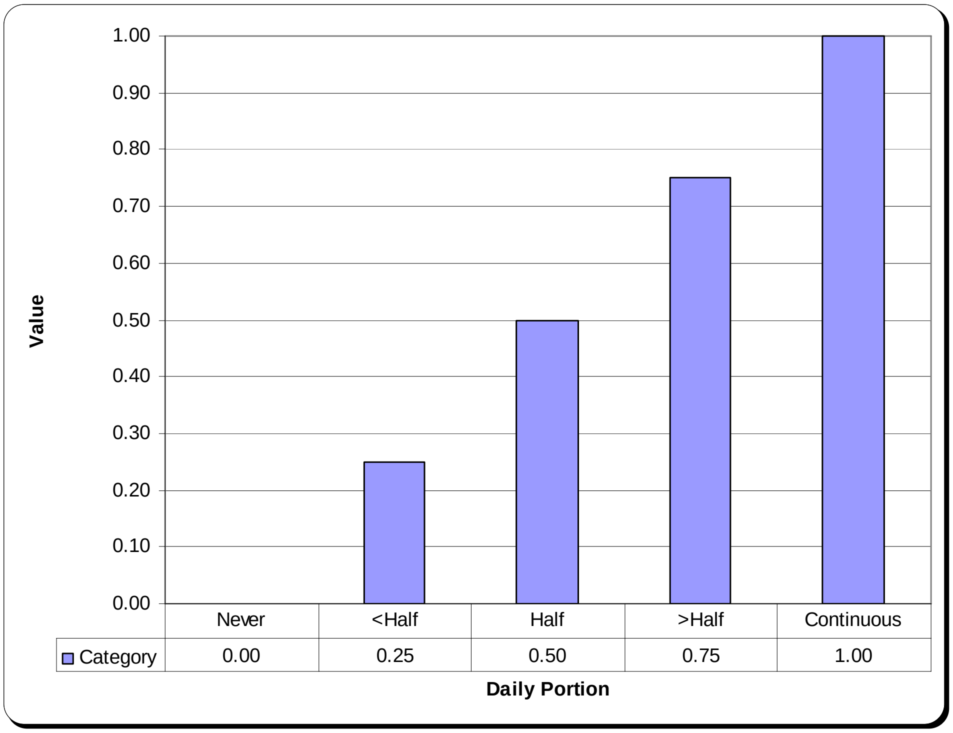

Figure 39. Value Functions-Availability

Reserve Ability

Reserve ability indicates whether an alternative's energy can be kept for normal as well as contingent operations. Ideally, the energy source needed by the system should have a reserve amount that can be placed on the island. This would eliminate the need for tedious amounts of transportation to the island. In some cases, the energy may not be storable. However, excess energy produced by the system during normal operations can also be saved using other resources. This would essentially mean that the energy is storable on the island.

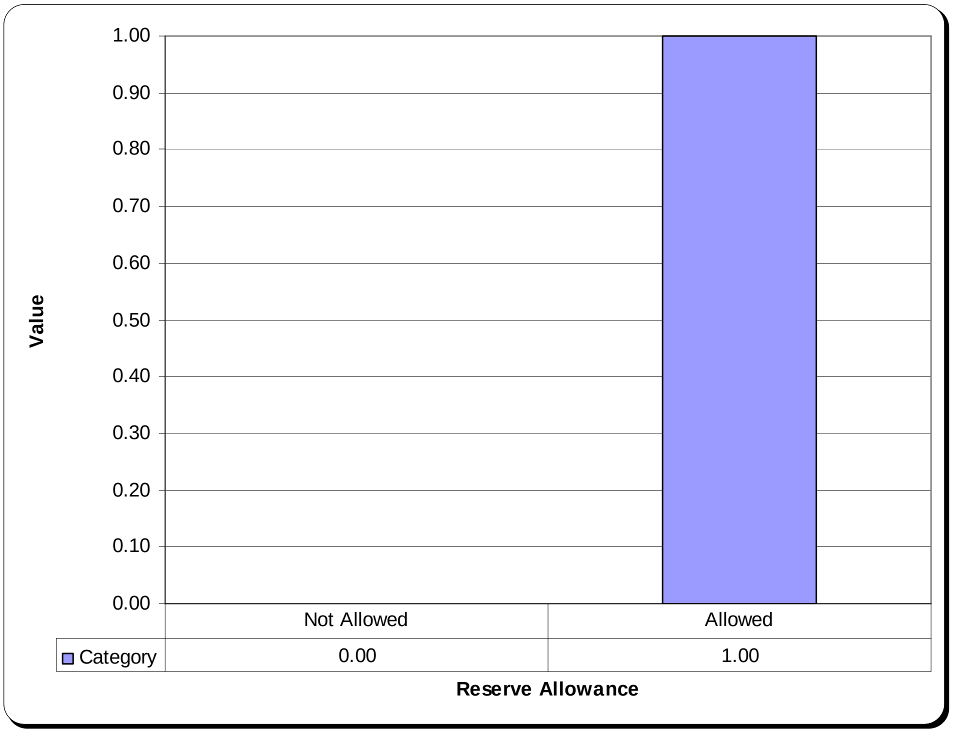

Figure 40. Value Functions-Reserve Ability

Capacity

Capacity refers to the ratio of how much energy can be obtained per cubic foot of space for energy storage. This is inserted into the hierarchy in order to reflect the decision makers' value in saving as much room as possible while still producing the necessary electrical needs. An ascending, linear value function is used here to indicate the possibility of a fractional ratio. Since diesel fuel provides .997 MBTU/cubic foot, the decision makers acknowledged that the lowest parameter would be 0.75 MBTU/cubic foot and the highest be 1.5 MBTU/cubic foot. This x-axis range places the status quo of diesel fuel in the middle of the value score.

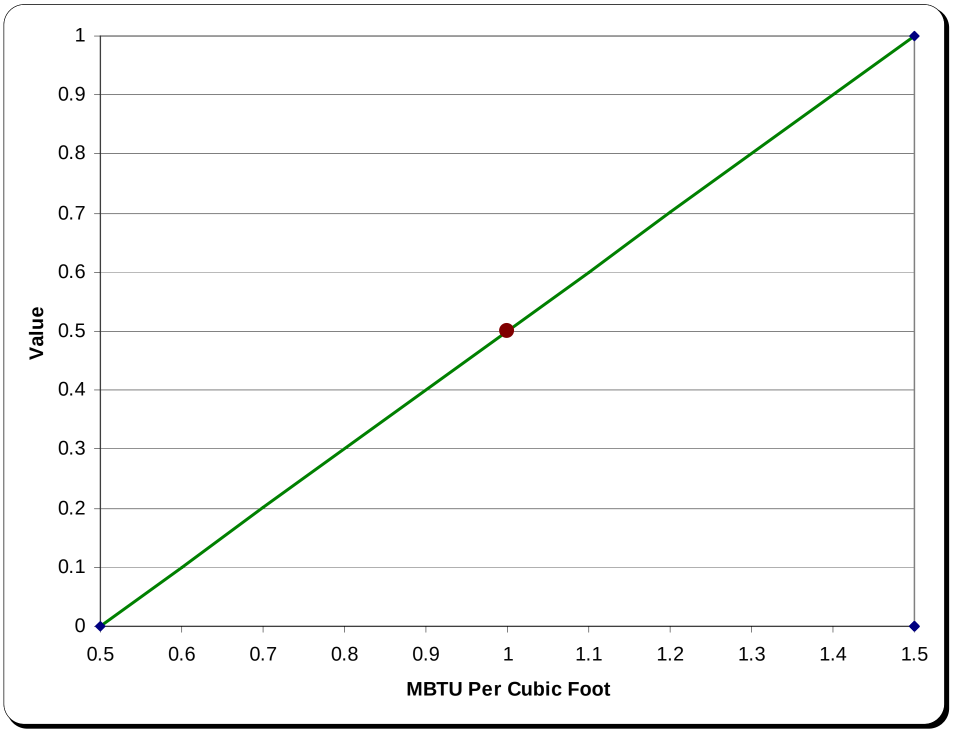

Figure 41. Value Functions-Capacity

Flammability

Flammability is the first characteristic of the 'fire diamond' that is usually used to label chemical containers. Flammability refers to how sensitive a chemical can be to ignition. A lower rating indicates a safer product, while a flammability rating of zero means the substance will not burn. Since the decision makers acknowledge that some level of flammability may have to be accepted, a categorical function is assigned using an increasing trend of value for lower flammability levels.

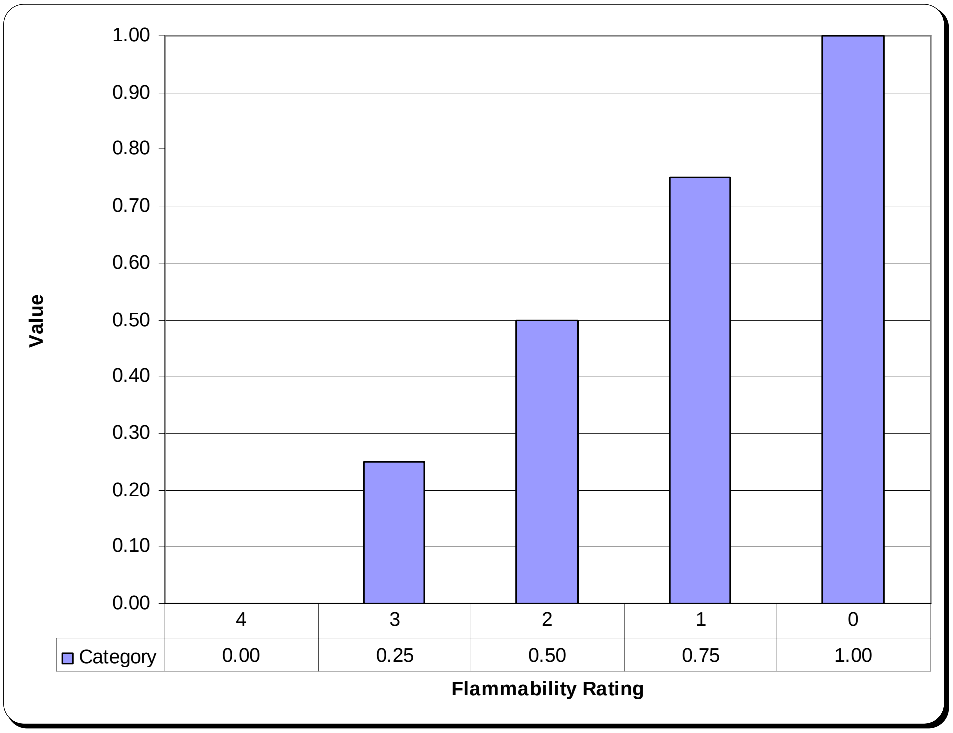

Figure 42. Value Functions-Flammability

Health

Health is another category in the ‘fire diamond’ of chemical labeling. It is a measure of how dangerous a chemical can be to the welfare of personnel within the vicinity of its exposure. Lower health levels indicate safer products. The decision makers have indicated that the same amount of values be given to score the health levels as the flammability levels.

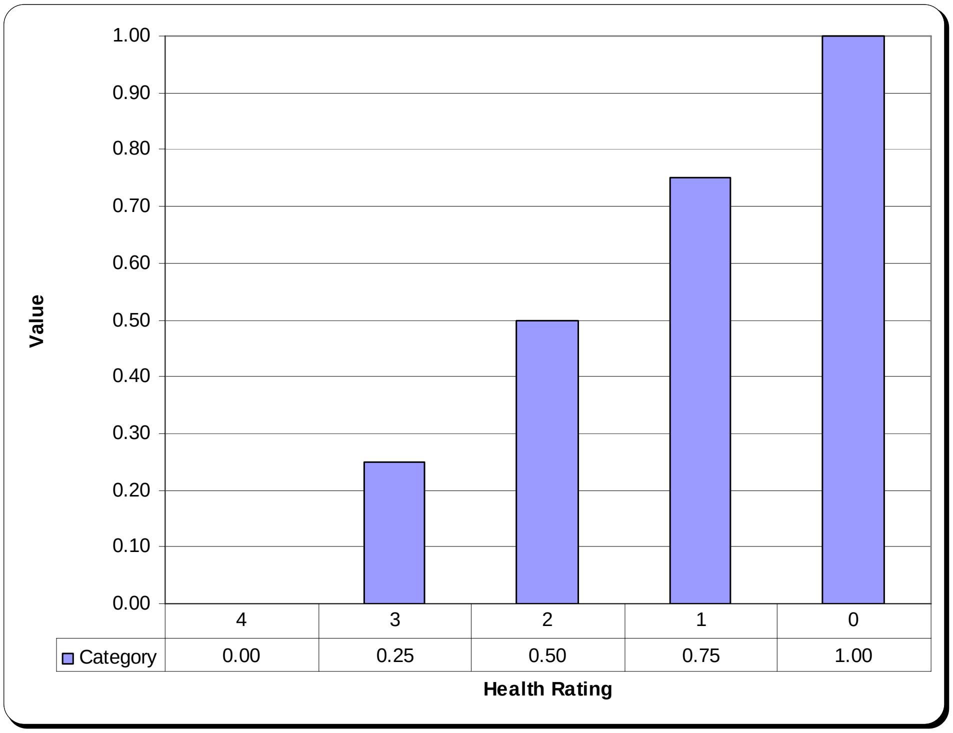

Figure 43. Value Functions-Health

Reactivity

Reactivity refers to the degree of stability in the 'fire diamond'. Lower reactivity ratings indicate more stable chemicals. Some chemical reactivity properties may still be allowed on the island. Therefore, the value function reflects the degree of value associated with each level of reactivity for each energy source alternative.

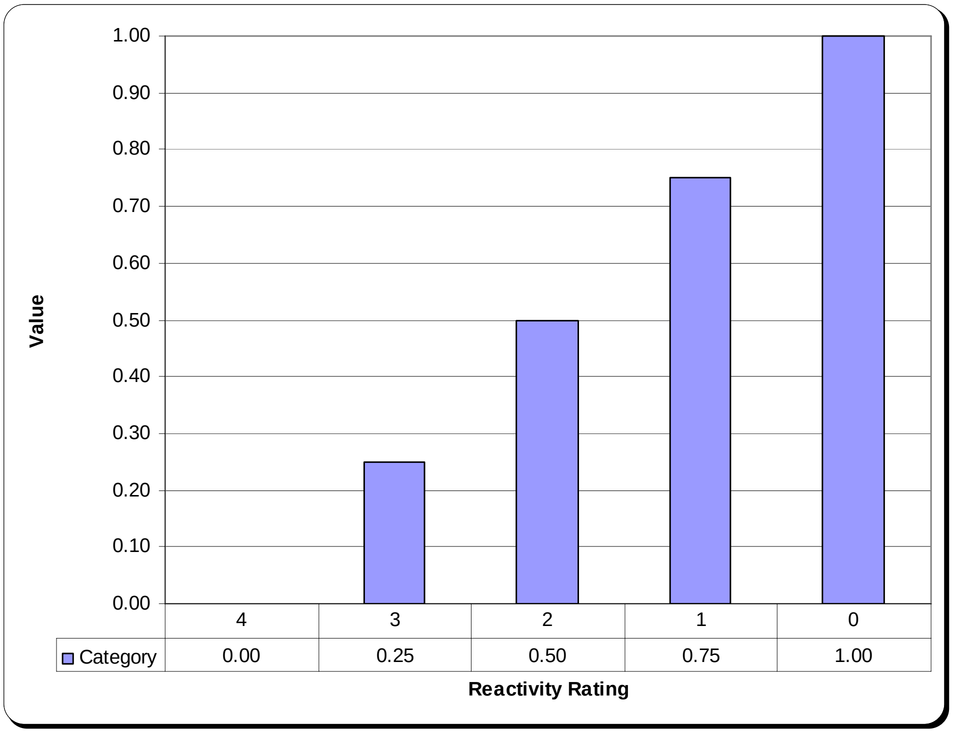

Figure 44. Value Functions-Reactivity

Special

Special is the last category under the 'fire diamond' which seeks to identify other unique properties of chemicals that may not have been mentioned in the previous three categories. These properties are considered to be highly useful as well even though it could not be expressed from health, reactivity, or flammability standards. The decision makers have indicated that almost all levels of special ratings would receive a value score of zero. The only symbol, besides not having one, that contains any value in this category would be a chemical that is corrosive or has no special rating.

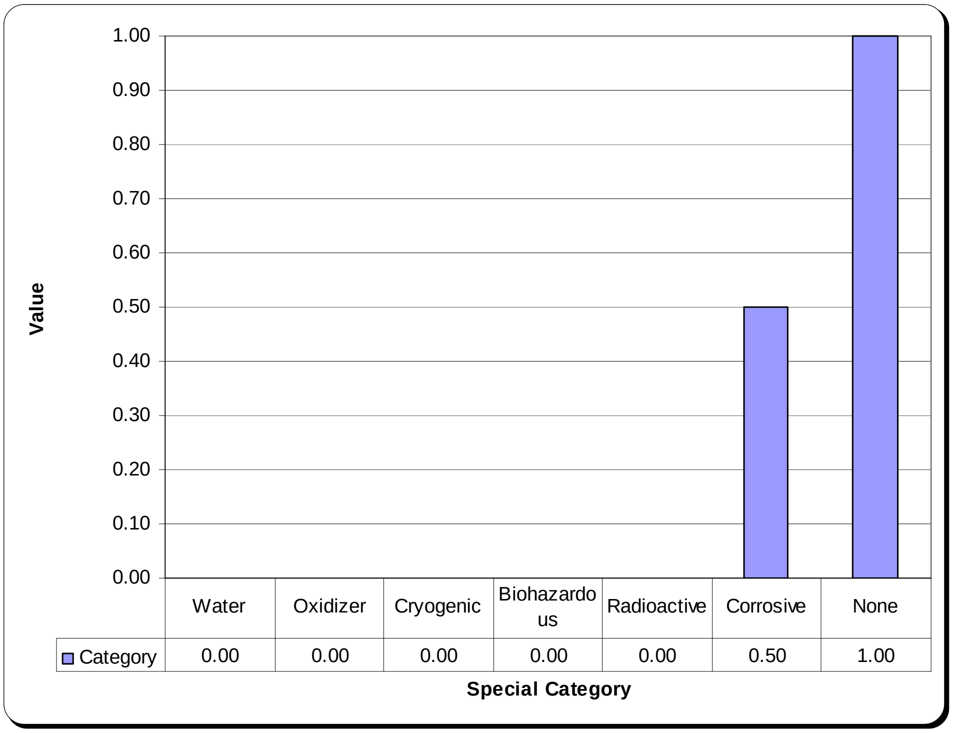

Figure 45. Value Functions-Special

A.3 Public Education

Public Education

The measure of public education reflects the level of useful knowledge that can be obtained from implementing any alternative. Some choices may be ideal for representing the standards and values of the national park as a protection agency. These alternatives are given credit for such a potential impact. It is difficult to fully convert the value of public education to a sensible representation. Therefore a rating scale of 0-10 is implemented for consideration by the public education expert on the island. A rating of 0 would mean that no education will be realized from the installation of that alternative. A rating of 10 would mean that the alternative would provide the highest level of public education in correlation to National Park Service values. Each rating score in between those extremes indicate the proportion of how much education can be obtained from the worst (0) to the best (10).

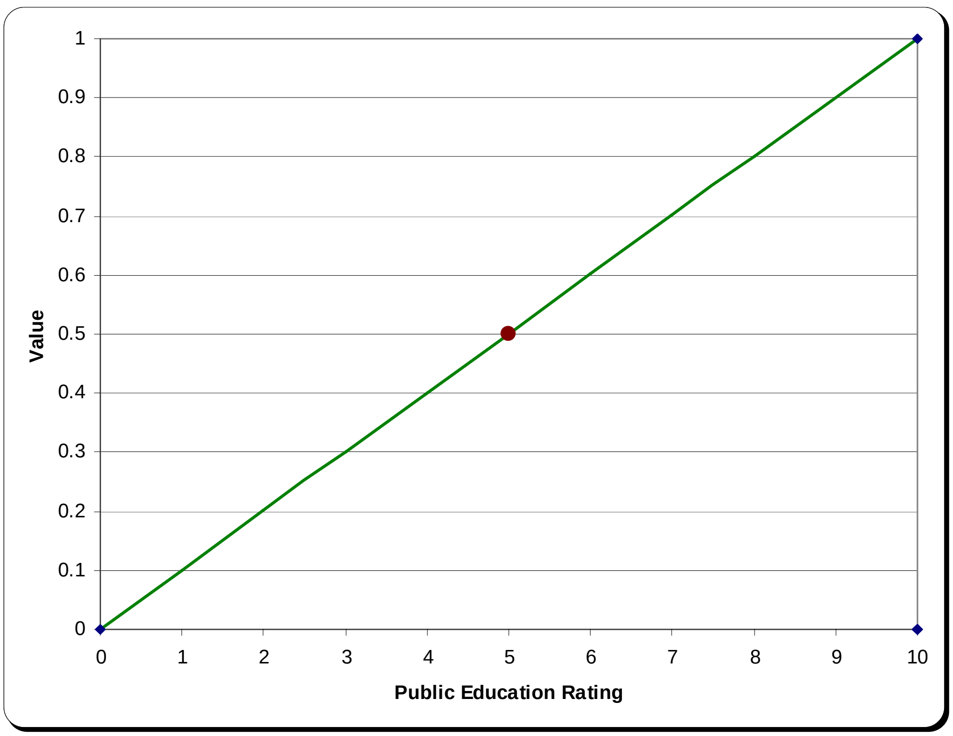

Figure 46. Value Functions-Public Education

A.4 Environmental Impact

Cultural and Historical

The NPS has certain standards of cultural and historical regulations that need to be met by any project proposal within its boundaries. Based on the impact that a project has on the cultural and historical relevance of a site, the NPS decides whether to accept its effects or not. A cultural and historical official is assigned to the GGNRA in order to ensure compliance with such standards. A scale rating of 0-10 is established in order to adequately capture the opinions of this official. A score of 0 would correlate to a severe detriment to the island from the installation of the alternative. A score of 10 would correlate to an alternative devoting the highest level of cultural and historical quality to the island. Any rating score in between these extremes is associated with the degree of impact to the cultural and historical elements from the highest (0) to the lowest (10).

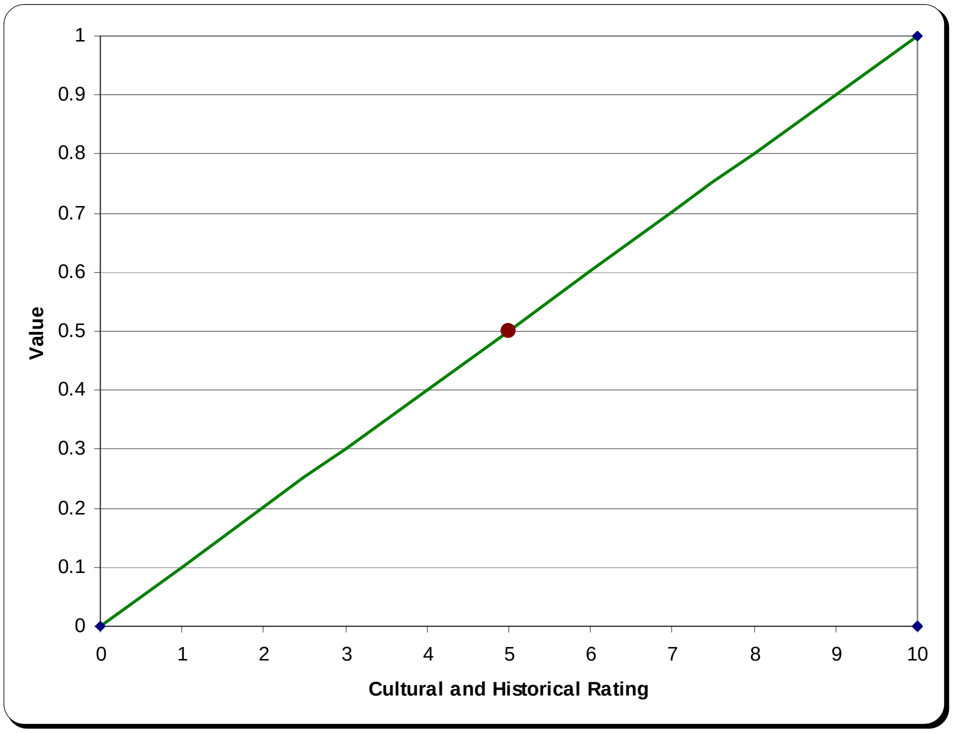

Figure 47. Value Functions-Cultural and Historical

Natural Resources

Natural resources need to be protected from potential acts of exploitation in the NPS. This is especially apparent in certain areas of the GGNRA. Alcatraz Island is home to various species of animals that need to be ensured with future prevalence. Therefore, a rating scale of 0-10 reflects how effectively each alternative impedes this progress. A natural resources expert was elicited for rating scores from each alternative. A natural resources score of 0 would mean that an alternative severely impacts the natural resources on the island. A score of 10 indicates that an alternative would provide the highest level of contribution possible to the natural resources of the island. Any rating score in between these extremes indicate the degree of how much that alternative impacts the natural resources on Alcatraz from the highest (0) to the lowest (10).

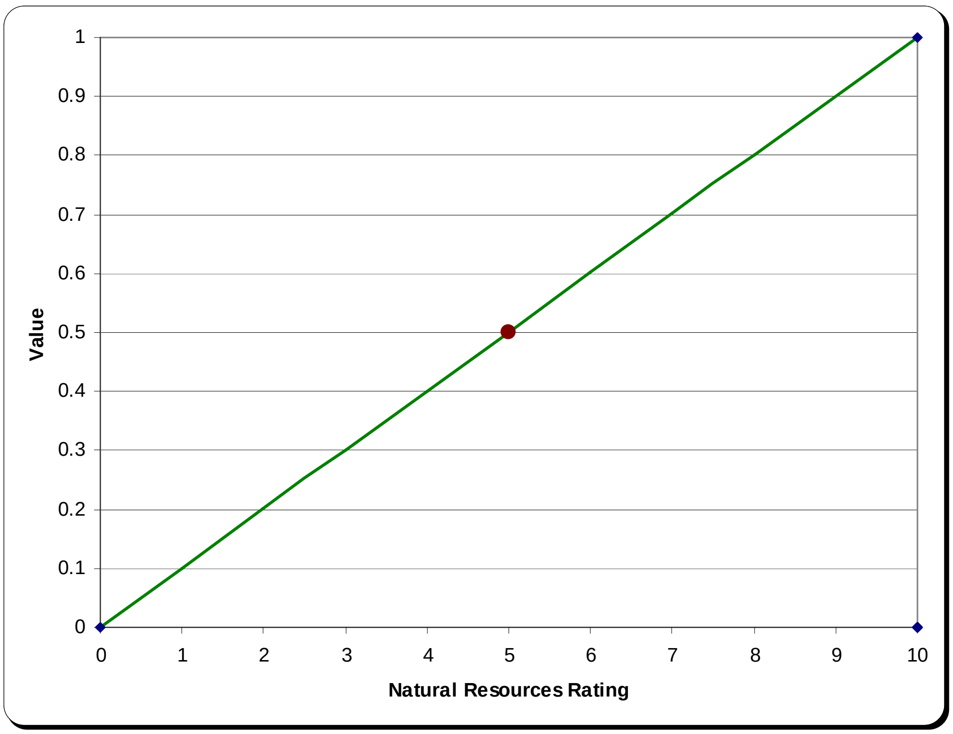

Figure 48. Value Functions-Natural Resources

Emissions

Emissions from electrical generation systems are already a major concern of the world. The NPS would consider the compliance of surrounding area regulations to be valuable for mission success. The Bay Area Air Quality Management Board dictates the type and amount of emissions considered to be safe for environmental consideration. The value function used in this case is an ascending, linear slope that measures the percentage of the limit that each alternative emits. If the emission exceeds the established limits, that corresponding alternative achieves a value score of zero in this category.

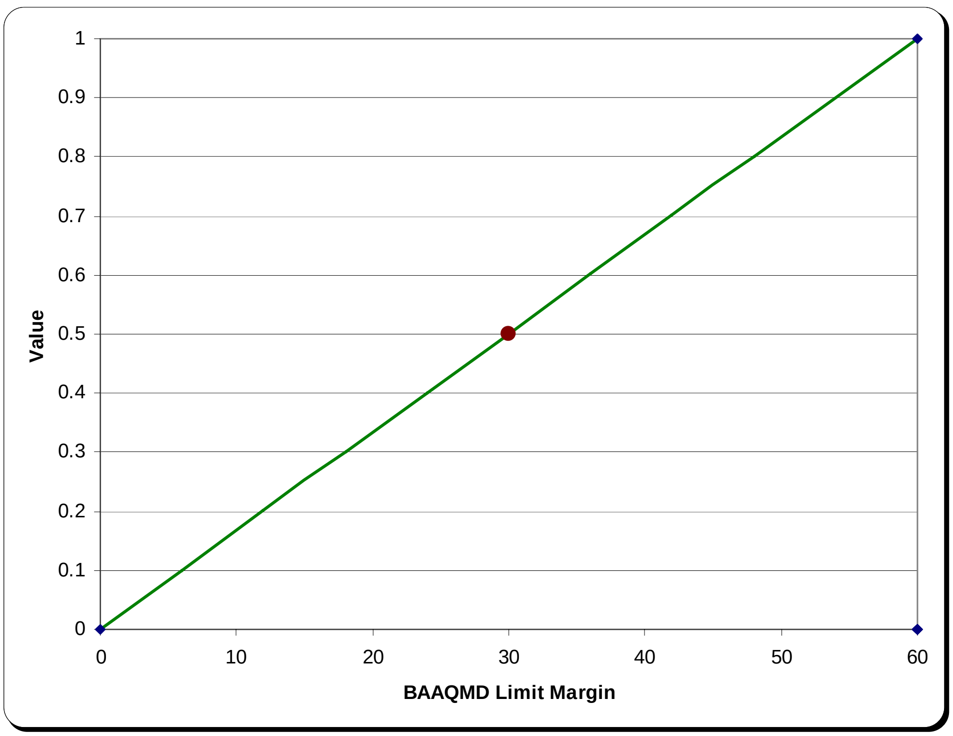

Figure 49. Value Functions-Emissions

Environmental Group

Environmental groups demonstrate another dimension of environmental responsibility for the NPS. Their opinions on each alternative will justify the quality of environmental compatibility that the NPS try to accomplish. A rating score of 0-10 dictates the level of compatibility with all aspects of the nearby environment. An environmental group rating of 0 from the environmental group representative indicates that the effects of an alternative are very harmful to the environment. A score of 10 correlates to an alternative that does not negatively impact the overall surroundings of the island. Any rating score in between these extreme values correspond to the proportion of negative impacts to the overall surroundings of Alcatraz from the most (0) to the least (10).

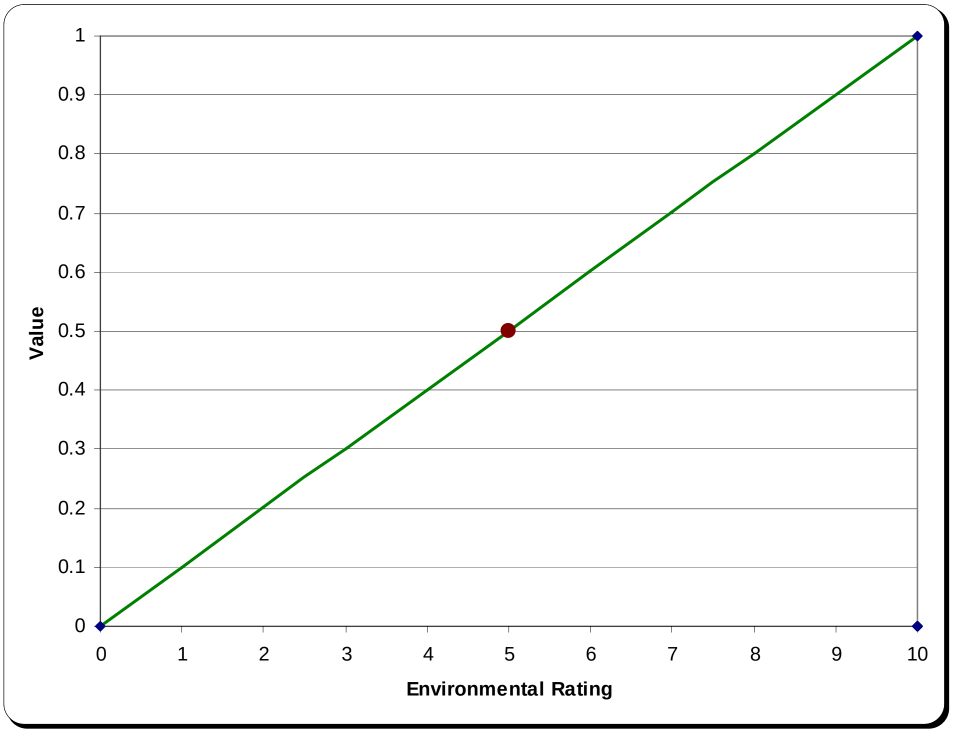

Figure 50. Value Functions-Environmental Group

Appendix B. Calculations

B.1 Alternative 1 (Solar Panels)

BAAQMD Limit Margin

There are no toxic emissions from solar panels. Therefore, the margin between the toxic emissions of this alternative and the Bay Area Air Quality Management District limit is the highest level possible. The state limit for is particulate matter 10 (10 microns or smaller) $50 \mu g/m^3$ a day (California, 2005).

$$100\% - \left(\frac{0 \mu g/m^3}{50 \mu g/m^3}\right) * 100\% = 100\%$$

B.2 Alternative 2 (Wind Turbine)

BAAQMD Limit Margin

There are no toxic emissions from a wind turbine. Therefore, the margin between the toxic emissions of this alternative and the Bay Area Air Quality Management District limit is the highest level possible. The state limit for is particulate matter 10 (10 microns or smaller) $50 \mu g/m^3$ a day (California, 2005).

$$100\% - \left(\frac{0 \mu g/m^3}{50 \mu g/m^3}\right) * 100\% = 100\%$$

B.3 Alternative 4 (Diesel Generator)

MBTU/Cubic Foot

The capacity is calculated by converting the energy stored in a gallon of fuel to cubic feet as shown below.

$$\frac{131{,}000BTU}{1gallon} x \frac{1gallon}{0.134cubft} x \frac{1MBTU}{1{,}000{,}000BTU} = 0.977612 \frac{MBTU}{cubft}$$

BAAQMD Limit Margin

There is a certain amount of toxic emissions from a diesel generator. Therefore, the margin between the toxic emissions of this alternative and the Bay Area Air Quality Management District limit must be calculated from the particulate matter 10 emitted. The state limit for is particulate matter 10 (10 microns or smaller) $50 \,{}^{\mu g}\!/_{m^3}$ a day (California, 2005). The level of particulate matter 10 is assumed to be around $2.76 \,{}^{\mu g}\!/_{m^3}$.

$$100\% - \left(\frac{2.76 \,{}^{\mu g}\!/_{m^3}}{50 \,{}^{\mu g}\!/_{m^3}}\right) * 100\% = 94\%$$

B.4 Alternative 5 (Solar Panels/Wind Turbine)

Construction Rating

The construction rating is calculated by taking the average of the solar and wind construction scores. This method is justifiable because the construction resources are fully available for solar panels. The only detriment is the amount of resources required for the wind turbine installation.

$$\frac{10(solar)+9(wind)}{2}=9.5(solar/wind)$$

Efficiency Ratio

The efficiency ratio for the solar and wind combination is also found by taking the average of the efficiency ratio for both units individually. This is justified because the combination of both units should be considered as a whole.

$$\frac{0.2(solar)+0.25(wind)}{2}=0.225(solar/wind)$$

BAAQMD Limit Margin

There are no toxic emissions from solar panels or the wind turbine. Therefore, the margin between the toxic emissions of this alternative and the Bay Area Air Quality Management District limit is the highest level possible. The state limit for is particulate matter 10 (10 microns or smaller) $50\,{}^{\mu g}\!/_{m^3}$ a day (California, 2005).

$$100\%-\left(\frac{0\,{}^{\mu g}\!/_{m^3}}{50\,{}^{\mu g}\!/_{m^3}}\right)*100\%=100\%$$

B.5. Alternative 6 (Wind Turbines)

BAAQMD Limit Margin

There are no toxic emissions from wind turbines. Therefore, the margin between the toxic emissions of this alternative and the Bay Area Air Quality Management District limit is the highest level possible. The state limit for is particulate matter 10 (10 microns or smaller) $50\,{}^{\mu g}\!/_{m^3}$ a day (California, 2005).

$$100\% - \left(\frac{0\,{}^{\mu g}\!/\!_{m^3}}{50\,{}^{\mu g}\!/\!_{m^3}}\right) * 100\% = 100\%$$

Appendix C. First-Tier Value Scores

C.1 Site Appropriateness

The site appropriateness value scores shown in Figure 51 indicate that the submarine cable had the highest impact. The absence of obtaining values for the peak decibel level, mean decibel level, and aesthetics rating was a detriment for the alternatives of the wind turbine, 2 wind turbines, and solar panels/wind turbine. In addition, the submarine cable scored the highest possible value points for each site appropriateness value.

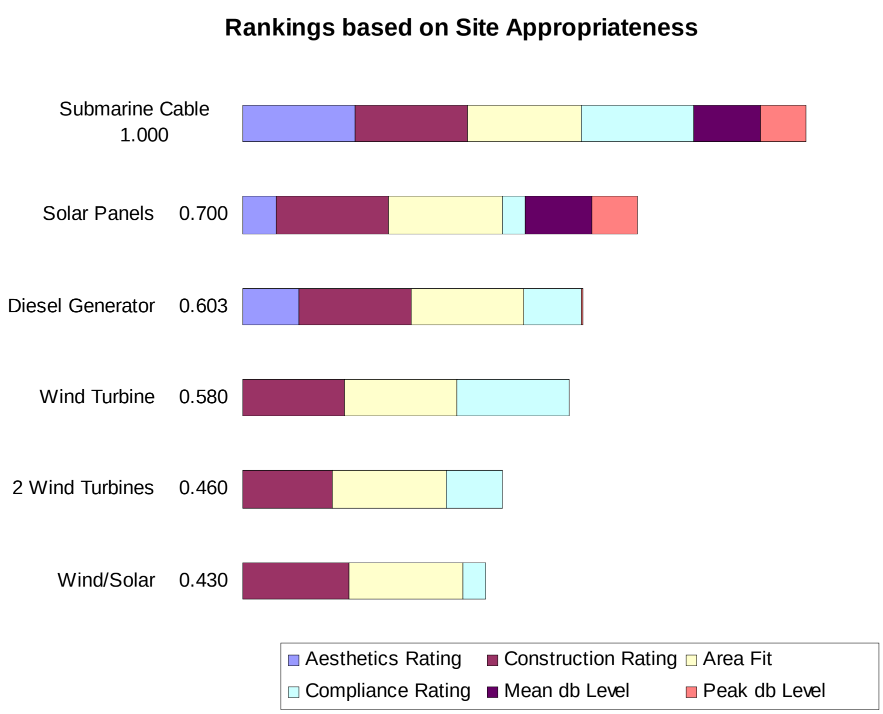

Figure 51. First-Tier Value Scores-Site Appropriateness

C.2 Operation

The first-tier value scores for operation in Figure 52 indicate that the submarine cable alternative is still the highest ranking alternative. The technical support availability value, shown by its measure of hours until arrival, was a large contributor to the submarine cable, diesel generator, and solar panel alternatives. The maintenance value would have made the value score of the diesel generator alternative more competitive with the submarine cable. However, these scores show the margin of victory apparent in the operation tier for the submarine cable.

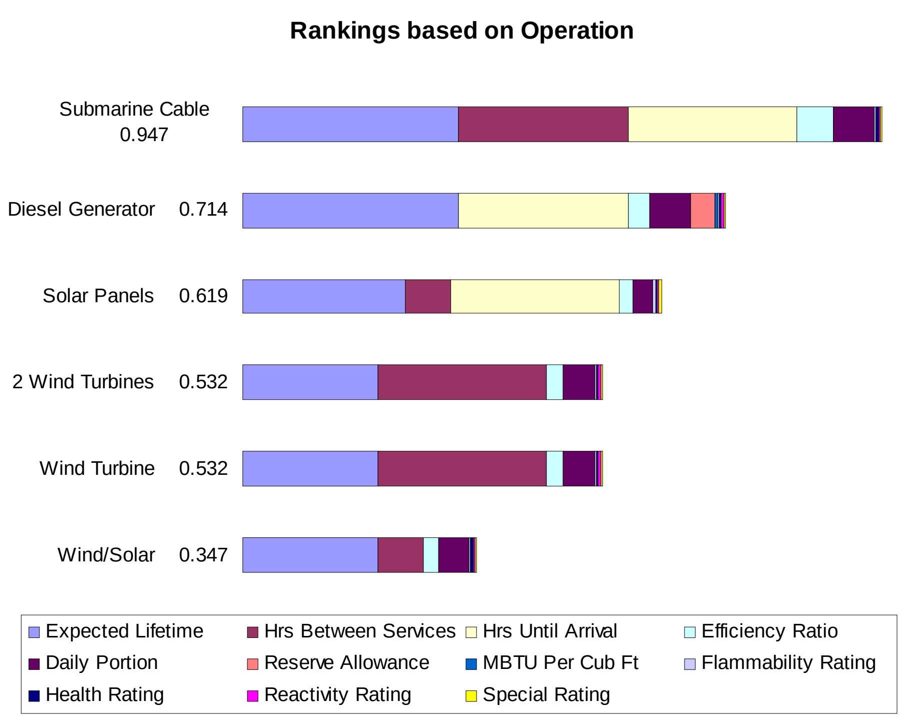

Figure 52. First-Tier Value Scores-Operation

C.3 Public Education

Figure 53 shows that the first-tier value scores of public education were either fully met or not at all. Interestingly, the submarine cable was one of the alternatives which did not score any value in this category, even though it has the highest overall value score. The diesel generator alternative also lacked any scoring in this tier. All other alternatives received maximum value scores for public education.

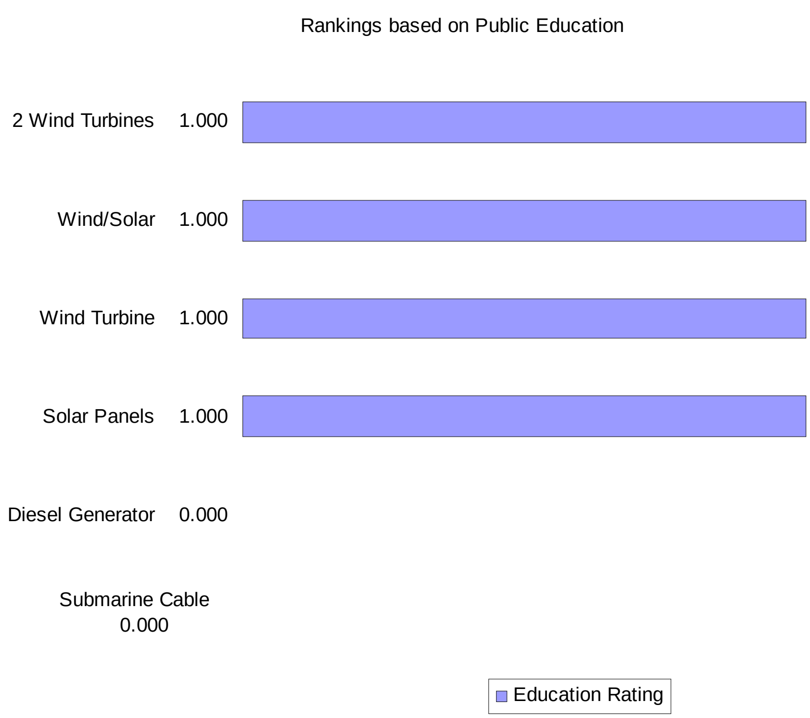

Figure 53. First-Tier Value Scores-Public Education

C.4 Environmental Impact

Figure 54 shows the environmental impact first-tier value scores for each alternative. Based on this figure, the submarine cable is the highest scoring alternative once again. However, the margin of dominance was not as high for this plot. The lack of the solar panel alternative from receiving higher cultural and natural preservation ratings resulted in the slim margin of inferiority. The only score associated with installing 2 wind turbines was from the emissions values.

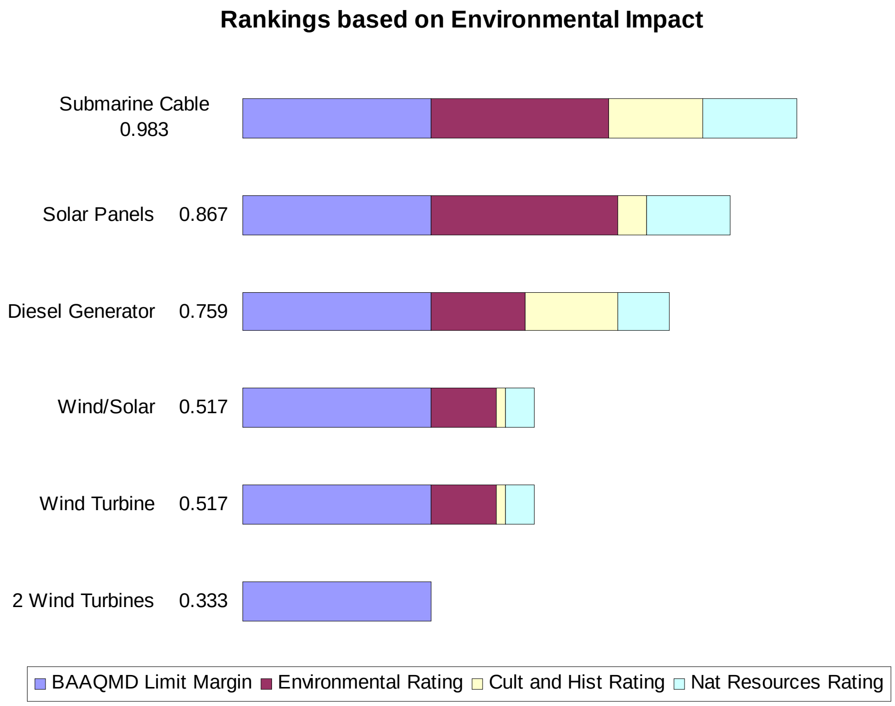

Figure 54. First-Tier Value Scores-Environmental Impact

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Vita

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14. ABSTRACT

The purpose of this research was to investigate the impact of using a decision analysis technique for the selection of an electrical generation system for remote locations. Specifically, this thesis sought to answer five research questions addressing the types of energy sources used in remote locations, the decision-making processes used to identify these sources, the types of constraints incorporated in such a process, other valued factors, and their level of importance in relation to each other. The research questions were answered through a comprehensive literature review and the 10-Step Value-Focused Thinking Process on a specific case study in the National Park Service. Decision makers comprising of the National Park staff offered their input into the execution of this process. Electrical system manufacturers and distributors were also consulted as subject matter experts. The research identified several electrical alternatives that are currently being used by remote locations around the world. However, decision process used to make such selections were undisclosed. A value-focused thinking model indicated the highest scoring electrical alternative based on constraints and factors provided decision makers. Limitations and assumptions applied to the model further highlighted the significant details.

The culmination of this effort was the introduction of a decision analysis technique to provide valuable information for the selection of electrical systems in remote locations. The implication of this study is the distribution of this technique to inhabitants in other isolated areas for effective decisions.

15. SUBJECT TERMS
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