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Renewable Energy in East Africa: An Introductory Evaluation Using a Systems Approach to Assess Alternatives to Providing Electricity

Isaiah O. Waindi [a] & Adeel Khalid [a]
[a] Systems Engineering, Division of Engineering, Southern Polytechnic State University, Marietta, Georgia, USA

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Renewable Energy in East Africa: An Introductory Evaluation Using a Systems Approach to Assess Alternatives to Providing Electricity

ISAIAH O. WAINDI and ADEEL KHALID
Systems Engineering, Division of Engineering, Southern Polytechnic State University, Marietta, Georgia, USA

Developing nations in Africa face significant challenges due to poor or no energy infrastructure, which continues to inhibit GDP growth. African nations in partnership with Western and emerging nations must develop flexible energy strategies, adaptable to the differing terrain and operating environment(s). Providing electricity for the region must be performed in sustainable, flexible, and affordable ways. In this article, the authors offer an introductory holistic look at the energy problem, outline the alternatives, and provide a general framework as to how a systems approach can be used to find renewable energy solutions.

KEYWORDS *East Africa, renewable electricity, systems approach*

INTRODUCTION

In this article we examine the current state of electricity in the East African (EA) region. We identify why modernization is necessary and why renewable energy options must be considered in concert with conventional energy options. In addition, we identify and illustrate how a systems approach to solving complex problems can be used in analyzing the EA region.

The African region is vast and very diverse, with each region (north, east, west, and south) having very different variables, such as terrain, economics, and politics. We will use as a case study three countries in Sub-Saharan African: Kenya, Uganda, and Tanzania. This area will serve as the

Address correspondence to Adeel Khalid, Systems Engineering, Division of Engineering, Southern Polytechnic State University, 1100 S. Marietta Parkway, Marietta, GA 30060, USA. E-mail: akhalid2@spsu.edu

foundation in evaluating the energy problem and identify several systems tools at the basic level to demonstrate problem solving and the importance of using a systems approach in development.

The Current State of Energy in East Africa

Africa is the second largest continent in the world, in terms of both size and population, yet the continent continues to experience slower than desired economic growth and significantly high poverty levels. Kenya, Tanzania, and Uganda have populations of approximately 40 million, 41 million, and 33 million respectively (CIA, n.d.).

According to the U.S. Energy Information Administration, the most demand for energy from 2007 to 2035 will come from countries that are not considered members of the Organization for Economic Cooperation and Development (OECD). As illustrated in Figure 1, this includes countries in the EA region. This growth, however, is not keeping pace with that of some emerging countries such as China and India. The high levels of unemployment, which directly correlate to the high levels of poverty, prevent the region from experiencing increased capacity in the rural areas. These three countries have measurably large unemployment levels with a large percentage of the population living in rural areas with no access to electricity, illustrated in Figure 2. The average urban electrification in the region is approximately 22%, and that in rural areas is 4%. Figure 3 gives a comparison of the energy consumption per capita for the region compared with some

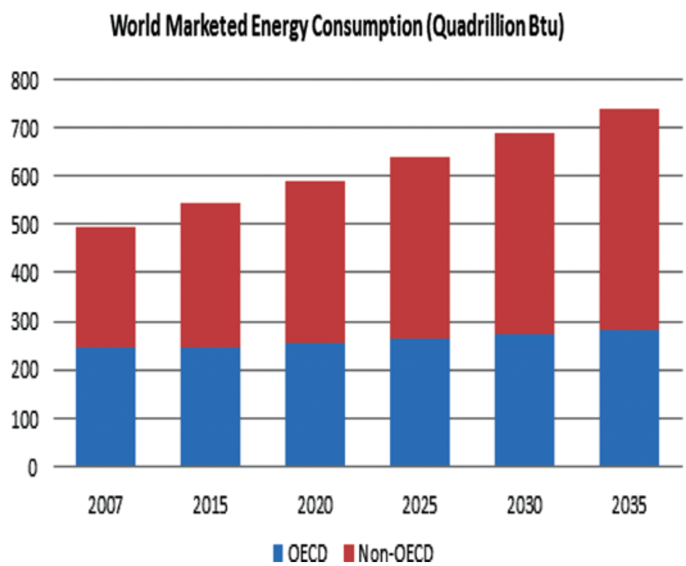

FIGURE 1 World marketed energy consumption (U.S. Energy Information Administration, 2010). (Color figure available online.)

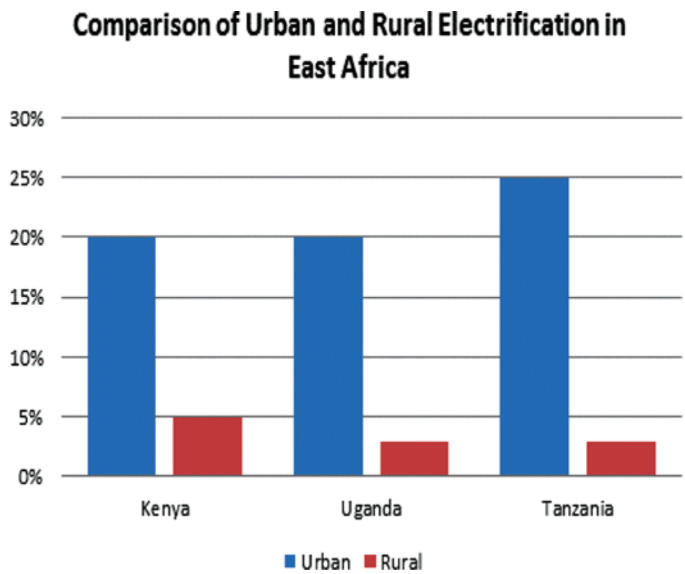

FIGURE 2 Urban and rural electrification in East Africa (Karekezi & Kithyoma, 2003). (Color figure available online.)

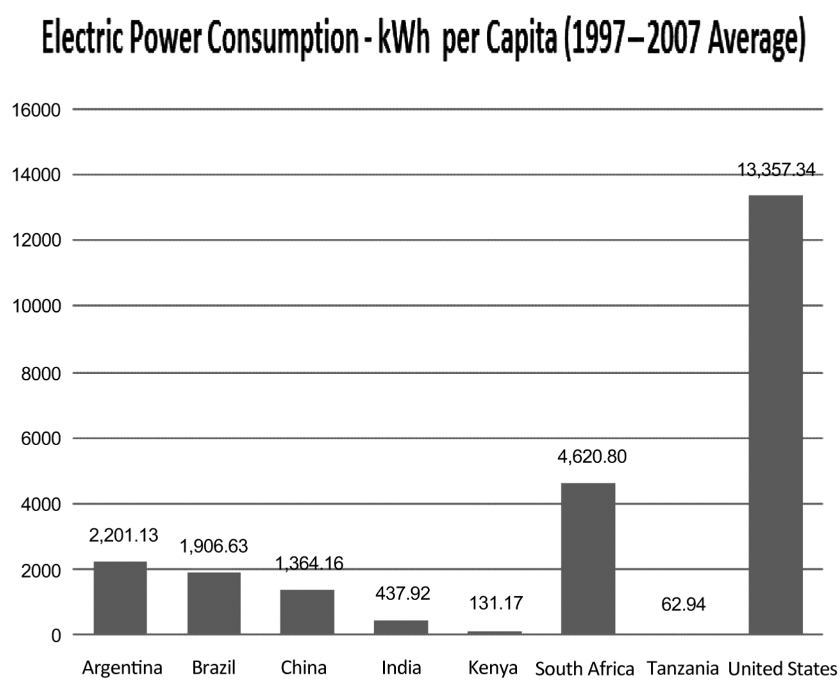

FIGURE 3 Comparison of electric power consumption per capita (The World Bank, 2010).

notable countries. When compared with the United States, for example, it is clear that a significant gap exists in the region in providing electricity across identified populations.

The current state of energy in the region is characterized by a heavy dependence on biofuels in the rural areas. While biofuels is one of the alternatives for renewable clean energy, the current form of use in the region is in the "traditional" sense and has serious environmental and health disadvantages (Karekezi, 2003). Research indicates that given the current wide-scale electricity limitations, rural communities are forced to resort to using unvented biofuel cooking stoves, which contribute to indoor air pollution. This is also contributing to higher numbers of respiratory illnesses.

The electricity sector in EA is also affected by heavy system losses. This is due to a heavy reliance in hydropower in producing electricity. This reliance, however, is affected by climate conditions in the region. Whenever severe drought is experienced, significant losses in electricity output are experienced. This leads to massive rationing of power, which affects the productivity of the industrial base as well as the local populous way of life in the cities.

The region is also faced with a slow economic growth due to poor government policies. The governments in the region do not have good executable frameworks and policies for electricity capacity expansion. This deficiency has made it very difficult for renewable energy implementation.

Infrastructure Development

The EA region must bring its infrastructure into the twenty-first century. To compete with China, India, and countries in Southern Africa, public transportation, roads, public health systems, and the energy sector must be developed.

Electricity Capacity Development

As new systems are developed, it will be necessary to consider alternative sources of fuel. This is necessary to ensure sustainability and security. The region has for a long time relied on the rest of the world to establish the trends with respect to energy policy. This must change as they seek to modernize and produce more electricity. They must consider renewable energy systems from the onset of development.

Renewable Energy

Renewable energy sources offer great potential to solving some of Africa's energy problems. As illustrated in Figure 4, renewable energy use is

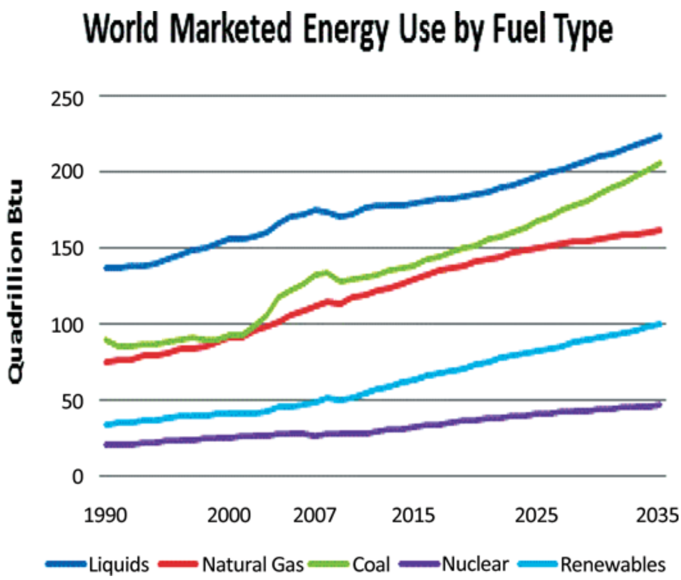

FIGURE 4 World market energy use by fuel type (U.S. Energy Information Administration, 2010). (Color figure available online.)

projected to continue increasing; however, it does not keep pace with use from natural gas or coal. Therefore, renewable energy solutions must be developed to reduce the dependency on coal for instance.
Africa has many avenues for renewable energy, including, the following.

Solar Power

The African continent has large desert areas with significant exposure to the sun. This could be exploited by using solar technology to provide electricity. Solar technology can be used in two ways. The first involves using solar cells, which convert energy from the sun's rays into electricity. The second method involves using the heat from the sun's rays to heat water in pipes or reservoirs. The super-heated steam could then be used to turn a turbine or generator, which would in turn generate electricity.

Geothermal Energy

The region has tremendous geothermal potential due to the Rift Valley region, which has volcanic activity underneath the earth's crust. Geothermal energy is natural heat from the earth's core that has been stored in rocks and water. This source is made possible because there is a constant flow of heat from the earth's core. The energy is extracted by drilling to tap the concentrations of steam at high pressures and depths low enough for economic viability. The steam is then used to power electricity-generating turbines (Karekezi, 2003).

Hydropower

This source uses moving water to power generators and turbines. This method of electricity generation is currently being used in the region. It is encumbered by changes in the climate (i.e., drought, which causes reduction in water levels leading to system losses, which leads to power rationing).

As hydropower is already used extensively in the region, it will not be discussed as one of the alternatives. More than 70% of current electricity generation in Kenya comes from hydropower and geothermal sources as illustrated in Figure 5.

Traditional forms of biomass are used in the region to produce energy. This energy is used in small stoves and in personal lanterns. The current form of use, however, has negative impacts on the environment as well as health consequences from indoor air pollution. Modern forms of biomass technology exist, which, if exploited by the region, could generate clean electricity for the rural areas.

Wind Energy

The EA region is not the best suited region for wind energy according to various studies and reports. However, the potential exists for wind energy in pumping water from wells as well as using low-speed wind vanes in the generation of electricity.

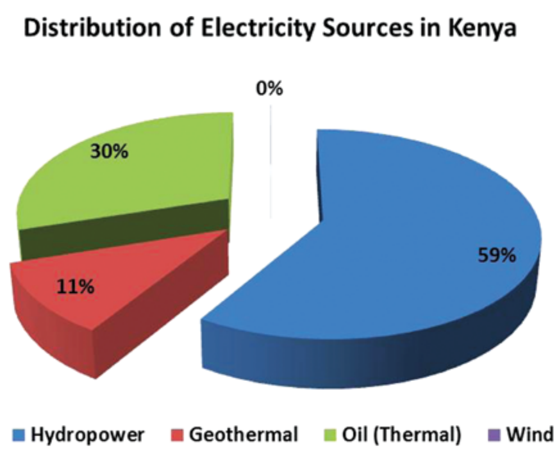

FIGURE 5 Distribution of energy sources in Kenya (United Nations Environmental Program, 2006). (Color figure available online.)

ANALYSIS

Problem Definition

Solving the EA region's energy problem is complex. There are numerous variables that must be addressed to identify feasible solutions. The first step to providing solutions is to adequately evaluate the problem. A systems approach offers a great way to examine the complexities, relationships between entities, and the system interfaces (boundaries) and so on. This article does not provide a comprehensive analysis but does identify some considerations for stakeholders and system designers. To develop alternatives for consideration, it is important to ensure that the problem is well understood. Defining the problem is a vital step that must first be performed before requirements can be formulated. These requirements are then used to analyze the alternatives and validate the solution.

Problem Statement Formulation

There are numerous challenges with evaluating a problem statement with the renewable energy problem. A systems approach offers a methodical way of evaluation. According to Sage and Armstrong (2000), assessing the problem begins with a situation assessment (p. 87), as follows.

Situation Assessment

A situation assessment is composed of three steps:

1. Background scenario. This identifies the past state of the renewable energy utilization in the region. In this case, renewable energy had not been utilized for electricity production in any significant capacity. The EA region like most of Sub-Saharan Africa had been slow to see technological improvements that have improved their infrastructure and economies.
2. Descriptive scenario. This describes the current state of the system. The region has been dependent on conventional sources of electricity production with a heavy reliance on hydropower and traditional forms of biomass for localized energy production in the rural areas. Between the three countries, Kenya is the only country in the region that currently uses geothermal energy from three plants that produce approximately 70 MW of power, representing about 16% of electricity added to the national grid (Byakola, Lema, Krisjandottir, & Lineikro, 2009).
3. Normative scenario. This describes the desired state of the system. This gives an idea of the objectives that this system should attempt to achieve. The overall objective of this system is to provide clean, reliable and affordable electricity for the EA region. The challenges to this objective include the following.

Lack of Adequate Policies

In the past, the governments have not had policies that have advocated or supported the renewable energy push in the electricity production discussion. Existing policies have not been well articulated and have failed to have a clear strategy for widespread development. This has led to local projects that have failed because of the lack of local government and community support, especially in the rural areas.

Governments have failed to implement laws that support a clear energy strategy pushing for energy security. Energy security and independence have been discussed at the government level and renewable energy must be a part of this discussion as the African continent goes into the twenty-first century.

Lack of Technology

Each region faces different challenges with managing and developing plans for energy security. For example, while there might be some similarity, China does not face the same challenges as the United States. Similarly, the EA region has very different challenges from those countries. These technologies are being developed to solve problems for the regions that identified the need. Wind energy is a great source of electricity in the United States; however, it may not work as well in EA. Alternatively, solar power would be well suited for the tropical region, which receives great amounts of sunlight.

Technology maturity is another challenge. With increasing demand for oil from China, India, Brazil, and other emerging nations, renewable energy has begun to receive significant attention and investment as countries look for energy independence and security. Previously, renewable energy technology for a long time did not keep pace with the changes in oil prices. It is much more cost effective to produce electricity using coal than it is to produce it from solar energy or wind energy. However, continued increases in oil prices due to the increased demand meant that renewable energy sources could become competitive; hence, companies became more willing to invest in their development. Africa can benefit from this as the region depends on the technology developed from Western countries.

Another important point is the reliance on technology developed overseas but a lack of technical competence. The region relies on technology developed by the Western world; hence, the technical skills sets are not available locally. For the rural areas, significant training must be performed at the local level for any systems being developed to ensure supportability and maintainability.

Financial Constraints

The region relies on donor support from the United States and Asian and European nations; 50% of the region lives below the poverty level, and there is a heavy reliance on traditional subsistence farming (CIA, n.d.). Any program would require substantial external support, which would significantly limit the potential development.

Identification of Needs

The situation assessment gives a good indication of what are the needs, which is useful in identifying objectives. This is important in both understanding the problem and developing useful alternatives that could potentially solve the renewable energy problem. The overall top level needs for this system can be identified as shown in Table 1. Using these top level needs, a system definition matrix can be developed that documents the scope and bounds of the problem.

System Definition Matrix (SDM)

As shown in Table 2, the SDM is useful in listing the needs, objectives, and criteria for the system. It also lists the possible parameters, variables, and constraints, effectively defining the bounds for the system (Sage & Armstrong, 2000). With the SDM, a clear dialog can begin with stakeholders, which will be useful in the development of requirements.

Using the SDM, a cross interaction matrix (CIM) can be developed that evaluates how the objectives interact with each other. This is useful in identifying which objectives may enhance each other or where there might be conflict (Sage & Armstrong, 2000).

Table 3 shows a CIM for the renewable energy problem, where a "+" indicates a positive association, a "–" indicates a conflicting association, and "0" indicates no apparent association between the objectives. From the CIM, it becomes apparent that the objective "to increase availability of affordable electricity" may conflict with the objective "to reduce harmful effects of pollution" and "to reduce harmful health effects from pollution." This indicates that those requirements may hinder each other and will probably require tradeoffs with each other if the system is to become successful.

TABLE 1 Top Level System Needs

Indicator	Need
N1	Energy security and independence
N2	Increased capacity for electricity production
N3	Poverty reduction
N4	Environmentally clean systems
N5	Safety protection

TABLE 2 System Definition Matrix (SDM)

	SCOPE		BOUND		
Needs	Objective	Criteria	Parameters	Variables	Constraints
Energy security and independence	To reduce the reliance on foreign oil for electricity generation	Reduced oil imports spent on electricity generation	Amount of oil utilized for electricity generation	Barrels per day	Cost
Increased electricity capacity	To increase the availability of affordable electricity for urban and rural areas	Increased electricity production and consumption per capita	Number of available sources of electricity generation	kWh per capita	Cost, land availability, technology
Poverty reduction	To create a technical workforce and improve way of life	Creation of and increased employment in job sector	Number of jobs created and or increased	Labor force per sector (industry and services)	Cost, technical competence, technology availability
Environmentally clean systems	To reduce the harmful effects of pollution on the environment	Reduced de-forestation, reduced emissions	Available forest acreage	Kg per household	Emissions laws and standards
Safety protection	To reduce the harmful health effects from pollution	Reduced lung and respiratory diseases	Doctor visits	Number of doctor visits	Laws and public policy

TABLE 3 Cross Interaction Matrix (CIM)

Objective	To reduce the reliance on foreign oil for electricity generation	To increase the availability of affordable electricity for urban and rural areas	To create a technical workforce and improve way of life	To reduce the harmful effects of pollution on the environment	To reduce the harmful health effects from pollution
To reduce the reliance on foreign oil for electricity generation	NA	+	+	0	0
To increase the availability of affordable electricity for urban and rural areas	+	NA	+	–	–
To create a technical workforce and improve way of life	+	+	NA	+	+
To reduce the harmful effects of pollution on the environment	0	–	+	NA	+
To reduce the harmful health effects from pollution	0	–	+	+	NA

Objective Tree Hierarchies

The tree identifies the hierarchy of objectives. It is useful in identifying lower-level objectives, which are more measurable than top-level objectives (Sage & Armstrong, 2000). At lower levels, activities and functions are defined that stakeholders are able to pursue. In accomplishing the low-level objectives, the higher-level objectives are accomplished as well. For the renewable energy system, Figure 6 shows how an objective tree can be used.

The objective tree answers the questions of "how" and "why" a system should be developed. Going down the tree looking at any branch tells the "why" for any lower-level objective, while looking up the tree should identify "how" for the higher-level objective.

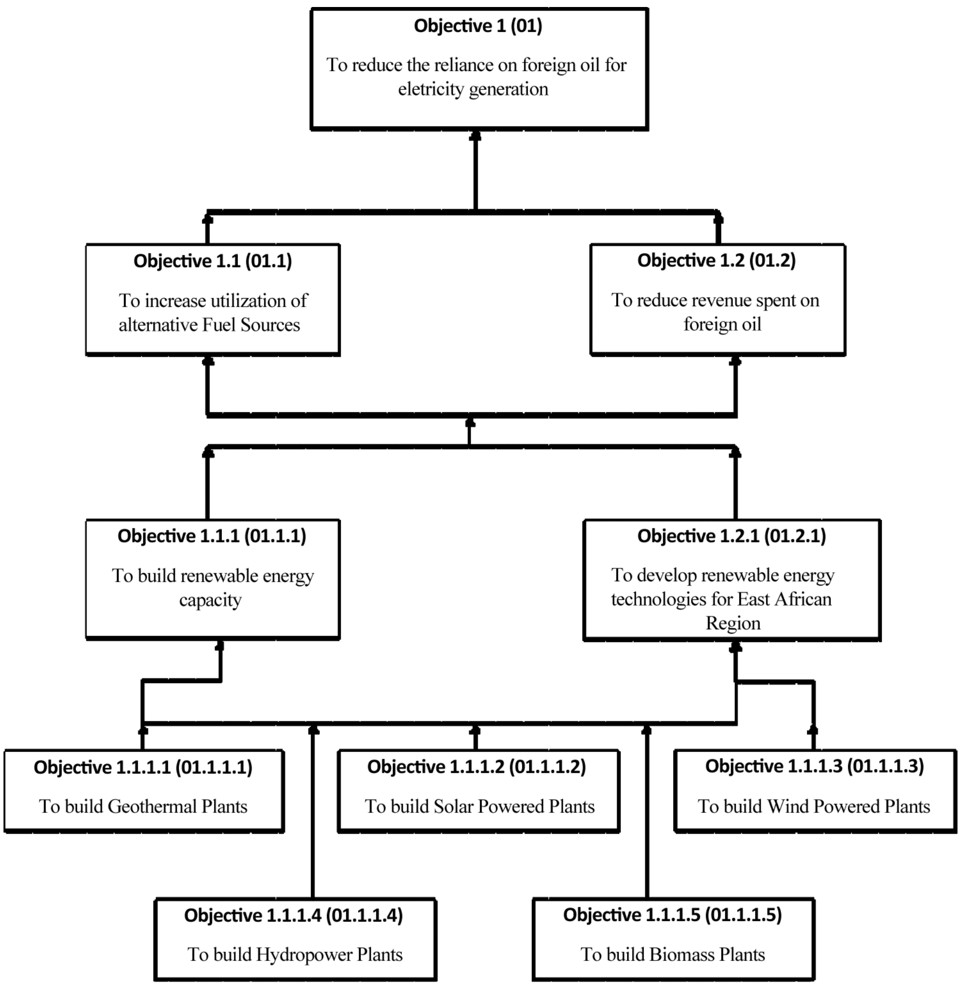

FIGURE 6 Example of objective tree for renewable energy problem.

System Strategy

Using the information just given, a comprehensive strategy begins to appear that can be used to analyze the alternatives. Before alternatives can be considered, the objectives will help in understanding the overall system. From the top-level needs, derived down to the system objectives, a picture of the system begins to develop as illustrated in Figure 7.

It becomes clear that three stages are required to develop an effective system:

1. Small-scale system scenario. These alternatives must address the needs for rural areas. Considerations must be modular and adaptable to the harsh terrain witnessed in the African rural areas. These systems should be intended to serve local communities with no intention of being integrated into the national grid. The main purposes for these systems should be basic lighting, cooking, and refrigeration.
2. Hybrid system scenario. These systems are meshed between the small-scale systems for rural areas and the large power systems necessary for urban cities. These systems are intended to provide power for larger populations such as community centers. These should be designed to

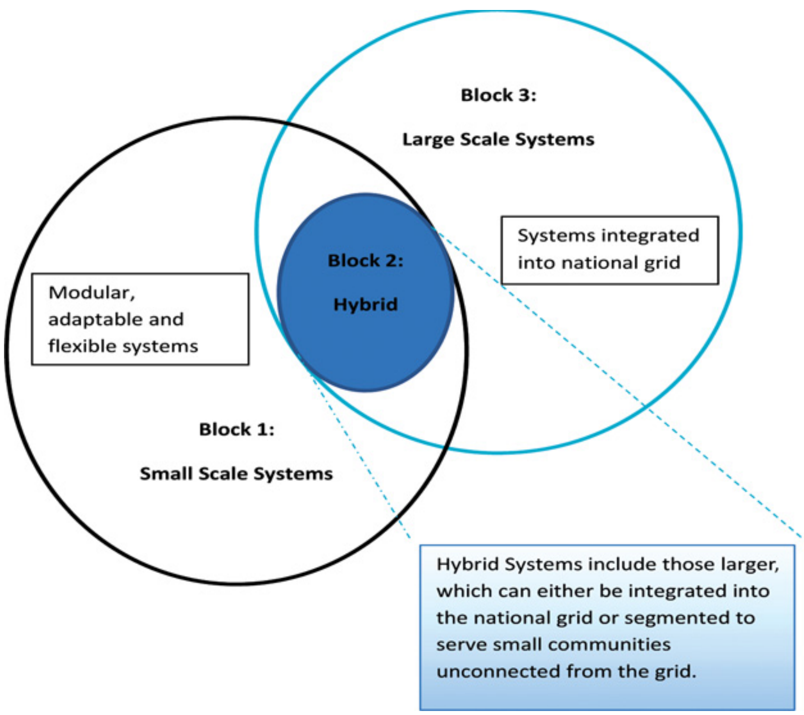

FIGURE 7 Strategic picture of overall system. (Color figure available online.)

provide power for hospitals, schools, police stations, as well as individual homes. These systems can be integrated into the national grids and so should be flexible. The benefit of this type of system is that it creates a network of hubs or nodes interspersed throughout the region. A scale-free network would work well in this environment as grid integration may not be feasible. Considerations should be given for scale-free development where each plant would serve as a hub or node for a segmented area. This would provide a means to ensure that the national grid system does not become overloaded. It would also mean, however, that if one of the nodes or hubs went down, the system may or may not be able to rout from another source until power was restored, depending on the number of nodes within the network.

3. Large-scale scenario. The large-scale system would be intended for large metropolitan areas. It would function as the typical large cities with large urban populations, businesses, and industrial complexes. This system would be the typical grid-connected network. Renewable energy solutions such as biomass should be integrated into this system.

REQUIREMENTS

Requirements Formulation

Once a sense of the objectives is developed, the next step is developing requirements with which alternatives can be assessed. Formulating appropriate requirements is perhaps the most important step in systems engineering. Understanding the end users' needs by translating them into requirements is important in ensuring the "best" system is developed. Requirements act as the bridge between the user and the systems engineers developing the system.

Developing requirements is labor intensive and requires significant involvement from all stakeholders in order to ensure that each requirement clearly and adequately captures the intent of the objective. Given the scope of this article, the focus is more on a technique that can be used to begin the requirements formulation process.

One system engineering tool that relates the user objectives to design requirements is the quality functional deployment (QFD) matrix. QFD uses a set of matrices (house of quality) to correlate the user needs (objectives in this case) to the product's technical requirements (Evans & Lindsay, 2008). QFD keeps the focus during system development on customer requirements. QFD can be useful in identifying potential issues at an early stage of development (Sage & Armstrong, 2009). Figure 8 shows an example of a QFD model.

From the QFD model, determining the technical requirements becomes the first step before the QFD model can be effectively used. If the customer

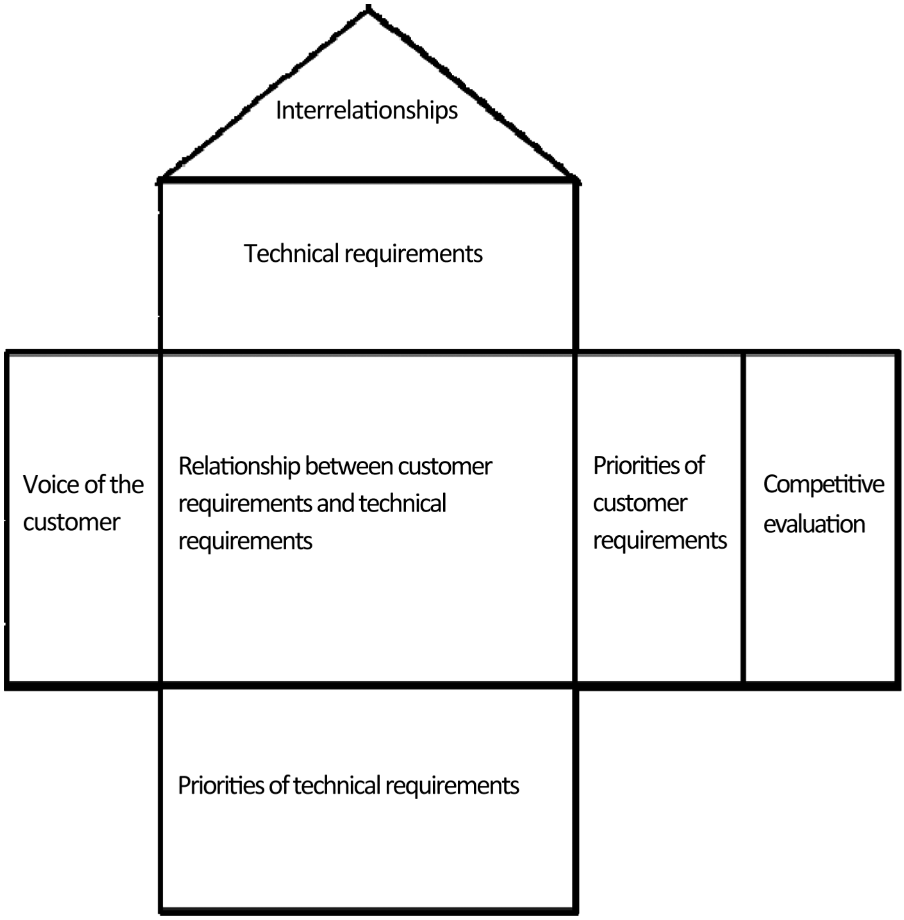

FIGURE 8 House of quality (Evans & Lindsay, 2008).

requirements or objectives in this case are the "whats," the technical requirements answer the question "how." The technical requirements must be related to each customer objective in more measurable or quantifiable means. For the renewable energy problem, this can be expressed as shown in Table 4.

Using the determined objectives and the derived requirements, a flowchart can be developed based on the following requirements as shown in Figure 9.

A QFD model can now be developed using the customer objectives and by relating them to each of the requirements. This process helps to identify the most important priorities of the overall system, which is useful in determining contractual requirements that must be fulfilled. The next series of figures identify how QFD is used for the electricity problem.

The first stage is assigning "levels of importance" to each customer objective (customer expectation) in this example as shown in Table 5. Those

TABLE 4 Relating Objectives to a Measurable Technical Requirement

Objective	Criteria	Variables from SDM	Technical requirement
To reduce the reliance on foreign oil for electricity generation	Reduced oil imports spent on electricity generation	Barrels per day	Electricity sources
To increase the availability of affordable electricity for urban and rural areas	Increased electricity production and consumption per capita	kWh per capita	Electricity quantity
To create a technical workforce and improve way of life	Creation of and increased employment in job sector	Labor force per sector (industry and services)	Labor force proficiency
To reduce the harmful effects of pollution on the environment	Reduced de-forestation, Reduced emissions	Kg per household	Clean electricity
To reduce the harmful health effects from pollution	Reduced lung and respiratory diseases	Number of doctor visits	Electricity access

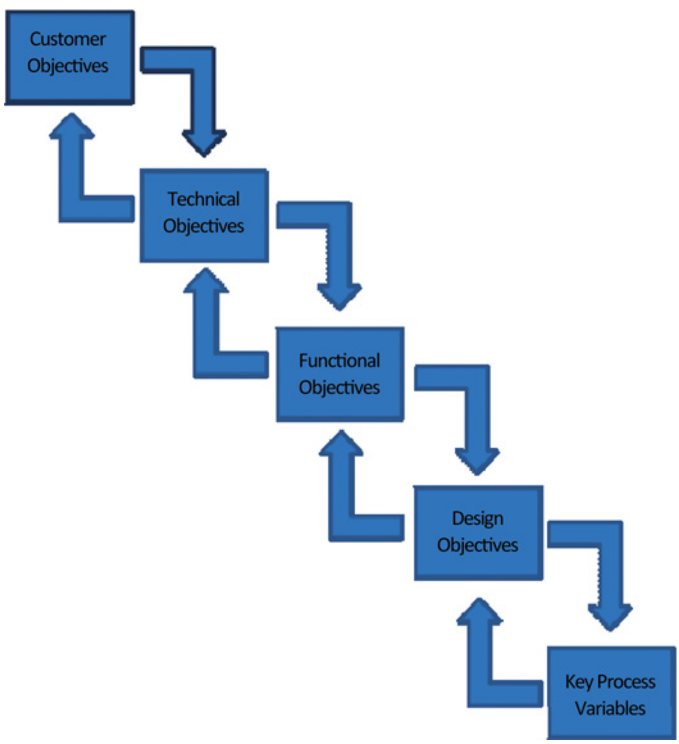

FIGURE 9 Customer requirements flow. (Color figure available online.)

TABLE 5 Customer Objectives Related to Technical Requirements

Y's (What's)	Importance	Alternative electricity sources	Electricity quantity	Labor force proficiency	Clean electricity	Electricity access	Total
To reduce the reliance on foreign oil for electricity generation	3	M	M	L			21
To increase the availability of affordable electricity for urban and rural areas	5	H	H			H	135
To create a technical workforce and improve way of life	4			H		L	40
To reduce the harmful effects of pollution on the environment	3	H			H		54
To reduce the harmful health effects from pollution	4	H	L		H		76
Total		117	58	39	63	49	326
Relative Weight (Priority)		35.89%	17.79%	11.96%	19.33%	15.03%	

levels of importance are basically numerical "weights," which will be used to assign scores in the house of quality.

From the customer top level needs, "increasing the availability of affordable electricity for urban and rural areas" is assigned the highest weight. This is because that objective can be linked to most of the other requirements. Using the importance rating of each objective, the derived technical requirement can then be assessed for each objective. Here a scale with weights is used as follows: low = 1, medium = 3, and high = 9.

The scale is used to score each technical requirement in the house of quality matrix with each objective getting an "L", "M," or "H"; for example,

Using the objective: "To reduce the reliance on foreign oil for electricity generation" has an assigned importance of 3.

When this is compared to the derived technical requirement of "alternative electricity sources," an "M" is assigned.

So using: Importance × weighted scale

For this example, $3 \times 3 = 9$

The totals for the individual scored technical requirements are then summed up for each column as shown in Table 5. This process continues for each requirement, down to the key process variables, which help drive each requirement. The next few pages show how the model is translated into the key process variables.

As previously mentioned, developing requirements is a critical step and there are many tools available to ensure that adequate requirements are captured. This article just highlights one such tool that could be used in the beginning stages of the requirements formulation. This model shows that customer objectives can be traced down to a requirement and conversely that requirement back up to an objective. An observation from the model identifies the key design requirements as building new and updating existing plants. As these requirements are traced back through the house of quality, it becomes clear that in order to solve the problem and hence meet the objectives, the alternatives will have to meet that requirement.

ANALYSIS OF ALTERNATIVES

Analysis of alternatives (AoA) is an objective analysis effort that studies the costs, effectiveness, and risks for potential solutions to a stated requirement. AoA should inform decision makers well enough so they can wisely choose an alternative. Given the scope of this article, a complete AoA cannot be performed. This article will, however, highlight a useful tool that can be used in the AoA.

When it comes to comparing these alternatives, many analysis tools exist but this report will highlight the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS) method. The main idea behind TOPSIS is that the chosen alternative should be as close to the ideal solution and as far from the negative-ideal solution as possible. TOPSIS is a useful tool in evaluating alternatives in multicriteria decision making.

As previously mentioned in Figure 6, the best approach is dividing these technologies into three segments: large, small, and a hybrid system that may constitute a cross between two or more of the other systems. For the purposes of this report, the AoA will be performed on the large- and small-scale items under consideration.

Hydropower is not considered because it is currently the primary source of electricity generation in the region. The purpose of this article is to identify additional sources that could bolster the current capacity.

The Large-Scale Scenario

This section will focus on the large system approach but could be performed similarly for small-scale systems. Providing electricity for the region poses some significant challenges. The next section looks at the available technologies and assesses their viability in meeting the set-forth objectives.

Solar Energy

Solar power can be broken into two categories: solar photovoltaic (PV) technology and concentrated solar power (CSP). PV directly converts the sun's energy into electrical energy and solar thermal energy. This system uses solar cells, which convert energy from the sun into electricity. This electricity can then be used to power equipment.

CSP uses the heat from sunlight to generate electricity. This technology differs from solar PV in that CSP does not directly convert the sun's energy into electricity. There are three main types of CSP systems:

Linear concentrator systems (LCS). This technology uses long rectangular mirrors that are curved in the direction of the sun. Several kinds of LCS exist: parabolic trough systems, which have receiver tubes running along the "focal" of each parabolic mirror, and the linear Fresnel system, which has receiver tubes positioned above several mirrors (Nair, 2009). These tubes carry superheated water, which drives the turbine used in the generation of electricity.

Dish (engine) systems. Sunlight is reflected onto a thermal receiver using a large mirrored dish. This dish is mounted onto a base, which is powered to track the dish with the sun's movement. This receiver absorbs heat, which is transferred to a generator (Nair, 2009).

Power tower systems. This system uses an array of flat mirrors (Heliostats) that concentrate the sunlight to the top of a tower. This tower has a thermal receiver that generates heat used to run a turbine (Nair, 2009).

Solar energy is advantageous in that the sun is a readily available resource and the region receives abundant sunshine. This technology has near zero emissions, which make it great for sustainable development. Another important factor is that the technology is proved and reliable. The challenges with solar energy are high setup costs, which may be difficult to overcome considering the financial constraints on the region. Another challenge is that implementation requires a significant foot print, which makes this not suited for small-scale projects.

Geothermal Energy

Geothermal energy takes heat from within the earth's crust, which can be used to generate electricity. Geothermal plants use high temperature (300°F to 700°F) from either wet or dry wells, which are drilled beneath the earth's surface.

The benefit of geothermal energy is that it produces near zero emissions, which is good for the environment. Another advantage is that plants do not require a significant footprint when compared to solar energy plants.

The challenges of implementing geothermal energy for electricity production are the high initial setup costs, which are still lower than those for solar energy. Another significant challenge is the fact that the resource is limited. The heat in the earth's core may decrease over time, which affects the life cycle for these projects.

According to the U.S. Energy Information Association (EIA), there are three types of geothermal plants:

Dry steam plants. This system uses steam that is piped directly from a well that turns the generator turbines.

Flash steam plants. This system takes hot water at high pressure from deep inside the earth's core and converts it to steam, which in turn drives the generator turbines. As the steam cools and condenses into water, it is recycled back into the ground and the process is repeated.

Binary cycle power plants. This system transfers heat from geothermal hot water to another liquid (e.g., oil). This liquid then turns to steam, which is used to drive a generator turbine.

Biomass Technology

Electricity from biomass is best exemplified by cogeneration. Cogeneration uses a power station to generate both electricity and heat (Karekezi, 2003). Conventional power plants radiate heat as a byproduct of the electricity they produce. However, in cogeneration, also known as combined heat and power (CHP), the byproduct heat is captured from the basic industrial process and used in conjunction with a water (liquid) source to produce steam, which turns a generator turbine. Biomass as a source of electricity generation is suited for the EA region, which has a rich agricultural industrial base.

Biomass offers the advantages of being environmentally friendly; it is inexpensive to implement compared to solar and geothermal. The technology is relatively easy and very efficient. Biomass is suited for both small-scale and large-scale integration, and cogeneration is probably the best suited approach for the region. This is because electricity would essentially be a beneficial byproduct of a basic industry such as sugar cane or corn production.

There are several challenges with using biomass; it does not generate enough capacity to be used as a sole source of electricity production. This limitation, however, makes biomass a good consideration for smaller-scale electricity production where factories are located in rural farm areas with segregated populations. The electricity produced can power the factories and local communities, and the surplus can be sold to the national grid if necessary.

Another challenge with biomass as a small-scale option for electricity generation is the setup costs. While these costs have been identified as being less than those for the other options, rural areas where this technology is probably best suited is also where the poorest communities are often found.

THE SMALL SCALE ALTERNATIVES

Wind Energy

Wind energy is categorized with the small-scale systems as the region is not ideally suited for developing large-scale wind farms. This is due to the low wind speeds in the region, which when compounded with the system development costs, create the infeasibility. The region has wind speeds ranging approximately between 3.5 and 5.5 meters per second (7.8 and 12.3 miles per hour) (Climate Charts.com, n.d.).

Wind systems convert the kinetic energy produced by the wind, which is converted into mechanical energy. The mechanical energy is used to drive a generator, which produces electricity. The great advantage of wind technology is near zero emissions.

Microbial Technology

Microbial fuel cells (MFCs) obtain a small current, which exists naturally in dirt as it breaks down organic material. A chemical reaction occurs in which an anode and a cathode are used to generate small amounts of electricity (Nair, 2009).

The advantage of microbial technology is that "dirt" is readily available. The challenges with this technology are low power generation. Currently, only low power levels can be produced, which can only power devices such as batteries or light-emitting diodes (LED) lights. Another challenge is the lack of technology maturity.

Biomass Technology

The previous section discussed how biomass could be used for large -scale electricity production. This section highlights how biomass (biogas) could be used for electricity generation but on a much smaller scale. Biogas is derived from a mixture of methane and carbon dioxide produced during the decomposition of organic substances (Nixon Energy Solutions, n.d.).

Using biomass technology in this way would provide electricity for rural areas that are very remote, thus making connection to the national electricity grid difficult.

A Systems Approach to Evaluating Alternatives

Using a systems approach provides designers with a great way to analyze and assess alternatives with complex considerations. One method is the

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model, which offers several advantages for analysis:

1. It is simple to use.
2. It is difficult to dispute the resultant rankings obtained from the model.

The Renewable Electricity Large System (RELS) Alternatives

For this analysis, the first step is to create a decision matrix by grouping the alternatives with objective/subjective criteria as shown in Table 6. Once the decision matrix is obtained, the model can be executed as shown in Tables 10 through 19.

A qualitative scale is necessary for weighing the subjective criteria. The environmental and operating costs are shown as subjective criteria for this analysis.

The next step is to assign numerical values to all the subjective criteria as shown in Table 8 using the qualitative weight scale in Table 11, as shown in Table 12.

Once numeric values as assigned to every value, the next step is to normalize the values. This is done by dividing the numerical value of each attribute for each alternative by the square root of the sum of squares of each value corresponding to that attribute as shown:

$$\frac{Attribute}{\sum[(Attributes)^2]}$$

The results are shown in Table 13.

TABLE 6 Technical Requirements Related to Derived Functional Requirements

Y's (What's)	Relative weight	Create renewable energy sources	Increase electricity capacity	Create jobs and training	Emissions reduction	Build local infrastructure	Total
Alternative electricity sources	36	H	H	L	H	H	1327.91
Electricity quantity	18	M	H	L	L	M	302.45
Labor force proficiency	12	M	L	H		H	263.19
Clean electricity	19	H	L		H		367.18
Electricity access	15	M	H		H	H	450.92
Total		631.288	649.693	161.350	650.000	619.325	2711.656
Relative weight (Priority)		23.28%	23.96%	5.95%	23.97%	22.84%	

TABLE 7 Functional Requirements Related to Design Requirements

Y's (What's)	Relative weight	Build plants (geothermal, solar, biomass)	Upgrade existing plants	Create technical and trade schools	Establish new and upgrade current emission standards	Establish electricity connections	Total
Create renewable energy sources	23.280543	H	L	L	L	L	325.9276
Increase electricity capacity	23.959276	H	H	L	L	L	790.6561
Create jobs and training	5.9502262	H	M	H	L	H	0
Emissions reduction	23.970588	H	L	L	H	L	124.9548
Build local infrastructure	22.839367	H	M	H	L	H	1119.129
Total		684.26	313.38	258.74	123.63	258.74	2360.67
Relative weight (Priority)		29.0%	13.3%	11.0%	5.2%	11.0%	

TABLE 8 Design Requirements Related to Key Process Variables

Y's (What's)	Relative weight	International aid and local investment	Efficient technologies	Laws, policies and frameworks	Current/ existing infrastructure	Total
Build plants (geothermal, solar, biomass)	28.99	H	H	L	L	550.7353
Upgrade existing plants	13.28	H	H	L	L	265.5032
Create technical and trade schools	10.96	H	L	L	L	230.1735
Establish new and upgrade current emission standards	5.237	L	L	H	L	62.84556
Establish electricity connections	10.96	H	M	L	H	241.1342
Total		582.8798	429.4308	82.33062	197.2465	1390.533
Relative weight (Priority)		42%	31%	6%	14%	

TABLE 9 Alternatives Breakdown Table

Large-scale system	Small-scale system
Geothermal	Wind
Solar	Microbial
Biomass	Biomass

TABLE 10 RELS Decision Matrix

	Data					
	Capital cost ($M)	Environmental impact	Technology readiness level (TRL)	Gross output (MW)	Pollution control	Operating costs
Geothermal energy	1,850	Excellent	9	7200	Above average	Excellent
Solar photovoltaic energy	1,190	Below average	4	3600	Above average	Below average
Concentrated solar energy	1,400	Average	6	2400	Exellent	Below average
Biomass	480	Average	7	2160	Average	Above average

TABLE 11 Qualitative Weight Scale

Qualitative scale	
Excellent	9
Above average	7
Average	5
Below average	3
Poor	1

TABLE 12 Updated Data Matrix

Data matrix						
	Capital cost ($M)	Environmental impact	Technology readiness level (TRL)	Gross output (MW)	Pollution control	Operating costs
Geothermal energy	1,850	9	9	7200	7.0	9
Solar photovoltaic energy	1,190	3	4	3600	7.0	3
Concentrated solar energy	1,400	5	6	2400	9.0	3
Biomass	480	5	7	2160	5.0	7

Once the normalized matrix is set up, the next step in analyzing the alternatives is establishing a relative importance by assigning weighted values. The weighted values are shown in Table 14.

Each alternative is assigned a weight, which is then factored with each attribute value in Table 13. The weights are assigned based on the importance

TABLE 13 Normalized Matrix

Evaluation criteria						
	Capital cost ($M)	Environmental impact	Technology readiness level (TRL)	Gross output (MW)	Pollution control	Operating costs
Geothermal energy	0.6978	0.7606	0.6671	0.8301	0.4901	0.7398
Solar photovoltaic energy	0.4488	0.2535	0.2965	0.4151	0.4901	0.2466
Concentrated solar energy	0.5281	0.4226	0.4447	0.2767	0.6301	0.2466
Biomass	0.1810	0.4226	0.5189	0.2490	0.3501	0.5754

TABLE 14 Weight Scale

Weight scale	
Significantly more important	9
Slightly more important	7
Equal	5
Slightly less important	3
Significantly less important	1

as considered from the house of quality model in the Requirements section. The results are shown in Table 15.

Now the extreme positive and negative values for each attribute are identified:

Separation of each alternative from ideal is measured by the n-dimensional Euclidean distance.

$$S_i^{*/-} = \sqrt{\sum (Alternative\ Value - Pos/Neg\ Ideal\ Solution)^2}$$

TABLE 15 Matrix With Weights Applied

Weights applied						
	Capital cost ($M)	Environmental impact	Technology readiness level (TRL)	Gross output (MW)	Pollution control	Operating costs
Geothermal energy	0.1249	0.1121	0.0913	0.1748	0.0877	0.1090
Solar photovoltaic energy	0.0803	0.0374	0.0406	0.0874	0.0877	0.0363
Concentrated solar energy	0.0945	0.0623	0.0609	0.0583	0.1128	0.0363
Biomass	0.0324	0.0623	0.0710	0.0524	0.0626	0.0848

TABLE 16 Positive and Negative Ideal Solutions

	Ideal solution					
	Capital cost ($M)	Environmental impact	Technology readiness level (TRL)	Gross output (MW)	Pollution control	Operating costs
Positive ideal solution	0.0324	0.0374	0.0913	0.1748	0.0626	0.1090
Negative ideal solution	0.1249	0.1121	0.0406	0.0524	0.1128	0.0363

TABLE 17 Distribution From Positive Matrix

Distribution from positive matrix							
	Capital cost ($M)	Environmental impact	Technology readiness level (TRL)	Gross output (MW)	Pollution control	Operating costs	S*
Geothermal energy	0.0086	0.0056	0.0000	0.0000	0.0006	0.0000	0.1215
Solar photovoltaic energy	0.0023	0.0000	0.0026	0.0076	0.0006	0.0053	0.1357
Concentrated solar energy	0.0039	0.0006	0.0009	0.0136	0.0025	0.0053	0.1636
Biomass	0.0000	0.0006	0.0004	0.0150	0.0000	0.0006	0.1288

Relative closeness to ideal solution is measured using the following equation.

$$C_i = \frac{S_i^-}{S_i^* + S_i^-}$$

Results of the TOPSIS Model

The results of the TOPSIS model, as shown in Table 19, reveal geothermal energy as the best alternative for providing electricity as a large system. Interestingly, the model also revealed that the next option for consideration is the utilization of biomass.

A similar analysis can be performed for the alternatives for small-scale systems, which would provide system designers with good indications of which alternatives are best suited given a similar set of attributes.

TABLE 18 Distribution From Negative Matrix

Distribution from negative matrix							
	Capital cost ($M)	Environmental impact	Technology readiness level (TRL)	Gross output (MW)	Pollution control	Operating costs	S⁻
Geothermal energy	0.0000	0.0000	0.0026	0.0150	0.0006	0.0053	0.1531
Solar photovoltaic energy	0.0020	0.0056	0.0000	0.0012	0.0006	0.0000	0.0970
Concentrated solar energy	0.0009	0.0025	0.0004	0.0000	0.0000	0.0000	0.0620
Biomass	0.0086	0.0025	0.0009	0.0000	0.0025	0.0023	0.1297

TABLE 19 Closeness to Ideal Solution

	Closeness to ideal solution
Geothermal energy	0.558
Solar photovoltaic energy	0.417
Concentrated solar energy	0.275
Biomass	0.502

SUMMARY

This article presents an overview of several techniques used by systems engineers in analyzing problems and validating solutions. Systems engineering offers many great tools that can be used for solving complex problems, many of which exist in developing nations.

Providing electricity is one such challenge faced by developing nations. Regions like Africa continue to face slow economic growth due to non-existent, poorly managed or underdeveloped energy infrastructures. While a realization that having good energy policies and infrastructures is becoming a significant focus for developing nations, the challenge continues to be implementation.

Renewable energy offers great potential for solving Africa's energy crisis and should be considered as these countries build up their energy portfolios. The challenge then becomes how to implement renewable energy systems in these developing nations.

This article looked at Kenya, Uganda, and Tanzania in the EA region. The region is characterized by high levels of unemployment, traditional forms of energy production and generation, and large rural areas with no access to electricity having to depend on firewood for heating and lighting needs.

Renewable energy sources are a great way of meeting the growing demands for energy within the region as well as ensuring sustainable development. Currently, renewable energy sources include solar power, wind energy, geothermal energy, and biomass. This problem, however, is a large problem and cannot be easily solved without some analysis, which systems engineering tools afford. This article looks at the following tools using the renewable energy scenario:

Problem formulation
Requirements formulation
Analysis of alternatives

One shortcoming of this report is the lack of an economic feasibility assessment. This is an important part of any analysis and must be performed as cost is bound to be a significant variable.

RECOMMENDATIONS

The main recommendation of this article is that developing countries need to consider renewable energy sources as they build their production capacities. Developing countries will benefit in the long term if they implement these systems at the basic level as opposed to integrating them later. As electricity systems in the region are developed, renewable energy sources should be considered and built into the national grid and also in the rural areas where grid integration may not be necessary. This article recommends that renewable systems in the region should be implemented in the following three phases.

Small Scale

These systems should be flexible and modular with no intention of grid integration. The basic uses for these would be lighting, cooking, and the ability to charge equipment. More analysis is necessary in developing useful alternatives for the small-scale sector. This segment offers local entrepreneurs the opportunity to develop technologies that can be used to support the initiative. This article does not examine those technologies but offered the example of microbials that have great potential in electricity sources at a small-scale level.

Large Scale

A lot of work is necessary if the EA region is to develop infrastructures comparable to those of the West. The goal here should not be to duplicate their systems but to emulate the best things about them and implement them in a way that is viable for the EA region. The region should invest in newer technologies with respect to hydropower, geothermal, and biomass technologies.

The Way Ahead

Both the small- and large-scale considerations are going to require significant changes to the overall culture before successful systems can be implemented. Some of these considerations include the following.

Strategic Frameworks and Policies

These systems are guaranteed to fail without good measurable frameworks and policies. Laws and policies must be established that emphasize and drive the industry toward sustainable development. The region depends on donor aid that is used for infrastructure development. Historically, this aid has not been used efficiently in executing the development plans. Without good frameworks and policies, poor execution will continue to occur and the region will continue to lag behind the rest of the world in developing sustainable energy resources.

Technology Development

The region must develop solutions that are indigenous. The article highlights several technologies for which the sources are available locally but the technology is developed primarily in the West. African countries must begin to participate in the development of these technologies to ensure that the solutions presented will meet their energy needs.

Local Financial and Human Capital Investment

The region depends on foreign donors such as loans from the World Bank, which often have to be repaid with high interest rates. This takes away from the GDP and prevents investment from going back into developing other areas of the economy. One way the region can alleviate this burden is by shifting some of the revenues from taxes and revenue streams such as tourism into infrastructure development. If this is executed in conjunction with good frameworks and policies, it will greatly increase the chances of implementing successful systems.

Another important area is human capital investment. Workers must be trained to ensure technical competence and skill proficiencies, which will drive job growth and promote economic growth. This can be done by establishing renewable energy schools, which educate the local workforce on the technical aspects of building and maintaining renewable energy systems.

Foreign Investment

The current reality is that building energy systems that include renewable solutions is going to require foreign investment. However, due to the political climates in most of these countries, these investments are very limited as the investors are often concerned with the levels of risk. This means that the EA region will continue to rely on foreign donors in the foreseeable future. While this has some disadvantages, it does present some benefits like getting approval for large projects and the help to implement them. These donors also provide great opportunities for long-term financing, which local options currently cannot provide.

Organizations such the United Nations and The World Bank have invested large amounts of money investigating the problems faced by developing nations and are often eager to help them develop and implement solutions that work. This proves beneficial for countries that can leverage those good strategies for significant investments for these organizations.

Renewable Energy Works

In conclusion, renewable energy solutions must be considered for any country considering energy infrastructure growth. The global environment faces significant challenges that are guaranteed to continue into the twenty-first century. Developing countries must institute "responsible" systems that ensure that the economies continue to grow and thrive.

A LOOK AHEAD: WHERE WE GO FROM HERE

This article provides only an introductory look at some of the renewable technologies. Additional research and exploration in the areas of technologies (e.g., hydrokinetic energy) and cost estimation models are required. Additional system design techniques not included in this article need to be explored.

REFERENCES

American Wind Energy Association. (2001). *Wind energy applications guide*. Retrieved from http://archive.awea.org/pubs/documents/appguideformatWeb.pdf

Byakola, O., Lema, T., Kristjansdottir, T., & Lineikro, J. (2009). *Sustainable energy solutions in East Africa: Status, experiences and policy recommendations from NGOs in Tanzania, Kenya and Uganda*. Oslo, Norway: Friends of the Earth Organization. Retrieved from http://naturvernforbundet.no/getfile.php/Dokumenter/rapporter/2009/REPORT_-_SUSTAINABLE_ENERGY_SOLUTIONS_IN_EAST_AFRICA.pdf

Cherian, A. (2009). *Bridging the divide between poverty reduction and climate change through sustainable and innovative energy technologies; Scaling up sustainable innovations that can address climate change concerns and poverty reduction needs*. United Nations Development Program.

Climate maps adapted from NASA Surface Metrology and Solar Energy Methodology. (2010). Retrieved from http://www.climate-charts.com/World-Climate-Maps.html.

Economic Commission for Africa (UNECA) on behalf of the Joint Secretariat of UNECA, UNEP, UNIDO, UNDP, ADB and NEPAD. *African Regional Implementation Review for the 14th Session of the Commission on Sustainable Development (CSD-14). Energy for Sustainable Development*. Retrieved from http://www.uneca.org/csd/csd4 report on energy for sustainable development.htm#issue3

Evans, J., & Lindsay, W. (2008). *Managing for quality and performance excellence* (8th ed.). Mason, OH: South-Western Cengage Learning.

Fries, P. (2007). AREED: Developing sustainable energy solutions in Africa. *The United Nations (UN) Business Focal Point Magazine*, United Nations Environmental Program.

Genera4–Renewable Energies. (2010). *Biogas*. Retrieved from http://www.genera4.cl/en/biogas.php

Geology, & Earth Science. (2010). *Map of East African region showing geological phenomena*. Retrieved from http://www.geology.com

Karekezi, S., & Kithyoma, W. (2003). *Renewable energy in Africa: Prospects and Limits–Renewable energy development*. The United Nations (UN) Workshop for African Energy Experts on the NEPAD Initiative. Retrieved from http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkarekezi

Maier, M., & Rechtin, E. (2009). *The art of systems architecting* (3rd ed.). Boca Raton, FL: CRC Press.

Nair, M. (2009). *Renewable energy for Africa: An overview of nine potential technologies*. The Hague, Netherlands: The Institute for Environmental Security.

Nixon Energy Solutions. (2010). *Biogas*. Retrieved from http://www.nixonenergy.com/biogas.html

Preben, M. (2008). *Energy security in Africa with renewable energy*. Bonn, Germany: Nordic Folkecenter for Renewable Energy.

Rosnes, O., & Vennemo, H. (2008). *Powering up: Costing power infrastructure investment needs in Southern and Eastern Africa*. Africa Infrastructure Diagnostic.

Sage, A., & Armstrong J. Jr. (2008). *Introduction to systems engineering*. Wiley Series in Systems Engineering. New York, NY: John Wiley & Sons.

United Nations. (2010). *Energy for a sustainable future: Summary report and recommendations. The Secretary-General's Advisory Group on Energy and Climate Change (AGECC)*. New York, NY: United Nations.

United Nations Environmental Program (UNEP). (2006). *Kenya: Integrated assessment of the energy policy–with focus on the transport and household energy sectors*. Geneva, Switzerland: Author.

United Nations Industrial Development Organization (UNIDO). (2008). *A summary report of the International Conference on Renewable Energy in Africa–Renewable Energy in Africa Bulletin. International Institute for Sustainable Development (IISD)*. Retrieved from http://www.iisd.ca

U.S. Energy Information Administration. (2010a). *International energy outlook 2010*. Retrieved from http://www.eia.gov

U.S. Energy Information Administration. (2010b). *Renewable fuels module: Assumptions to the annual energy outlook 2010*. Retrieved from http://www.eia.gov

Walt, V. (2009). Out of Africa: Saharan solar energy. *Time Magazine*. Retrieved from http://www.time.com/time/specials/packages/article/0,28804,1872110_1872133_1872141,00.html

Wasson, C. (2006). *System analysis, design, and development: Concepts, principles, and practices*. Wiley Series in Systems Engineering and Management. Hoboken, NJ: John Wiley & Sons.

World Bank. (2010). *Electricity consumption per capita*. Retrieved from http://www.theworldbank.org