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COMPARATIVE ANALYSIS OF ENERGY SOURCES IN PUERTO RICO

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Abstract

Currently, many countries are looking for different alternatives to produce energy, mainly to reduce environmental impacts and energy costs caused by actual methods of generation. Also, oil is becoming scarce; therefore it is extremely important to reduce the dependency on external sources, such as oil. Puerto Rico has its particularities due to its geographical location, making this one of the major challenges of this research effort. At the moment there are many new alternate sources of energy that have been identified, but which one is the best? Which one contributes more to the energy generation objectives of a country? Through this project energy sources such as oil, coal, natural gas, nuclear, solar, wind, and wave power would be studied and analyzed for an island, in this case Puerto Rico. A methodology is being developed using the Analytical Hierarchical Process to compare different sources of energy in terms of economical, technical, environmental, social, and political issues. The results of this research can be used as a decision making tool to develop energy public policies in Puerto Rico.

I. INTRODUCTION

Throughout the years, energy production has been an important concern for many countries and individuals. An example of this is the Energy Policy Act of 2005, stated by the government of the United States. As established throughout the article: "A part of the bill has the stated purpose of achieving energy self-sufficiency by the year 2025 (a very ambitious goal) within the United States, Canada, and Mexico." (Malmedal, Kroposki, & Sen, 2006). In other words, the government of the United States is promoting and encouraging people to identify renewable sources for the production of energy. Two other examples are Spain and Italy. In the Italian case, "policies incentivize the energy production, while Spanish policy gives an incentive to energy sale" (Diaz-Reyes F., 2008).

Mostly, this concern is due to two important factors: global warming and high costs of energy generation. Actually, most of the energy produced around the world comes from non-renewable sources, such as oil, carbon, and gas (US Energy Information Administration, 2006). These fuels, unfortunately, are causing harmful effects on the environment due to the emissions created during energy generation as well as when they are expelled from their reserves. Without any doubt, these two issues have been important in justifying why researchers are working hard and efficiently to identify other ways to produce energy, and why it is important that each country identifies the best way to produce its energy. In order to achieve this goal, each country should study its resources and capabilities of producing alternate sources of energy.

Puerto Rico is a 3,500 square miles island that depends on imported fuels for the generation of energy. As established in the paper *Wind characteristics on the Caribbean Island of Puerto Rico,* "Puerto Rico lacks domestic hydrocarbon reserves and relies on imports for

nearly all of its energy requirements" (Altali & Farrugia, 2003). In other words, Puerto Rico has to buy fuel to other countries in order to produce the energy needed.

Taking this into consideration, it is key for Puerto Rico to identify natural resources that could help in generating alternate sources of energy and improve its energy system. Through this study, different energy sources will be analyzed and compared in order to identify which energy sources best fit the energy demand in Puerto Rico. This study should not take into consideration only technical aspects but also economical, environmental and socio-political implications to society.

II. Justification

Energy generation is very important for the continuous development of this world. Currently, most of this energy is produced using fossil fuel (US Energy Information Administration) which is causing negative effects on the environment because of the emissions and therefore contributing to the global warming (Zahedi, 1994). For this reason, many industrialized, rich countries and companies are seeking to decrease their pollution, since they are the greatest pollutants (Zahedi, 1994). In order to achieve this goal, governments are making great efforts to establish policies in which they can promote environment protection.

For example, according to Ahmad Zahedi, in 1989, the total energy produced was more than 200 billions of mega joules which emitted the pouring of nearly 6000 million kilograms of CO_2 into the atmosphere. During those days, 90% of the energy produced was from non-renewable energy sources (Zahedi, 1994). In the other hand, nearly 70% of the world's energy is produced today using non-renewable sources, but approximately 581.3 Peta joules are being produced using non-renewable. (Worldwide electricity production form renewable energy sources, 2010).

Although in percentage the usage of non-renewable energy has decreased, in absolute numbers it has not decreased.

After the Kyoto Protocol to the United Nations Framework Convention on Climate Change in 1997, many countries are conscious of this situation and are taking actions to establish legislation to enforce the development of renewable energy techniques to produce energy. Some of the countries that are working towards achieving a better energy portfolio are United States, Spain, England, and Germany among many others (Malmedal, Kroposki, & Sen, 2006) (Arán Carrión, Espín Estrella, Aznar Dols, Zamorano Toro, Rodríguez, & Ramos Ridao, 2007). Unfortunately, sources and techniques evaluated as favorable for a location are not necessarily appropriate in every place. Therefore, rigorous studies and analyses shall be made in order to achieve good solutions.

In order to analyze alternatives, countries have to study its background to gather information such as natural resources available, its society, and location, among others. In this research an analysis will be done using the island of Puerto Rico as the case study. As previously mentioned, Puerto Rico lacks of reserves of oil, carbon or natural gas but depend on those fuels to produce its energy. Actually, of the energy produced in Puerto Rico, 69% is produced with oil, 15% is produced with coal, 15% is produced with natural gas and 1% is produced with renewable sources (Cordero, 2010)

Due to its geographical location, Puerto Rico has natural resources that can be used to produce energy. Currently, several of these sources, such as sun and wind, among others, are being used and evaluated to generate energy. However, how can it be identified which is the best way to produce energy taking into consideration technical aspects as well as economical and

socio-political ones? For this reason, it is desired to make an objective evaluation of these sources to identify which is the best alternative to produce energy in Puerto Rico.

As established by Pohekar, several methods based on weighted averages, priority settings, outranking, fuzzy principles and their combinations are employed for energy planning decisions (S.D. Pohekar, 2003). These methods are widely used when it comes to multi-criteria decision making as is the case under study. Some of the methods presented are the PROMETHEE, ELECTRE, and the Analytical Hierarchical Process (AHP). This same article, *Application of multi-criteria decision making to sustainable energy planning-A review*, suggests that the most used method in these projects is the Analytical Hierarchical Process (S.D. Pohekar, 2003). The AHP was a method introduced by Saaty in 1977 to solve complex decision problems (Triantaphyllou & Mann, 1995). One of the advantages of AHP is that it takes into account the public opinion and promotes the participation of different experts. With this method not only quantitative information is considered but also qualitative data (Arán Carrión, Espín Estrella, Aznar Dols, Zamorano Toro, Rodríguez, & Ramos Ridao, 2007).

As mentioned before, it is desired to identify the best alternative to produce energy in Puerto Rico considering the economical, socio-political, environmental, and technical points of view. Therefore, the use of tools such as multi-criteria decision making techniques, benefit the process. In this case, the Analytic Hierarchical Process (AHP) will be used.

III. PROJECT DESCRIPTION

A. Purpose

To develop a systematic method to evaluate and compare different energy sources in order to select the best alternative or alternatives to generate energy in Puerto Rico. This

comparison will take into consideration different aspects such as economical, socio-political, environmental, and technical.

B. *Objectives*

The main objective of this research is to identify which energy source or sources are more appropriate and cost efficient to produce energy in Puerto Rico. A secondary objective is to analyze two renewable and three non-renewable energy sources available in Puerto Rico.

IV. METHODOLOGY

As previously mentioned, energy generation is a critical concern shared by many countries. This is mainly because energy is being produced with fossil fuels, which not only contaminate the environment but also are getting more expensive continuously. Therefore, it is important to identify alternatives to deal with this situation. One of these alternatives could be using renewable resources to produce energy, but it is important to mention that not all renewable resources available to generate electricity are abundant in every place. Therefore, it is necessary to evaluate each energy alternative taking into consideration all the implications regarding each source and the place where it may be established.

Now, the question is how to identify which is the best source? This project focuses in establishing a method through which decision makers have a tool to make well informed and analyzed decisions to identify which are the best energy sources to produce energy in Puerto Rico. In terms of this project, not only renewable sources will be analyzed, but also non-renewable sources in order to find the best energy portfolio for the island of Puerto Rico. The non-renewable sources that will be taken into consideration are oil, natural gas, and coal; while solar energy and wind energy will be studied under the renewable energy sources. Although this

study suggests a comparison, it is important to mention that the energy sources will be analyzed in terms of their economical, environmental, technical, and public policies performances.

In order to accomplish the purpose of this project, the first step is to identify the factors among which each criterion will be subdivided. Because there is a subjective and objective criterion, it is also important to identify how each factor will be measured. Since the energy sources that are going to be studied were previously identified, the next step will be gathering the relevant information regarding each factor. It will be necessary to find the information that provides answers to each of the factors under investigation.

As a next step, a comparison of the energy sources will be done using the method called Analytical Hierarchical Process (AHP), which provides an objective comparison among the alternatives. The first step to achieve this comparison is to develop a four by four (4 X 4) matrix in which the four criteria are compared with each other (pairwise comparison) to identify which is more important (refer to Table 1).

	Environmental	Technical	Socio-political	Economical
Environmental	1	1	1	1
Technical	1	1	1	1
Socio-political	1	1	1	1
Economical	1	1	1	1

Table 1: Matrix of the comparison for Criteria

In this project, the four main criteria will have the same weight and it will be considered as part of the process. The other pairwise comparison will be done by giving values from 1 to 9 identifying the preferences between two elements, where:

1 = same importance

3 = moderate importance

5 = strong importance

7 = very strong importance

9 = absolute importance

The next step is to compare the factors of each criterion among them. In order to do this, other matrices will be developed to identify which factor is more important within each criterion. The matrices will be developed using the same technique as the matrix developed for the criteria. Since a comparison matrix will be developed for each criterion, four (4) weighting vectors will be obtained. Using this weight, another matrix will be developed in order to get a final weighting vector from which the best alternative could be obtained. Finally, a consistency index will be calculated in order to determine if the values obtained are reliable.

The information in these matrices will be completed using the opinion of experts of each area. For this purpose, questionnaires will be handed in to those experts. This part of the study will be completed using the Delphi Method. "Delphi may be characterized as a method for structuring a group of communication process so that the process is effective in allowing a group of individuals, as a whole deal with a complex problem. This method is primarily employed in cases where judgmental information is indispensable, and typically use a series of questionnaires interspersed with controlled opinion feedback" (Okoli & Pawlowski, 2004). As we can see, this method will complement our study and will make it more reliable.

Once this process is completed, an engineering economic analysis will be performed in order to study the viability of the proposed alternative(s). To decide about the alternative(s) viability, the internal rate of return technique will be used. A sensitivity analysis will be done with two objectives in mind: to understand how the decision will change when parameters are varied, and to analyze if the viability is affected when the data of the recommended source(s) is varied.

V. PRELIMINARY WORKS

As we previously mentioned, in order to complete this study, the Analytical Hierarchical Process will be used. Therefore, the first part of this analysis consisted in identifying the criteria by which all the alternatives to be considered in the study will be evaluated. As we previously mentioned, these criteria are environmental, economical, technical, and socio-political. Under this set of criteria, factors were developed in order to analyze each criterion. The following diagram demonstrates the process that is going to be followed through the analysis (refer to Figure 1). The environmental criterion is not shown in the picture for simplicity, but will be taken into consideration.

The environmental criterion will be analyzed taking into consideration the following factors:

Gas emissions and air pollution
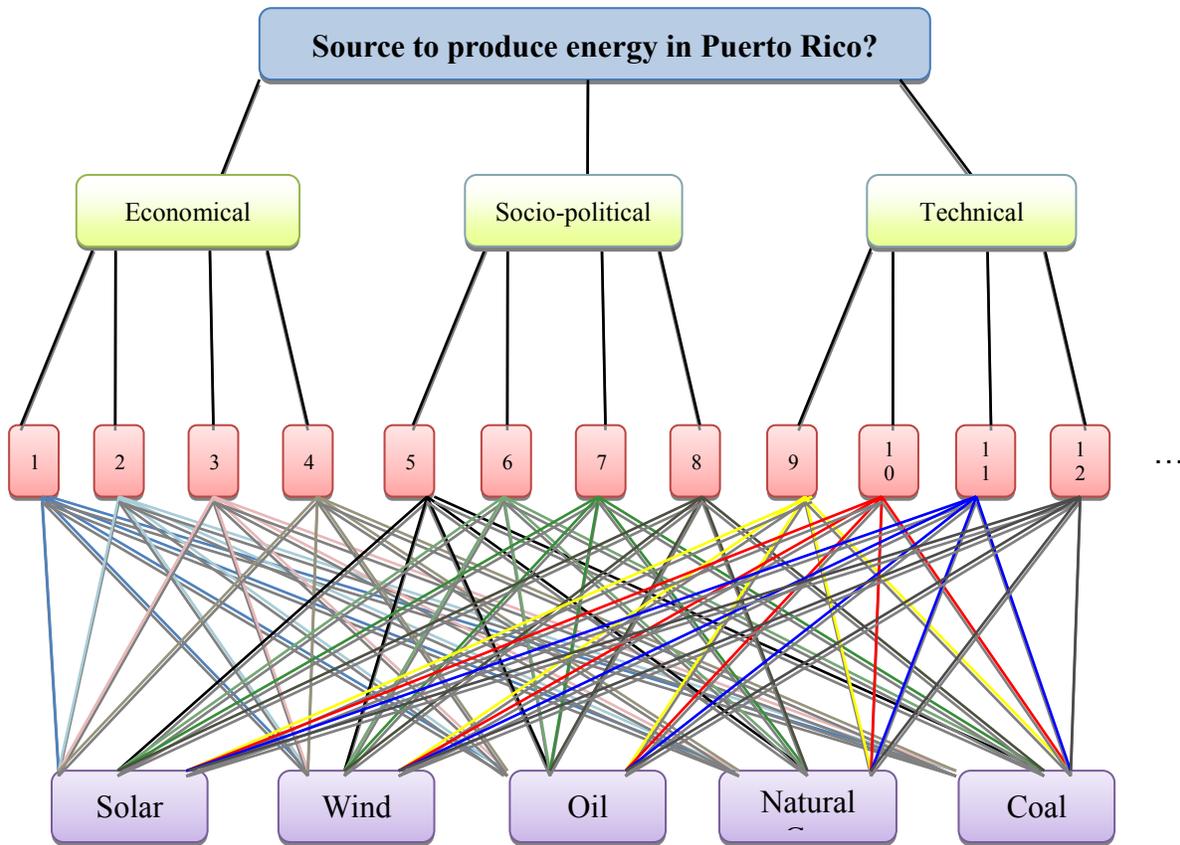
Flora and fauna

Deforestation

Hydrology

Figure 1: Description of the analysis

The economic factors to be studied are the following:

Investment

Generation costs

Maintenance and operation costs

Return on investment

The technical criterion will be studied under the following factors:

Useful life

Environmental impacts

Efficiency

Performance (Generation)

Finally, the socio-political will be studied under the following factors:

Community acceptance

Government policies

Security

Governmental acceptance

With this information, different set of matrixes were developed in order to do the pairwise comparison between criteria and factors. The first matrix developed was for the criteria (refer to Table 2). In this project, we are giving the same weight to each criterion. All sets of comparison have a 1, which means that all of them have the same importance.

	Environmental	Technical	Socio-political	Economical	Weighting Vector
Environmental	1	1	1	1	**0.25**
Technical	1	1	1	1	**0.25**
Socio-political	1	1	1	1	**0.25**
Economical	1	1	1	1	0.25
Total	**4**	**4**	**4**	**4**	**1**

Table 2: Weighting Vector for the Criteria

The same method will be used to identify the weighting vector of the factors, but this other matrices will be developed using the opinion of experts that will be identified later.

VI. NEXT STEPS

The objective of this project is to establish a method to identify the best source(s) to produce energy in Puerto Rico. As it was discussed, part of this journey was achieved but it is still on the way. We have developed the system through which the comparison will be accomplished but the proper weighting vectors to evaluate our alternatives in Puerto Rico are in progress.

In order to gather the most reliable information the opinion of experts would be used. This information would be collected through questionnaires that will be developed. Therefore, our next step will be to develop the questionnaires and identify the experts in each area. Once this has been completed the information will be analyzed and matrices will be completed. With this information, an alternative or alternatives would be selected as the best source(s) to produce energy. With this in mind, an economical analysis of the option(s) would be performed to study its viability and the possibility of using that alternative to produce energy. Finally, a sensitivity analysis will be performed to evaluate the aspects that would make the decision to change.

VII. EXPECTED RESULTS

As we explained before, all criteria would have the same weight therefore each alternative would be evaluated under the same circumstances. Taking this into consideration, the expectations for the project are that wind and/or solar sources result the most convenient ways to produce energy in Puerto Rico. Nonetheless, this result may change depending on what the experts believe is more important.

VIII. WORKS CITED

(n.d.). Retrieved from US Energy Information Administration:

http://www.eia.doe.gov/kids/energy.cfm?page=coal_home-basics

(2006, Agosto). Retrieved from US Energy Information Administration.

Altali, K., & Farrugia, R. (2003). Wind characteristics on the Caribbean Island of Puerto Rico. *Science Direct* , 1701-1710.

Arán Carrión, J., Espín Estrella, A., Aznar Dols, F., Zamorano Toro, M., Rodríguez, M., & Ramos Ridao, A. (2007, June). Retrieved from Science Direct: http://www.sciencedirect.com

Cordero, M. (2010, Abril 21). Estrategias Energéticas para el Siglo XXI. San Juan, PR: Autoridad de Energía Eléctrica.

Diaz-Reyes F., G. M.-Q. (2008, July). Photovoltaic energy promotion in Europe: Italy and Spain, two visions, one aim. *IEEE Xplore* .

Malmedal, K., Kroposki, B., & Sen, P. (2006 , July). The Energy Policy Act of 2005 and its Impact on Distributed Generation. *IEEE Xplore* , 1-8.

Okoli, C., & Pawlowski, S. D. (2004). The Delphi method as a research tool: an example, design considerationos and applications. *Science Direct* , 15-29.

S.D. Pohekar, M. R. (2003 йил December). Application of multi-criteria decision making to sustainable energy planning - a review. *Renewable and Sustainable Energy Reviews* , 366-381.

Triantaphyllou, E., & Mann, S. H. (1995). Using the Analytic Hierarchy Process for Decision Making in Engineering Applications: Some Challenges. *International Journal of Industrial Engineering: Application and Practice* , 35-44.

Worldwide electricity production form renewable energy sources. (2010). Retrieved from www.energies-renouvelables.org

Zahedi, A. (1994). Energy, People, Environment. Development of an integrated renewable

    energy and energy storage system, an uninterruptible power supply for people and better

    environment. *Systems, Man and Cybernetics* , 2692-2695.