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An assessment of the implementation of renewable energy sources in the light of concerns over Chilean policy objectives

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Abstract

In recent years, the development of renewable energies in the electricity market in Chile has gained significant attention as a key alternative for energy sources diversification and meeting three key policy objectives: energy availability, environmental protection, and social-economic development. This study aims to assess various renewable energy sources in order to select suitable sources to accomplish the different policy goals in a country like Chile. For this purpose, a Multi-Criteria Decision Analysis (MCDA) method is employed to evaluate the relative importance of policy objectives. In addition, a sensitivity analysis is conducted to build various different policy scenarios measuring the impact of variations on the current weights of the decision criteria. The results show that solar, wind, and small hydro are the preferred sources in the Chilean renewable energy portfolio, maximizing the objective of meeting the three policy goals at the same time.

Keywords

Chile; MCDA; policy objectives; renewable energy; sensitivity analysis

1. Introduction

The increasing challenges faced by many countries to meet their energy needs in a secure and a sustainable manner have led to the increasing use of RES, which now plays a significant role in the energy policy of most countries. However, renewable energy development has taken different paths across countries, supported by different policy frameworks. Although the choice of policy varies by national context, there has been a convergence to design them for meeting common objectives, particularly, energy security, environmental protection, and economic development. However, there is no general agreement in the literature on what renewable energy sources, if any, are the most promising to become a major energy source in the accomplishment of different policy goals. With the purpose of assessing different renewable energy options in an energy sources portfolio and their policy implications, the common traditional approaches applied for energy planning have been based on classical optimization models, guided mostly by technical and economic criteria, and the multi-faceted nature of the problem has been widely ignored. It has become clear that the current structure of energy markets in the world is changing. Particularly, new regulations require increasing the focus on the environmental and social impacts of the energy systems. For these reasons, not only direct costs, but also non-monetary aspects need to be considered in the decision-making process for the purpose of energy planning. In handling multi-objective complex problems, the use of multi-criteria decision methods in energy policy offer a better fit to deal with problems where the common assumptions of classical optimization models do not apply. There are few studies of multi-criteria decision methods integrating complex interactions in the framing of viable energy policy and...
examining the policy effects aimed at energy security, socio-economic development, and mitigation of environmental concerns.

Over the last few years, there has been an increasing expansion of renewable energy sources in South American countries. However, most of the countries still lack a clear, certain, and comprehensive energy policy that can be used to evaluate the selection of the appropriate renewable energy sources that are compatible with the overall goals established for a national sustainable development. This study contributes in that respect, studying the assessment of various renewable energy options in the country case of Chile. For that purpose, for the first time, a Multi-Criteria Decision Analysis (MCDA) approach is used in order to select the appropriate renewable energy sources for the accomplishment of different policy goals in Chile. Even though the choice of energy policy elements for renewable energies might be quite situation specific in any given region or country, we believe that analyzing the relationship between energy-sector challenges and policy elements to generate an integrated energy policy, the case of Chile is a valuable contribution to the literature and to other emerging economies. The remaining of the paper continues as follows: Section 2 briefly illustrates the policy background and the current state of development of the renewable energy in Chile. Section 3 details the methodology used in this study. Then, the various renewable energy sources to meet different policy goals are assessed in Section 4. Finally, Section 5 concludes the study.

2. Chilean non-conventional renewable energy development

In recent years, the development of projects associated to non-large hydro renewable energy sources (RES) in Chile has gained significant attention as a key alternative for energy sources diversification in solving the energy problems of the country. The introduction of non-conventional renewable energy technologies for the first time in the energy matrix dates back to 2008 with the approval of Law No. 20,257. In 2013, it established a final target — to be met gradually with annual targets — of generating 20% of all the electricity in the country from renewable sources by 2025 (Law 20,698, better known as “Law 20/25”) (Nasirov et al., 2015). In addition, in 2015, the government prepared an energy roadmap, where a more ambitious goal is established to have 70% of renewable energy (including large hydro) in the matrix in Chile by 2050 (Ministry of Energy, 2015). Today, the installed capacity in renewable energy sources has increased sharply in recent years, reaching to 3,119 MW in 2016. This corresponds to 15% of the total power capacity in the system, having then already met and even surpassed the quota defined by the Renewable Law No. 20,257 for the year 2016. These numbers show that, potentially, there might be a promising future for the development and deployment of renewable energy technologies in Chile. It is expected that Chile will meet its 2025 target of generating 20% of electricity from renewable energy sources ahead of schedule.

3. Methodology

Several multi-criteria decision methods (MCDM) have been applied to numerous decision-making problems in the general field of renewable energy. However, the focus of this study is on the application of MCDM in the area of renewable energy planning and policy. This mainly includes the assessment of energy planning such as adoption to reach certain national target, decision factors, national planning, and system indicators. Most studies have either focused on electricity generation technology (e.g., wind, photovoltaic, and hydro) or have been specific to the performance of the overall power supply system, usually by examining different electricity mixes for a specific region or country. One of the most common MCDA tool, AHP is the method we used in this study for the assessment of exploiting renewable energy sources in Chile. The AHP was introduced first by Saaty in 1980 (Saaty, 1980). Over the past decades, it has been successfully implemented in the solution of numerous decision-making problems related to energy policies (Wallenius). AHP is a method of prioritization that enables decision makers to solve complicated and unstructured problems that may have interactions and correlations among different objectives and goals. It provides sufficient
statistical power to detect group differences or to investigate characteristics of a certain subgroup and can help in identifying and weighing criteria, analyzing the data collected, and proceeding with the decision-making process. Under the AHP method, a solution of a complex problem passes through different levels of hierarchy, namely: the objective/goal of the problem comes in the top, while the intermediate levels are the criteria and sub-criteria, and the lowest level represents alternatives (Saaty, 1980). The AHP method develops priorities among all the criteria and sub-criteria within each level of the hierarchy by using measurements from pair-wise comparisons and relying on the judgment of experts to derive priority scales. It is widely applicable due to its simplicity, ease of use, and flexibility. Another advantage of using the AHP method is that it provides the possibility of evaluating quantitative as well as qualitative criteria. The modeling process of the AHP in our research includes various steps, which are presented below.

**Step 1: Definition of the objective or goal** — The goal of the decision model is placed on the top of the AHP model. An assessment of appropriate renewable energy technologies for electricity generation in Chile is the goal of this decision model.

**Step 2: Identification of criteria and sub-criteria** — For the selection of criteria and sub-criteria for the assessment of renewable energy technologies, this study mainly adopts the three policy criteria of energy goal, environmental sustainability goal, and socio-economic goal, and then 14 sub-criteria to establish an assessment structure for Chile’s renewable energy sources (See Figure 1.).

**Step 3: Construction of the hierarchy framework for analysis** — The criteria and sub-criteria were designed into a hierarchy descending from the overall objective or goal to the various stages and related sub-criteria in successive levels. The top level of the hierarchy represents the defined objective, while the second level of the hierarchy consists of three criteria (energy, environmental, and socio-economic goals). Finally, the bottom level of the hierarchy characterizes the renewable energy alternatives in Chile.

**Step 4: Collecting empirical information and data** — In this phase, a group of experts were selected for the purpose of the research, and each one received the same questionnaire. The expert group consisted of highest ranked public figures from the Chilean energy ministry, independent consultants who has a deep expertise in the Chilean energy sector, and scientists from energy research centers in Chile. In this study, a constant sum approach is used asking the experts to divide 100 points between every pair, depending on their comparison between the two of them based on their importance for the Chilean energy policy (100 implies full importance and 0 no importance at all).

**Step 5: Building a decision matrix and performing the consistency test** — Pair-wise comparisons of the different dimensions were converted into comparison matrices in this phase. These comparisons matrices have been solved with the AHP methodology to determine priority alternative dimensions for the Chilean renewable energy policy.

**Step 6: Enhancing a decision support tool with sensitivity analysis** — A sensitivity analysis is applied to show the impact of changes in the model criteria and to determine the degree of influence that the criterion has on the overall model output. A sensitivity analysis helped to construct proposed scenarios that generate more information for decision makers, allowing them to realize how different conditions affect their decision making without forcing them to change their original considerations.

4. **Empirical results**

In the assessment of the optimal options among various renewable resources in Chile, we employed 14 sub-criteria in three categories to assess five renewable alternatives for electricity generation. For each level through the model, a pair-wise comparison matrix is built. The weights of each criterion and their ranking for decision making are obtained by using AHP and are presented in Table 1. The results show that energy goal and environmental goal are the two most important criteria with relative weight of 0.49 and 0.31, respectively. The socio-economic aspect is the third one, and, therefore, the least important criterion. The overall inconsistency of judgment in the pair-wise
comparison for criteria was calculated to be around 0.05, which is within the limits of 0.10. The results for each technology presented in Table 1 show that experts’ perspectives confirm that under this scenario, solar energy sources (0.229) is the most favored RES among all five sources, followed by small hydro (0.218), wind (0.205), biomass (0.192), and geothermal (0.161) in this scenario.

In the next step, a renewable energy source portfolio was assembled by applying sensitivity analysis to achieve a set of policy goals. The key objective of sensitivity analysis is to identify how the model would respond to any adjustments in the weights of the three policy goals. Therefore, by modifying the weights assigned to the three policy goals, we can assess the preference of alternatives corresponding to a particular condition. Three policy scenarios were built in the sensitivity analysis: the energy scenario, the environmental scenario, and the economic scenario. The results for each scenario are detailed below.

Figure 1. The assessment framework.
Scenario 1: Energy scenario

In this scenario, the preference of alternatives for a particular condition is tested assuming that the energy goal is the dominant policy goal. As presented in Figure 2, in this case the weight of energy goal is augmented to 0.890, while the weights of environmental goal and socio-economic goal are reduced proportionately to 0.070 and 0.040, respectively. As it can be seen in Figure 2, solar energy technology has the highest score (0.340), followed by small hydro (0.257), wind energy (0.180), biomass (0.136), and geothermal energy (0.086).

1Other environmental impacts include the following factors: landscape impact, acoustic emissions, electromagnetic interferences, unpleasant odors, and microclimatic changes.
Scenario 2: Environmental scenario

In the environmental scenario, the weight of environmental goal is increased to 0.900 to be the leading policy goal. As described in Figure 3, wind energy (0.323) and small hydro energy (0.245) are the two most important renewable energy sources in terms of environmental indicators and, therefore, it is believed that their development significantly facilitates to achieve of the environmental goal.

Scenario 3: Socio-economic scenario

The relative importance of the social-economic goal is highlighted in this scenario as the principal policy goal (0.900). As can be seen in Figure 4, in this case solar energy is the most preferred alternative with the highest score (0.323), followed by wind energy (0.245), biomass (0.185), small hydropower (0.141), and geothermal energy (0.107). According to this result, development of solar
technologies is regarded as an opportunity to stimulate economic growth in terms of achieving the socio-economic goal of the country.

5. Concluding remarks

The Chilean government established time-bounded targets for renewable energy and the integration of renewable energy policies into national planning. However, as in many countries, policy makers face the challenge of determining which policy goals to pursue and what type of renewable energy source to develop. This study aims to study how different policy goals — energy, environmental, and socio-economic goals — define the use of adequate renewable energy sources in Chile. The results are obtained under three different scenarios.

In the energy scenario, solar energy again scores highest. Over the last few years, the Chilean government has shown strategic interest in pushing the development of solar energy as a crucial element for the future energy strategy of the country. Therefore, adding solar energy sources to the energy mix can be a valuable opportunity for contributing to the country’s energy diversification strategy and reducing the dependency from external fossil fuel sources. In this endeavor, solar energy is becoming more important every year. At the end of 2016, installed solar capacity in Chile has more than quadrupled over the past three years, reaching 1,267 MW, and solar projects under construction sum up to 1,787 MW and a large scale of solar projects for 13,113 MW with environmental approval.

Wind energy is the most preferred renewable energy source in the environmental scenario, followed by small hydro. Operation of wind energy generates zero emissions of harmful substances that do not add to global warming. However, as other sources of renewable energy, wind energy does have an environmental impact, but likely lower than several other forms of human and industrial activity. One of the important environmental advantage of using small hydropower and wind energy is that they produce less life-cycle global CO\textsubscript{2} emissions.

Finally, in the socio-economic scenario, solar energy is again considered the best source to reach the economic goal. Based on all four scenarios, solar is the most preferred energy source to be developed a used, followed by wind and small hydro in the renewable energy portfolio of Chile. Over the last couple of decades, rising power costs and fears over energy security in Chile have been negatively impacting the development and competitiveness of the major energy intensive industries, especially the copper industry.

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