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An optimization approach for long term investments planning in energy

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HIGHLIGHTS

- Multiperiod optimization model for investments plan in energy sources.
- Investments on renewable and non-renewable energy sources are included in the model.
- Objective function is the maximization on Net Present Value.
- Capability to assess and plan the evolution of the energetic matrix at different circumstances.

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ABSTRACT

This paper presents a mathematical programming model for planning investment in energy sources. The problem formulation considers the use of renewable and not renewable sources and demands, revenues, operation, start-up, and amortization costs of new energy facilities and the amount of reserves of fossil fuels. The objective is the maximization of the Net Present Value (NPV) in the time horizon. The results provide the visualization of the investments made: time periods in and their amounts and also how the energy matrix is affected by those investments. In particular the model was applied to Argentina. The most important feature of the model is the ability to assess and to plan the evolution of the energetic matrix at different circumstances.

1. Introduction

The use of renewable sources for energy production is becoming a key issue for the future of every country. The main reasons to analyze the production of energy by means of renewable sources are the high dependency in fossil fuels for transport, electricity, heating, etc., the global warming as a consequence of using these fuels, its constant price raise and the uncertainty and limitation of world reserves levels. About 10% of the world energy consumption is produced using some sort of renewable energy, taking into account in this sector the production of hydroelectricity which is the main source [1]. Many countries around the world started, several years ago, the process of producing energy using sustainable alternatives like the wind, sun, geothermal, biomass and waste; the leading countries in this issue are: United States, Germany, Spain, China, India, Brazil and Japan. Considering that the consumption of energy increases every year following the population growth; and the oil, gas, carbon and uranium reserves are limited, the search for sustainable alternatives is fundamental.

In the last five years, several works can be found in the literature dealing with this problem, Krajacic et al. [2] studied the production of electricity for Portugal in order to cover all the demand of this country by means of renewable energy sources (RES). They use H2RES simulation model to integrate several renewable sources (wind, solar, biomass, hydropower and ocean waves) in the energy system. They also include some sort of storage systems to accumulate energy in order to reduce the number of generation units. The authors conclude that the tool have some limitations to make the analysis, pointing out that there is no automatic optimization based on cost, environmental and social impact using this system. The 100% RES is achieved using hydropower (32%) and wind (24%), which in terms of real solution considering the cost and environmental impact, needs more insights.

The model proposed by Baringo and Cornejo [3] is a stochastic mathematical program with equilibrium constraints (a stochastic MPEC) to analyze the risk involved in wind power investments. In their proposal they consider that the wind power investment and operation have several uncertainties and risk involved such

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as: (a) the production of a wind power facility ready to operate is both variable and uncertain, (b) the wind power farm investment costs are expected to decrease while technology acquires maturity but to which extension such decrease will materialize is uncertain and (c) given the previous uncertainties the profit for a wind investor is high and thus risk management must be taken into account. They solved three illustrative examples considering three different scenarios: (1) Investment Cost Uncertainty, (2) Load Demand/Wind Power Production Uncertainty and (3) both Load Demand/Wind Power Production and Investment Cost Uncertainty. In order to test the model, they work with a Case Study based on the IEEE 118-Bus Test System which comprises 54 generating units, 99 loads, and 186 transmission lines. They conclude that the proposed model is tractable for systems of realistic size provided that the number of considered scenarios is small enough. In another work, researchers from the same group [4], proposed a bilevel model for investments decision making for a strategic energy producer. The upper-level problem represents both the investment decisions of the producer and its strategic offering corresponding to each demand block and scenario. This upper-level problem is constrained by a collection of lower-level problems that represent the clearing of the market for each demand block and scenario. The target of these lower levels problems is to maximize the corresponding declared social welfare, subject to power balances, production/demands limits and transmission constraints. With this model proposal the authors provides a methodology to assist a strategic producer in making investment decisions on power generation, they also pointed out that the resulting model, although computationally expensive, is tractable.

Connolly et al. [5] generates a model to satisfy the energy demands for Ireland by means of renewable sources. According to these authors, in Ireland 96% of the energy demand is provided by using fossil fuels, where 89% is imported. EnergyPLAN tool is used to perform the analysis and they include the electricity, heating and transport consuming sectors. The renewable sources considered in this study are biomass, solar, waves, wind and hydropower. They also increase the capabilities in the energy storage system. They propose to solve four scenarios: 1 – 100% renewable based on biomass, 2 – 100% based on hydrogen, 3 – 100% renewable maximizing the generation of electricity and 4 – a combo of the other previous three. The results obtained are very different for each scenario. The authors consider that the energy demands are frozen to year 2007 and the analysis was made based on the technical and resource perspectives not from an economical point of view. As the authors pointed out the study is useful for illustration purposes.

Pina and coworkers [6] presents a modeling framework to optimize the investment in new renewable electricity generation on the long-term horizon time for Portugal. The authors take into account the hourly dynamics of electricity supply and demand. The framework is built combining two of the most used energy planning tools, TIMES as a long-term model for the optimization of investment in electricity generation capacity and EnergyPLAN as a short-term model for optimizing the operation of the system. They claim that the combination of both tools is crucial for the development of pathways for the transition to electricity systems with high penetrations of renewable energy sources and that the proposed methodology can also be applied to study the introduction of different energy efficiency measures.

Mondal et al. [7] evaluates the strategies for future energy-supply for the United Arab Emirates (UAE) power sector. The analyses are done by applying MARKAL model. Different policies such as a CO2 emission reduction constraint, renewable energy production targets, and subsidy minimization through international benchmarking for domestic gas prices are applied for this analysis. The results show that the alternative policy scenarios directly allocate clean advanced and renewable technologies to generate electricity. These scenarios reduce CO2 emissions in power sector. The simulation results from model show that alternative sustainable energy development policies expected total system cost is not significantly higher.

Several analogous works can be found in the literature, just to mention some of them, Cosic et al. [8] analyzed the case of a 100% renewable energy system for Macedonia, Lund and Mathiesen [9] perform a similar study for Denmark and Mason et al. [10] evaluate the case for New Zealand.

Reading those works, it can be seen that several criteria are used to study an energy system based on renewable sources. The criteria selected to perform the study is fundamental in order to make the right decisions. Ostergaard [11] evaluates a set of optimization criteria applied to an energy system model of Western Denmark; some of them were technical and others economical. The most used in the literature are: renewable energy shares, carbon dioxide emissions, economic costs, societal costs, energy costs and total costs.

Energy production meets the challenge of satisfying ever-increasing demands with traditional resources decreasing and the consequent requirement of incorporating new sources. New tools are needed in order to harmonize, integrate the different requirements, resources and capacities. In this work, a MILP (Mixed Integer Linear Programming) formulation is presented to analyze the planning of investments and operation of different energy sources. The proposed model allows to attain different objectives. First, the different energy sources are simultaneously taken into account, including renewable ones. The objective of this study is to handle renewable energy in combination with non-renewable ones in order to extend the life of natural resource reserves. For the next decades, the energy supply will be reduced from fossil fuels and depends on a higher proportion from renewable sources. Thus, a mathematical analysis tool is required to effectively assess the trade-offs about them, considering different aspects as investments, resources availability, operation, setup, amortization, etc. Second, the formulation adopts a multiperiod representation that enables the evaluation of the evolution of the different performance indicators along the time horizon. Also, the time required to start the operation of the new facilities from the moment the corresponding investment is decided, as well as the amortization value are taken into account. From the modeling point of view, the model proposes a formulation based on disjunctive programming that allows an appropriate representation of the alternatives considered in the problem. The model is solved in reasonable computation times and, thus, different scenarios can be easily assessed.

Although the proposed formulation is posed for Argentinean case taking into accounts the renewable energy sources that better adapt to Argentina, this model can be applied to any country or region. Also, the parameters adopted in the examples of this work can be adjusted to specific cases, for example: time horizon, energy sources, demands, economic parameters, etc.

The remainder of this paper is structured as follows. First, the addressed problem is described and the main assumptions are introduced in Section 2. Then, in the subsequent section, the proposed formulation is presented. Finally, in Section 3 several scenarios are considered to demonstrate the capabilities of the proposed approach in order to evaluate an energy system.

2. The model

The composition of the energy matrix in Argentina is shown in Fig. 1; data is extracted from Argentina's Energy Agency (Secretaría de Energía de la República Argentina, 2007). It can be observed that