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A multiple objective decision making model for energy generation portfolio under fuzzy uncertainty: Case study of large scale investor-owned utilities in Florida

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ABSTRACT

The objective of this paper is to present a methodology to evaluate the viability of developing solar photovoltaic projects for large investor-owned utilities. By taking into account the trade-off between the cost per kWh of electricity generation and total risk for an investor-owned utility, a multi-objective model of the energy generation portfolios is developed. The decision making model can determine the proportion of different energy generation sources in an investor-owned utility portfolio that reduces risk while providing the lowest cost per kWh of electricity generation possible. In order to measure the risk of the investor-owned utility for energy portfolio selection, an investigation of possible dangers and failures of energy generation portfolios is made and 9 main failure modes are identified. The failure mode and effects analysis is employed to calculate the risk priority numbers for each risk. To deal with the uncertainties of the levelized cost of electricity and risk levels of failure modes, the fuzzy method is introduced and an equivalent crisp model is derived which is then solved by employing a multiple objective particle swarm optimization algorithm. The analysis for four large scale investor-owned utilities in Florida is presented to highlight the performance of the developed optimization method.

1. Introduction

In recent years, there has been a huge increase in the consumption of energy due to industrial development and population growth. Energy is considered to be the lifeline of economic development [45,69]. Global energy demand and prices have been resilient during a global recession, leading policy-makers in countries with the potential to produce energy to look at that sector as a potential engine for economic growth [29]. Many countries struggle to upgrade their energy systems to fully support current and future requirements of energy security and access, sustainability and economic growth [44]. As the global economy continues to expand, fossil pollution fuels such as oil and coal are depleted, environmental pollution and greenhouse gas emissions continue to increase, and energy and environmental protection are becoming the focal points of sustainable development [56]. New and renewable sources of energy have become more important [26], of which solar-energy resources are gaining popularity. The interest in solar photovoltaic energy is growing worldwide [68] owing to its high modularity, no requirement for additional resource (e.g., water and fuel), no moving parts and low maintenance required [43]. Photovoltaic (PV) power generation is an effective way to deal with the energy crisis and protect the environment both in the U.S. and overseas [50]. The U.S. has a great potential to benefit from sustainable growth of renewable energy, especially solar energy, due to the 2nd largest electricity demand in the world [11] and adequate suitable land area for PV development [5]. Thus, it is necessary to examine the risks that affect the financial health and survival of investor-owned utilities and study the effect of adding PV power generation to their portfolio for both minimizing risk through diversification while at the same time maximizing profit if possible. This paper focuses on identifying the optimal energy generation portfolio (EGP) for large scale investor-owned utilities in Florida.

Portfolio optimization dates back to the seminal work of Markowitz [40], who proposes a methodology to construct efficient portfolios based on a trade-off between expected return of a portfolio and its associated risk measured in terms of the

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portfolio variance. The portfolio selection model has been widely used in many application areas such as investment, information technology, and project management [8,33]. The mean–variance model assists in the selection of the most efficient portfolio based on expected returns (mean) and the standard deviation (variance) of the various portfolios [41]. Applications of this concept to energy investment where risks are considered can be seen in [4,6,15,46,54,55]. Ref. [14] applied portfolio theory in the Italian electricity market for different energy sources such as biomass, wind, hydro and photovoltaic, and demonstrated that risk can be mitigated by the diversification of investments in renewable energies. A comprehensive review of the state-of-the-art in energy portfolio optimization can be found in Ref. [32]. While these studies have made significant improvements in energy generation portfolio optimization, to our best knowledge there is no research that considers reducing the risk that affects the financial health and survival of the large scale investor-owned utilities while providing the lowest cost of electricity generation possible.

The uncertainties in the EGP have rarely been considered in the literature. For example, in reality, the estimation of energy generation cost may rely on experts' evaluations rather than historical data because of the complexity of the energy market. With the introduction of fuzzy set theory, fuzzy numbers can be employed to describe subjective imprecise quantity [67]. Fuzzy set theory was used to handle portfolio selection problems by [62]. He used fuzzy numbers to represent the decision makers' aspiration levels for the expected rate of return and a certain degree of risk. Later on, many scholars studied how to develop and use the mean-variance framework to select the portfolio in this situation by using fuzzy set theory, e.g. possibilistic models by Refs. [10,23,73], and credibilistic models by Refs. [25,34,49], etc. Recently, Bilbao-Terol et al. [7] have used goal programming and fuzzy technology to select a socially responsible portfolio. In this paper, the EGP under a fuzzy environment is considered and fuzzy theory is used to deal with uncertain information in modeling the energy generation portfolio selection for the four large scale investor-owned utilities in Florida.

Another contribution of this paper is the development of a particle swarm optimization (PSO) algorithm. This improved algorithm, which is designed based on the particular nature of the model to solve the above problem, can automatically control the particle-updating in the feasible solution space and avoid redundant searching for infeasible particle positions.

2. Statement of problem

2.1. Solar potential for Florida

Solar photovoltaics provide a viable source of emissions-free electricity in Florida. Florida's climate makes it particularly suited to the type of economic growth that solar energy production can create. Not only can it power homes, businesses and schools, it also charges an economy. Solar energy is capable of creating both high- and low-tech jobs, and will boost new construction. Investing in solar power will simultaneously promote Florida's energy production while securing its energy independence in the future. In essence, Florida is capable of becoming a hub of solar energy. Annual average daily direct normal solar radiation for the U.S. shows Florida with 14 MJ/m^2 (million joules per square meter) while it is as high as 28 MJ/m^2 in some other areas in the country [30]. This proves that while Florida is not the best place for solar energy project development, it has good potential for benefiting from the solar radiation [30].

Solar energy installations are beginning to rapidly expand in Florida. The best examples of this are three large-scale Florida Power & Light (FPL) solar power plants. FPL recently constructed three solar energy projects; a 25-MW plant in DeSoto County (one of the largest photovoltaic facility in the country), a 10-MW photovoltaic facility at the Kennedy Space Center, and the 75-MW Martin Next Generation Solar Energy Center hybrid parabolic-trough in Martin County, Florida [13].

2.2. Investor-owned utilities in the state of Florida

Table 1 shows the top four Florida's investor-owned utilities ranked by their generation capacity. These four investor-owned utilities cover Florida in its entirety with a combined total generation capacity of approximately 44 GW, which is 77% of the total generation capacity of all Florida utilities [13]. Smaller scale municipal electric utilities, rural electric cooperatives, state projects and public power districts make up the remaining 23% (13 GW) of the total electricity generation capacity in Florida. In addition, Florida is an importer of electricity, purchasing from states such as Georgia, Alabama and Mississippi [13].

2.3. Energy generation portfolio selection

Investor-owned utilities usually distribute their investments among different types of energy generation. To be adopted on a large scale, the risks and opportunities associated with development of renewables should be appropriately studied and measured. Realistically reaching this goal would involve implementing the new sustainable energy systems alongside the existing generation. Masini and Menichetti [42] addressed issues related to diversifying technological portfolios. Awerbuch [2] suggested that renewable energy technologies should not be compared based on stand-alone costs but should be rather evaluated on the basis of portfolio cost. Awerbuch and Berger [3] investigated how renewable energy sources can contribute to risk reduction in a mixed portfolio. They suggested that adding wind, photovoltaics and other fixed-cost renewable energies to a portfolio of conventional generating assets leads to decreased overall portfolio cost and risk, even though the stand-alone generating costs of renewable energies may be higher.

Based on Ref. [42], if risks are properly handled, a portfolio with a high share of renewables should outperform portfolios with a low share of renewables, inducing investors to further invest in these technologies. Masini and Menichetti [42] examined the impact of these factors on three categories of variables: i) the overall share of Renewable Energy (RE) in the generation portfolio; ii) the degree of technological diversification of the portfolio resulting from the investment decisions and iii) the share of each specific technology in the portfolio.

Table 1
Investor-owned utilities in the state of Florida [53].

Investor owned utility	Generation capacity in Gigawatt's (GW)	Percentage of total Florida's capacity
Florida Power and Light Company	25 GW	44%
Tampa Electric Company	11 GW	19%
Gulf Power Company	5 GW	9%
Progress Energy Florida	3 GW	5%
Total generation capacity	44 GW	77%