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A stochastic methodology to evaluate the optimal multi-site investment solution for photovoltaic plants

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ABSTRACT

The problem with evaluating the investment in a multi-site photovoltaic plant, such as that proposed in this paper (which can be viewed as a profitability analysis), is that it requires the development of an innovative methodological approach.

By setting an upper limit of capital to invest, among sites with different Direct Normal Irradiations (DNI), those in which many photovoltaic systems can be installed are identified as is the optimal size within predefined ranges. The primary objective is to maximize the net return on investment for a multi-site plant with a lifespan of approximately twenty years. The proposed approach uses a stochastic business plan, through which data are generated via the Monte Carlo simulation. Subsequently, using the Response Surface Methodology procedure, it is possible to identify the regression meta-model that describes the optimum region and therefore the point (investment amount for individual sites and the corresponding size of plants) that maximizes the overall Net Present Value. The proposed approach is completely generalized and, as such, can be replicated. A properly conducted test case is presented and clearly illustrates the methodology.

1. Introduction and literary review

Renewable energy technologies, pushed in some Countries by governmental incentives, had in the last years a strong increase in their application, both in private and public applications. In particular, photovoltaic (PV) systems have had a significant importance: PV technology has grown, over the past years from 24 GW worldwide to 178 GW (European Photovoltaic Industry Association, 2015).

Furthermore, solar energy can be used not only for electricity but also for heat production. For example, the combination of solar systems and heat pumps (HP) can reduce environmental pollution of about 41% of energy consumption per unit investment for cooling and 35% for heating (Tsai, 2014; Renno and de Giacomo, 2014).

Considering an expansion of the distributed generation of energy, smart grids could help to better integrate Renewable Energy Sources (RES) with distribution and transmissions systems (Song et al., 2014).

The role of PV systems in industrial contexts is very important to reach the World's sustainability goals (Rahmann and Castillo, 2014).

As regards the plant location problems in the literature different contributions are present. All the studies analyzed operate in a deterministic regime and many do not take into account the economic aspects associated.

An author has dealt the issue of the location choice of a multi-site investment using the multi-choice goal programming. In particular, the author presented as application case the analysis of four possible wind turbines installations for power generation in five possible locations. The limit of the proposed methodology is that the problem is addressed in a deterministic regime and that does not arrive to the determination of the mathematical relationship existing between the different possible combinations of investment and the objective functions (Chang, 2015).

Other authors have demonstrated the importance of site selection in the realization of small-scale solar and wind power. A case study in two Brazilian regions was realized, quantifying the influence of the parameters on the power potential for wind and solar energy, demonstrating the importance of considering the aggregate effect of these attributes. The study was performed to demonstrate the influence of location, area and shape attributes. The analysis was conducted according to the method of fixing two of the

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attributes and evaluating the variation of the third one. The limit of this approach is that (Duailibe Ribeiro et al., 2016).

Other studies has been developed to determine the best location to host a solar thermoelectric power plant using Geographic Information Systems (GIS) combined with Multi Criteria Decision Making (MCDM). The aim was to identify the best alternatives on the basis of different criteria such as environmental, orography, location and climatology. The choice of the location did not consider the economic profitability of the investments and is based on deterministic assumptions (Sánchez-Lozanoa et al., 2015; Tahri et al., 2015).

A study that put in evidence the ideal locations for installing hybrid solar-wind power stations in the Middle East has been analyzed. The choice of the best locations is done via Boolean logic model and combining maps of suitable places for using wind turbines and maps of suitable places to utilize solar cells. Also in this study the economical aspect was not considered (Jahangiri et al., 2016).

Other authors applied genetic algorithms and location-allocation approach to identify the best territorial clustering in terms of balancing between energy production capacity and consumption (Yanık et al., 2016).

The economic evaluation of investments in plants that produce electricity from supplementary sources is traditionally addressed once the site location is selected via analysis of Net Present Value (NPV), Internal Rate of Return (IRR), Levelized Electricity Cost (LEC), and so on (Cucchiella et al., 2015; Dusonchet and Telaretti, 2015; Paudel and Sarper, 2013; Ren et al., 2009; Talavera et al., 2011). Sometimes the CO_2 emissions reduction is also provided (Cucchiella and D'Adamo, 2012; Mahesh and Jasmin, 2013) but almost always deterministically.

Alongside the traditional methods, in recent years, more advanced methodological approaches have attracted attention. These approaches have been developed in stochastic regime that is more realistic than the traditional deterministic one. The new concept introduced by these approaches is the identification of meta-model regression to describe the behavior of economic variables as a function of the values assumed by the projected variables, either in the form of point values (deterministic system) (Bendato et al., 2015a) or Probability Density Functions (stochastic system) (Bendato et al., 2016). The improvement in quality in the latter work (Bendato et al., 2016) was achieved by using statistical experimental methods based on the Design of Experiments and Response Surface Methodology (Bendato et al., 2015b; Cai et al., 2014; Cassettari et al., 2011; Da Silva et al., 2015; Kadaganchi et al., 2015; Mangili et al., 2015; Saravanakumar et al., 2014) combined, under the stochastic system, with the Monte Carlo method (Cai et al., 2014; Cassettari et al., 2015a, 2015b; Mosca et al., 2009).

The problem that will be addressed in this paper is conceptually very different from that in the literature, although it is, as in (Bendato et al., 2015a) and (Bendato et al., 2016), the assessment of investments in plants that produce electricity from solar energy.

The present study involves, in fact, the development of a methodology that allows us to identify the location and power of a certain number of photovoltaic systems to maximize the NPV of the overall capital made available by an investing in an institution.

In addition to the NPV, the methodology measures the impact of other parameters so that the investor can have a broader view than the mere creation of new capital.

In particular the project coverage ratio and the amount of CO_2 emitted into the atmosphere are considered. The first one allows to better understand the real investment profitability while the second one is the main environmental sustainability parameter.

The problem then becomes, from a mathematical point of view, determining the optimum value of a function in an N-dimensional domain (N being the possible location of sites). The reference function describes the NPV behavior of the chosen sites, percentage of investment of each site and resulting plant power. The stochasticity is linked to design elements, such as Direct Normal Irradiation (DNI) as well as the number and year that the inverters are replaced, the annual energy production, the feed-in tariffs and the energy purchase price. The decision-making element, however, is the overall profitability of the investment and is generated as a combination of the NPV at the individual sites.

The heart of the problem, therefore, becomes the search for the optimal point of a function, which is not known *a priori*; thus, it is necessary to proceed by suitably combining, in an organized sequence of methodological steps, a series of mathematical techniques, including the Design of Experiments (DOE), the Surface Methodology (RSM) and Monte Carlo method.

The result is a rigorous approach that, as demonstrated in the case studies, is able to effectively address this type of problem.

The novelty of the proposed approach is the possibility to reach, with a single methodology, the economic optimization of an *a priori* not known function, considering the real stochastic nature of all the involved variables.

Companies, institutions and/or individuals wishing to invest in this type of plants through the use of the proposed methodology are able to have a realistic, comprehensive and readily interpretable picture of the situation that they want to investigate.

Note that the proposed methodology could be applied to innovative experimental plants that are funded by external non-profit bodies; however, in these cases, this type of analysis is often neglected (Barillari et al., 2014).

2. The case study

As part of an investment diversification policy, a financial company considers it appropriate to undertake a study to assess the possibility of establishing new solar energy production facilities. The plants are located in Southern Italy at four different sites, and the maximum total outlay is estimated at €240 M.

By respecting these constraints, it was necessary to define where it was worth investing and how much of the total outlay was worth to be used. This with the aim of maximizing the investment results in terms of NPV and discounted profitability ratio (DPR) and considering, also, the environmental impact in terms of reduction of CO_2 emissions.

Even if investment analysis is a traditional knowledge for this kind of companies, the Management felt to lack expertise in this area because of the particular economical characteristics of PV plants. The company decided, then, to entrust the authors of a research paper on technological-economic and location-related issues with the task of guaranteeing the determination of the minimum scheduled NPV and the DPR threshold.

In addition, to meet the so-called “ethical balance” requirements, the investor intends to combine the economic viability (at least within certain limits) with the possible reduction in CO_2 that would be released to the atmosphere from fossil fuel plants of an equivalent size. Underlying these pollution avoidances is important to raise awareness on the sustainable manufacturing concept.

The company has indicated five reference sites in four different regions of Southern Italy: Ragusa, Sassari, Bari, Foggia and Reggio Calabria.

The main data considered by the authors for each site are:

- the DNI
- the availability of the land to be assessed at 7000/8000 mq/MWe