# *RELIABILITY BASED DESIGN APPROACH TO STOCHASTIC SUPPLY PLANNING INCLUDING RENEWABLE ENERGY SOURCES*

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## Overview

The integration of renewable energy sources (RES) in energy planning problems has led to an increased focus to incorporate risk management approaches in energy strategies. Besides the compelling advantages of RES resulting in decreased pollution and simultaneously presenting economically feasible solutions, a major problem remaining is if RES can be considered as reliable power sources. In energy planning problems issues concerning the unpredictability of the output can be specifically addressed by imposing the relevant variables included in the model to be volatile. This can be imposed on supply and demand side and consequently results in a paradigm shift from deterministic to stochastic supply-demand constraints. In order to specifically address the problem of variability in the output of RES, we impose the methodology of reliability based design optimization (RBDO). From this point of view, the stochastic supply-demand constraint has to be valid with a certain probability which is expressed in terms of the level of reliability. This ex-ante chosen level of reliability reflects the energy manager's attitude towards risk and can be directly incorporated as a parameter in the model formulation. The RBDO methodology can be considered as valuable because it has a dual goal, namely guaranteeing performance as well as system reliability under uncertainty. This makes the concept accessible to various applications in designing optimal energy planning strategies.

Generally, a crucial point in the design of stochastic energy models and especially in the formulation of chance constraint problems is the choice of the underlying probability structure of the stochastic variables. In many cases, the stochastic variables are assumed to be Gaussian, which is considered as an approximation but yet can be too simplistic in several applications. This can lead to procurement plans which are infeasible on the one hand or overly expensive on the other hand. However, other choices than Gaussian probability density functions can result in immoderate technical problems in the optimization models.

This paper proposes a proactive, stochastic energy planning model to evaluate the maximum reliable supply which can be provided by RES over the planning period of one year, by imposing the RBDO methodology. This specific model can be considered as the fundamental building block of a framework to include RES in stochastic energy management problems which are limited by reliability constraints. An advantage of the framework is, that it is embedded in an optimization model which can be adapted to cover a wide range of different problems. We consider photovoltaic power sources as well as wind turbine generators in a use case and calibrate suitable probability density functions based on historic weather data, which account for seasonal effects in the planning period of one year. The power sources itself are specified by their installed capacity. Within the scope of the model the approach of Gaussian distributions is considered as the benchmark model and compared to other models assuming Weibull, Exponential, Beta and Log-Normal distributions. To evaluate the accuracy of the different models, a retrospective validation in terms of the models' ability to reproduce the ex-post calibrated optimal solution via a backtest simulation is performed.

## Methods

The methodology of reliability based design optimization is implemented to determine the maximum supply which can be provided from RES in an energy park. This can be considered as a general problem dealing with reliability issues in stochastic RES energy planning. In the validation process, different stochastic models are compared. The solution can be computed analytically in case of the benchmark model assuming Gaussian, whereas in case of different probability density functions the solution is computed numerically. This paper applies probabilistic relaxation techniques via the sample approach of Calafiore and Campi (2005, 2006) where the original problem is approximated by the sample program, which is in content with robustness against a vast majority of unseen constraints. Furthermore, a sample and discard algorithm is applied in order to reduce computational complexity (Campi and Garatti, 2011). This approach makes the stochastic energy model accessible to generic formulations in terms of probabilistic descriptions.

## Results

The aim of this paper is twofold. First of all, we introduce the framework of a stochastic planning model which incorporates the estimation of the supply that can be provided from RES technologies, with a special focus on the security of supply, via the RBDO methodology. This can be considered as the basic building block for a modular framework which introduces stochastic supply planning of renewable energy technologies. An advantage of this formulation lies in the fact that it is formulated in terms of an optimization problem and can be incorporated in other widely used optimization problems. The basic model is illustrated by means of two applications in order to show the flexibility, which makes this framework adaptable to a great variety of stochastic planning problems. Not only variable load profiles of RES but also issues related to the unpredictability of these technologies can be considered. The supply-demand constraint is considered as a stochastic inequality which has to be true with at least a certain ex-ante chosen level of reliability. This reliability parameter reflects upon the energy manager's attitude towards risk and acts a threshold to determine the optimal strategy. Numerical solutions are obtained using methods of stochastic optimization to solve the problem based on scenario approximation and scenario reduction techniques. The proposed framework can be considered as a flexible planning tool which is able to supplement proactive managerial decisions concerning stochastic energy planning problems including RES.

The second goal of this paper is to compare different ways to model the power available (via Weibull, Exponential, Beta and Log-normal distributions) in the energy model. A retrospective validation based on a backtest simulation of the model's ability to reproduce the ex-post optimal strategy of the following year is performed. The results of the backtest approach show that the benchmark model of Gaussian distributions is outperformed by the model using an non-normal distribution to model solar irradiance and a Weibull distribution to model wind speed and reduces the average coefficient of variation of the root mean squared error by approximately 8 %. Further investigation shows, that the performance of the models depends on the ex-ante chosen level of reliability. The benchmark model is outperformed by all other models in the regime of energy managers with a level of reliability of approximately $\chi > 0.8$. This gives raise to the fact that Gaussian distributions can be considered as an approximation having the advantage of lower computational complexity, but can lack in an accurate description of reality. This reliability levels however are typical values considered in RBDO problems, which establishes the practical use of the framework introduced.

## Conclusions

This paper shows that the assumption of Gaussian distributions in stochastic reliability energy planning problems can be used as an approximation but is outperformed by distributions adapted to the specific problem (e.g.Weibull, Exponential, Beta and Log-normal) in the regime of higher levels of reliability. These levels of reliability are values which typically occur in RBDO problems. We formulate a framework which integrates renewable energy technologies independent of the probability distribution and thereby overcomes the shortcoming of being restricted to Gaussian distributions by solving the optimization problem based on the sample approach. This framework, which can be embedded in widely used optimization problems, can be adapted to a great variety of energy planning problems which accounts for issues related to a reliable performance.

## References

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