www.ceejme.eu

ISSN electronic version 2353 - 9119
*Central and Eastern European Journal*
*of Management and Economics*
*Vol 6, No. 4, 35-45, December 2018*

# Application of Monte Carlo simulations in economic analysis of a wind farm

**Anna DUBEL, Paweł JASTRZĘBSKI**
**AGH University of Science and Technology, Krakow, Poland**

**Abstract:**

**Aim:** The purpose of the study is to compare the impacts of factors such as: average wind speed, energy price, capital and operating costs, on the economic efficiency of a wind farm. The outcomes of such analysis are helpful to support decision making about an investment.

**Design / test methods:** The paper presents the application of Monte Carlo analysis to simulate the factors influencing the profitability of investments. Wind speed, energy price and operating costs were introduced into the Monte Carlo simulation model in the form of probability distributions with assumed parameters.

**Conclusions:** The factor that has the greatest impact on the ENPV of the investment is the average wind speed, which has a direct impact on the amount of energy produced. Therefore, the forecasts for atmospheric conditions in RES installations are recommended to be subject to special verification.

**Originality / value of the paper:** The example presented in the paper demonstrates how using the Monte Carlo method makes it possible to quickly and easily examine the profitability of an investment, taking into account risk factors such as weather conditions, energy prices, etc.

*Keywords: Monte Carlo simulations, economic analysis, renewable energy sources, wind energy, uncertainty.*

JEL: D61,Q2, C8.

---

*E-mail: adubel@zarz.agh.edu.pl; pjastrzebski@agh.edu.pl*
http://dx.doi.org/10.29015/ceejme.704

## 1. Introduction

The renewable energy sources (RES) constitute an important contribution to the sustainable development goals by limiting the climate change and negative environmental impacts related to the conventional energy production based on carbon combustion. This issue is discussed in the important reports and the EU policy documents, such as: the Directive 2009/28/EC on the promotion of the use of energy from renewable sources (European Commission 2009), the Intergovernmental Panel on Climate Change Fifth Assessment Report on climate change implications for the energy sector (IPCC 2014) and on the climate change mitigation challenges and approaches (Edenhofer O. et al. 2014), to name but a few. The energy policy of the European Union assumes the share of renewable energy sources in the total energy production in 2020 at the level of 20%. (European Commission 2010) Apart from the environmental gains related to the renewable energy sources, the European Union and the Polish government are also focused on the improvement of energy security and this could be achieved through the use of energy from renewable sources (Polish Ministry of Environment 2012; Paska & Surma 2013). For the EU economy and sustainable development it is important to use local potentials and create cooperation links between producers and consumers of energy in a municipality or in a county. Also within this aspect renewable energy sources deliver a considerable potential stimulating cooperation between economic actors in different sectors (such as farmers, technology designers and providers, transportation and logistics companies as well as private or public investors) and make it possible for energy consumers to become also energy producers.

In Poland, the development and support of RES is visible in the national strategies, i.e. Polish Energy Policy till 2030 (Polish Ministry of Economic Affairs 2009) and the National Plan for Action with regard to energy from renewable energy sources (Polish Ministry of Economic Affairs 2010) as well as policies, i.e. the Polish Energy Law from 1997 and the Polish RES Law from 2015. The incentives for the RES energy production are also evolving, stimulating more effective and efficient technologies (Ragwitz 2005, the Polish RES Law from 2015). However, the various kinds of RES are unequally supported, as the evolving RES policy in Poland is sometimes giving more support to one kind of RES over the other and these preferences are changing in time.

When it comes to the various kinds of RES, like: biomass, water energy plants, wind farms, photovoltaic farms, geothermal energy and waves energy, the share of the biomass in the world RES production is estimated the greatest during the years, at the level of 75% in 2010 and 51.5% in 2040 (EREC 2004). The share of wind energy in the total world RES production according to EREC 2004 report is anticipated to grow from 2.5% in 2010 to 10.8% in 2040. Even higher dynamics is foreseen in the photovoltaics from 1% in 2010 to 21% in 2040. Steady growth is estimated with regard to the geothermal energy from 4.9% in 2010 to 7.8% in 2040. Whereas with regard to energy possessed from water the decline is predicted from 16.3% in 2010 to 8.6% in 2040. These prognoses reveal that by 2040 the wind energy should be on the third place among all RES with regard to the volume of production, after biomass and photovoltaics. In Poland in 2013 the share of all RES is about 11.9% of the total primary energy production, of which 10.53% of from the wind plants and 5.54% from photovoltaics, (GUS 2015).

Bearing in mind all benefits and merits related to RES there are several issues hindering their widespread implementation. Fundamental is the issues that RES are considered as unstable energy supply sources. It is due to the fact that weather conditions, such as: the number of sunny days per year, wind strength and direction as well as geographic conditions make it difficult to estimate the predicted production of renewable energy. Because these factors are uncertain, it is difficult to estimate the revenues and financial performance of investments with regard to the renewable energy sources. The risk of RES projects may be too big and in such case the investment decision will be very hard to make. Therefore the key issue is to estimate risk related to the occurrence of the outcome of the planned decision (chosen action). This can be evaluated using Monte Carlo simulations. Selected factors influencing production volume and investment efficiency, such as: weather conditions, changes in energy prices, changes in operating costs, etc., are introduced into the Monte Carlo simulation model in the form of probability distributions determining their variability. As a result, a certain indicator is obtained, e.g. an updated Net Present Value in the form of probability distribution, which determines the risk of achieving the expected output value.

This paper analyses the uncertainties related to the performance of the selected renewable energy sources based on environmental and physical conditions in Poland. The Monte Carlo simulation method is applied in order to simulate the impact of analysed parameters change on the final outcomes of the economic analysis of a wind farm. In the following chapters the simulation method and its results together with the assumptions are presented.

## 2. Monte Carlo simulation method

Apart from deterministic methods, such as sensitivity analysis or scenario analysis, a probabilistic approach of the Monte Carlo simulation is used to simulate the effects of risk on the outcomes at stake. The Monte Carlo method simulates distribution of output as function of input distribution. The use of the formal probabilistic approach is considered an advantage, as not only the possible outcomes can be simulated, but also their likelihood. Moreover, the Monte Carlo method makes it possible to model interdependent relationships between the input variables. At the same time the drawbacks of the method include the computational burden (Katz 2002).

The Monte Carlo method is a quantitative mathematical technique (Harrison 2010) that allows one to see the possible outcomes, with their probabilities of occurrence, for the analysed decisions (choices of action) and thus it allows to assess the impact of risk contributing to the better - more informed, decision making under uncertainty.

In case of the financial and economic analyses the Monte Carlo simulation procedure starts with the construction of the reference project cash flow sheet, which includes all relevant relationships between the input variables (Katz 2002).

The next step is to identify critical variables, i.e. input parameters that may have the most impact on the economic performance of the project, and to draw up a list of output variables (e.g. individual cash flows, NPVs or IRRs) that are being analysed.

The difficult thing in the implementation of the Monte Carlo simulation method is to determine the series of values that can be implemented as uncertain input parameters, with probabilities of their occurrence estimated based on their probability distributions. Layouts are based on engineering analysis, expert analysis or historical data analysis. It is important that the variables in the analysis are expected to have predicted values, that is, their distributions are supposed to reflect the future rather than the past. In cases where there is a very limited number of data (e.g. minimum, expected and maximum), it is recommended to use simple triangular distributions, where the smallest and highest values are unlikely to occur (i.e. their probability of occurrence is less than 5%) and the highest probability of occurrence has the estimated value.

Such approach to the problem is obviously debatable, but sometimes this is the only solution to overcome the issue of the limited number of data (Katz 2002).

The simulation process consists of successively generating random numbers, used to select from the probability distribution of each uncertain input parameter of random variables. In this way sets of random variables are obtained. The process continues repeatedly to obtain a sufficient number of variable values for statistical analysis and a sufficient number of output parameters.

## 3. Economic analysis

A financial analysis helps an investor to take rational decision about an analysed investment. Whereas an economic analysis broadens this perspective including positive effects (benefits) and/or negative effects (costs) of the investment imposed on other stakeholders and/or related to the environment. Ex-ante cost-benefit analysis of experimental and new technologies is related with the high uncertainty, which can be accounted for in a kind of probabilistic sensitivity analysis conducted with the use of a Monte Carlo simulation method.

In the paper the Monte Carlo simulations are conducted to account for uncertainties in economic analysis of an investment in the wind farm. Based on the assumptions data ex-ante analysis is performed for 25-years period and in particular the Net Present Values (NPV) of the investments are calculated. Software @Risk ver.7.5 from Palisade Co. is used for the calculation.

## 4. Assumptions

The analysis is performed for a theoretical wind turbine assuming its technical and operating conditions, such as wind speed. The analysis is based on the assumptions presented in Table 1. The assumptions are taking into consideration the legal, economic and geophysical conditions that are relevant for Poland.

**Table 1. Technical, environment related and financial assumptions about the analysed wind farm**

| | | |
|---|---|---|
| TECHNICAL ASSUMPTIONS | | |
| air density ρ | 1.22 | $kg/m^3$ |
| mechanical efficiency of system ηm | 0.95 | $kg/m^3$ |
| electric efficiency of turbine ηel | 0.85 | $kg/m^3$ |
| capacity factor Cp | 0.59 | $kg/m^3$ |
| radius of turbine r | 45.00 | m |
| rated power of turbine Pr | 2.00 | MWe |
| wind speed v | 7.00 | m/s |
| ENVIRONMENT RELATED ASSUMPTIONS ABOUT EMISSIONS | | |
| emission of $CO_2$ | 810 | kg/MWh |
| emission of $SO_2$ | 1.539 | kg/MWh |
| emission of $NO_x$ | 0.968 | kg/MWh |
| emission of CO | 0.238 | kg/MWh |
| emission of TSP | 0.063 | kg/MWh |
| FINANCIAL ASSUMPTIONS | | |
| energy price | 448.82 | PLN/MWh |
| operational cost | 245 000.00 | PLN/MW/year |
| investment cost | 6 500 000.00 | PLN/MW |
| discount rate in financial analysis | 4.00 | % |
| discount rate in economic analysis | 4.50% | % |
| cost of $CO_2$ emission | 0.29 | zł/$MgCO_2$ |
| cost of $CO_2$ emission certificate | 0.16 | zł/$kgCO_2$ wg EBI |
| cost of emission of $SO_2$ | 0.53 | zł/$kgSO_2$ |
| cost of emission of $NO_x$ | 0.53 | zł/$kgNO_x$ |
| cost of emission of CO | 0.11 | zł/kgCO |
| cost of emission of TSP | 0.35 | zł/kgTSP |

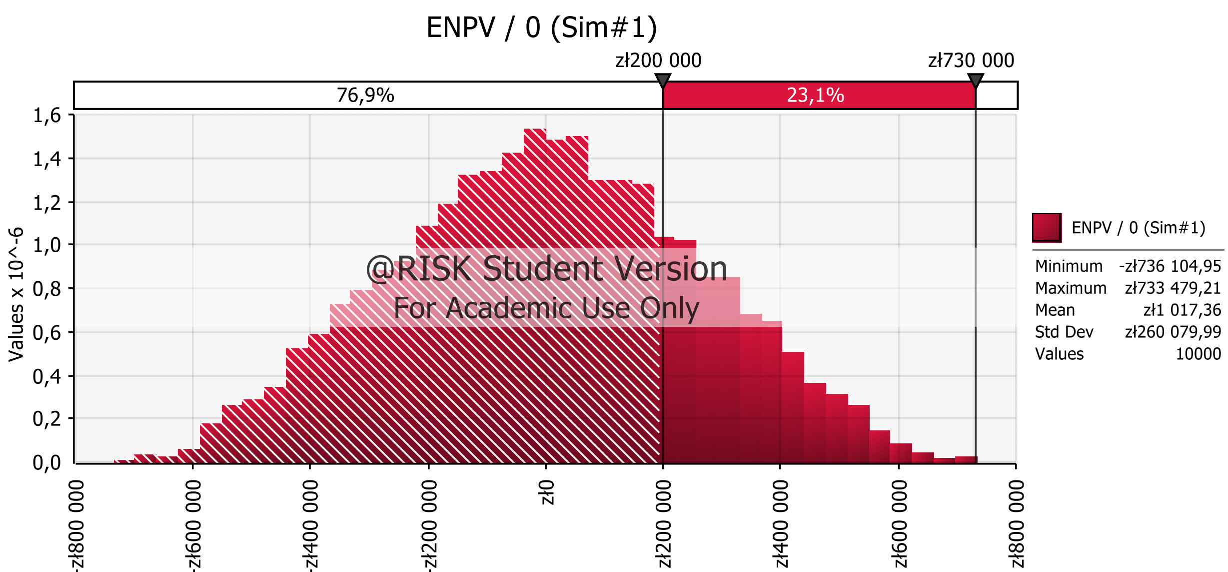
Source: own elaboration.

For the Monte Carlo simulations the price of energy is assumed at the level at which ENPV equals to zero. The defined critical variables are the following: the price of electricity, the investment costs and the operating costs. The critical variable in the financial and economic analyses that has direct strong influence on the financial and economic performance of the RES investment is the amount of energy that is produced by the wind turbine. This, in turn depends, among other things, on the wind speed. The calculations in the analysis presented in the paper are based on the average annual speed, which in fact in real life conditions varies according to the season. Therefore, in order to account for this uncertainty in the analysis, the triangular probability distributions are considered, with deviations from expected values of +/-5% for average wind speeds, +/-10% for the energy prices, +/-10% for the operating costs and +/-10% for the investment costs. In fact, for the purposes of such analysis, the probability distributions should be based on historical data. However, in the absence of them, as in this case of the conducted ex-ante analysis, the triangular distributions can be used, as described earlier. Finally, the value of ENPV is assumed to be 200 000 PLN or more as a criterion to decide to pursue the investment.

## 5. Results

The results of the calculations are obtained revealing the probability distribution of the expected value occurrence and the determined effect of the analysed variables (such as: investment and operating cost, wind speed and the price of energy) on the economic efficiency of the project. A series of ten simulations and ten thousand of iterations each were made. The results are presented in Figure 1 featuring the probability density and in Figure 2 presenting inputs ranked by effect on output mean.

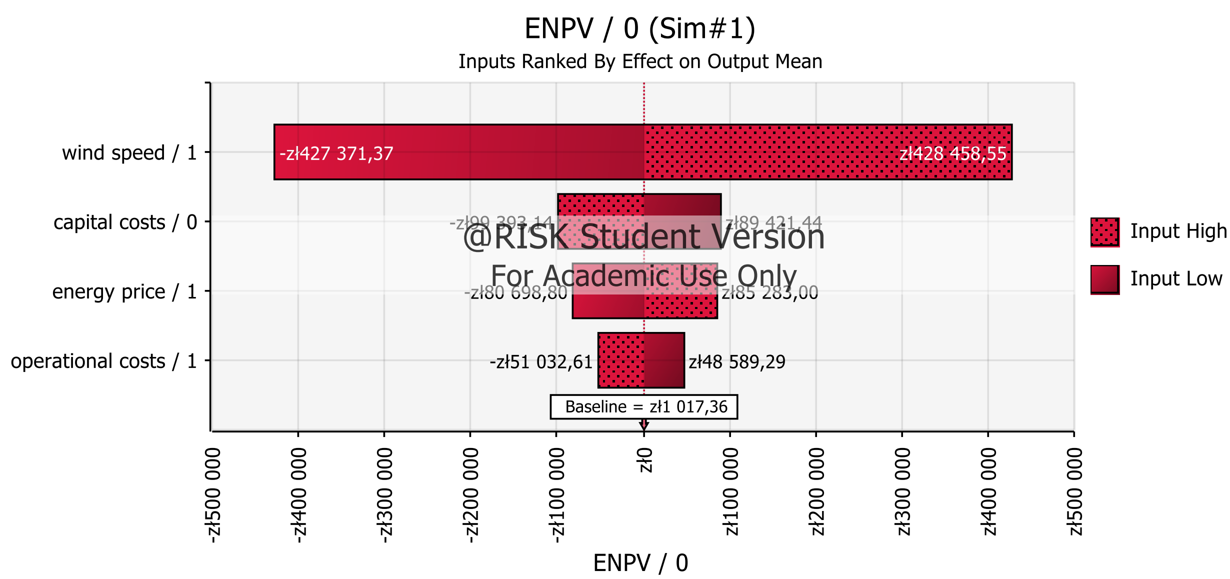
**Figure 1. Probability density**




Source: own elaboration.

From the chart presented in Figure 1 the probability of achieving a satisfactory result of ENPV (in this case it is at least 200 000 PLN) can be traced. In the analysed case this probability of achieving Economic Net Present Value equal or higher than 200 000 PLN is 23.1%. It is then the decisions makers concern whether such a level of certainty about the satisfying outcome is enough for them to make the positive decision about the implementation of the project or not.

**Figure 2: Inputs ranked by effect on output mean**




Source: own elaboration.

The second chart shows the impact of the analysed factors, such as: average wind speed, operating and capital costs, and energy price, on the ENPV. The presented outcome determines which factor the decision makers should focus on the most in planning the investment, as even a slight estimation error can distort the result and thus lead to erroneous decisions. In the analysed example wind speed constitutes the most influential factor, which effect on the investment is estimated to be more than three times greater than the effect of the other analysed factors. From the remaining factors capital costs are estimated to have the greatest impact on the ENPV, followed by the energy price and finally the operational costs. However, the differences between the estimated values of these variables are not high.

## 6. Discussion of outcomes

While deviations from investment costs, operating costs or even energy prices have an impact of around 20% on the ENPV, the wind speed is the crucial variable as it affects the expected results by about +/ - 400 thousand PLN. Accuracy of +/- 5% has a very significant effect on the final score. This is due to the fact that wind speed has a very significant effect on the amount of energy produced and on the volume of investment income.

The methodology for the economic analysis of investments recommended by the European Commission (2014) states that the probabilistic risk analysis is required in cases where after implementation of mitigation measures the residual risk exposure is still significant. Therefore the presented approach to sensitivity analysis related to economic efficiency of wind farms takes into account the probabilistic character of the impact factors that are beyond the investors' control.

The results obtained with the use of Monte Carlo simulations, as those presented in the paper, can be especially useful for investors as well as decision makers responsible for development of RES investments at local, regional and national levels, due to the fact that such analysis can make explicit the most influential uncertainties and risk factors having impact on the economic outcomes of their decisions. Also, such analysis can inform policy makers about the risk related to investments in different kinds of RES. This could have an impact on the choice of various RES kinds and the preferences to invest in a particular RES in the future.

## 7. Conclusions

With the use of the Monte Carlo simulations the impacts on the economic efficiency of a wind farm of factors, such as: average wind speed, energy price, capital and operating costs, were compared. This analysis shows that the average profitability of such an investment is mostly influenced by the average wind speed, which determines the amount of energy produced. Minor deviations from the wind forecasts may be crucial for investment decisions. Other factors such as the price of energy or the deviation of the level of capital or operating costs are less important.

This probabilistic assessment of risk was proven to provide crucial information to lower the investors or policy makers uncertainty about the investments in RES. In particular, information about the probability of achieving the desired economic outcomes or about the factor(s) having the highest impact on the outcome.

## Bibliography


Edenhofer, O. et al. (eds.), 2014. Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, Cambridge, New York.

EREC, 2004. The contribution of RES to the world energy supply in 2040 – report.

European Commission, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

European Commission, 2010. Energy 2020. EU Energy Strategy, COM(2010)639, Brussels.

European Commission, 2014. Guide to Cost-Benefit Analysis of Investment Projects Economic appraisal tool for Cohesion Policy 2014-2020. Directorate-General for Regional and Urban policy, Brussels.

GUS, 2015. Energy from renewable sources in 2014. [Energia ze źródeł odnawialnych w 2014 roku.], Central Statistical Office, Industry Division, Ministry of Economy, Energetic Department, Warsaw.

Harrison R.L. (2010). Introduction To Monte Carlo Simulation. *AIP conference proceedings*, *1204*, 17-21.

IPCC, 2014. Climate Change: Implications for the Energy Sector, The 5th Assessment Report Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Katz, R. W., 2002. Techniques for estimating uncertainty in climate change scenarios and impact studies. Climate Research 20:167-185.

Paska, J., Surma, T., 2013. Polish energy policy in view of the EU energy policy. [Polityka energetyczna Polski na tle polityki energetycznej Unii Europejskiej.] Polityka Energetyczna Journal, Vol. 16/4.

Polish Energy Law from 10 April 1997.

Polish Ministry of Economic Affairs, 2009. Polish Energy Policy till 2030. [Polityka energetyczna Polski do 2030 roku.], Warsaw.

Polish Ministry of Economic Affairs, 2010. National Plan of Action with regard to energy from renewable energy sources. [Krajowy plan działania w zakresie energii ze źródeł odnawialnych.], Warsaw.

Polish Ministry of Environment, 2012. Strategy of Energy Sefety and Environment. Perspective to year 2020, Project 28.06.2012, [Strategia Bezpieczeństwo Energetyczne i Środowisko. Perspektywa do 2020 r., projekt 28.06.2012], Warsaw.

Polish RES Law from 20 February 2015.

Ragwitz, M., Held, A., Resch, G., Faber, T., Huber, C., Haas, R.. 2005. Monitoring and evaluation of policy instruments to support renewable electricity in EU Member States. Fraunhofer Institute Systems and Innovation Research, Germany.

Saługa, P., 2011. Managerial flexibility in mineral project valuation, Mineral and Energy Economy Research Institute, Polish Academy of Science, Krakow.

Frederick, S.W., Loewenstein, G., O'Donoghue, T., 2002. Time Discounting and Time Preference: A Critical Review. Journal of Economic Literature. 40 (2): 351–401.

Stern, N., 2006. Stern Review on The Economics of Climate Change (pre-publication edition). Executive Summary. HM Treasury, London.