EFFICIENCY EVALUATION OF WIND POWER COMPANIES WITH EMPHASIS ON FINANCIAL RESULT

Zdenko Prohaska
University of Rijeka, Faculty of Economics, Croatia
zdenko.prohaska@ri.t-com.hr

Dario Maradin
University of Rijeka, Faculty of Economics, Croatia
dmaradin@efri.hr

Dejan Miljenović
University of Rijeka, Faculty of Economics, Croatia
dmiljeno@efri.hr

ABSTRACT
Observing the crucial business success aspects, the main objective of a company exclusively refers to achieving positive financial results. The question that arises is whether there is a significant relationship between the financial result of the company and its efficiency. For example, in certain industries, analyses of companies with higher financial results confirmed that they will generally achieve higher efficiency scores. The question is whether this can be applied to all industries and whether there is a direct impact of the financial result to the formation of company efficiency.

The aim of this research is to show the relationship between financial results and company efficiency. This research includes companies from the electricity sector as one of the major infrastructural sectors. More specifically, wind power companies that participate in the electricity generation from wind energy, as a renewable energy source which is now substantially in use, are being analyzed. This is especially important from the aspect of contributions from those companies to the development and sustainability of the whole electricity sector.

Keywords: *financial result, the efficiency of a company, wind power companies*

1 INTRODUCTION

Nowadays, one of the most important financial issues of companies is performance evaluation. A good operating performance is critical for successful business. Evaluation methods of companies' performance can help decision makers to gain an insight into the current situation and position of the company on the market and achievement of the desired objectives. One of the adequate methods that can be used to measure company performance is Data Envelopment Analysis (DEA), which is used in this paper. Accordingly, evaluation of performance efficiency is the main subject of this study.

A positive financial result is an important segment in business activities of any company. It appears as a precondition for security and business continuity. In the economy, many companies oscillate in the volume of production and sales, including the achievement of financial results. Because of these fluctuations in financial results in business, and the fact that capital is always a scarce resource of the company, it is concluded that it is extremely important how efficiently it will be used. It may be noted that the financial or operating result appears as a target value of corporate performance that provides an overall picture of the efficiency of assets (Sorić, 2002).

Therefore, it is important to analyse or evaluate the relative efficiency of companies focusing on their financial results. In this process, total assets and other technical inputs necessary for the operation of the business are viewed as company assets, and financial result and production are cited as outcomes of that business. The above is observed in the electricity sector, i.e. in the electricity generation from wind energy, a fast growing segment of renewable energy sources.

The aim of this study is to evaluate company efficiency with regard to financial results in the case of wind power companies, and to analyse whether there is a connection between the realised financial results and company efficiency. This is used to determine whether financial results have a direct impact on the formation of company efficiency.

2 LITERATURE REVIEW

Nowadays, evaluation of efficiency using the DEA method improves the methodology for analysing a wide range of units or entities that appear in production activities, but also in non-profit sector, such as education or health care. In literature, the observed organisational units are called decision-making units (DMU), and can be companies, banks, or other financial institutions, schools, tertiary education instutions, hospitals, post offices or police stations, etc. To gain a perspective on the actual volume of published papers in which the DEA method is used, it is necessary to point out over 3000 different publications, written from 1978 to 2001 (Tavares, 2002).

DEA is a mathematical programming method for measuring performance efficiency of DMUs. It is used to evaluate the relative efficiency of units operating in identical, or at least similar conditions, and when this is impossible, because of the specificity of a unit, to conduct a research using another scientific method. DEA assumes the performance of the DMU using the concept of efficiency (concept of productivity is also sometimes used) (Mantri, 2008). Although the terms are often used as synonyms, it is noteworthy that they are different terms. Efficiency can be defined as an ability to achieve outputs or objectives with minimal use of inputs or available resources. Also, efficiency is the maximum amount of output with the existing level of input. It is measured as the ratio of total outputs to total inputs. Also, the estimated efficiencies are relative to the best performing

DMU that is given a score of 100%, and the performance of other (inefficient) DMUs vary between 0-100% (Mantri, 2008).

Charnes, Cooper and Rhodes (1978) were the first authors that used the term *data envelopment analysis* (DEA) in their paper. They proposed a model (CCR efficiency concept) that had an input orientation and assumed constant retums to scale (CRS). Subsequent papers have considered altemative sets of assumptions, such as Banker (1984), Banker, Charnes and Cooper (1984) (in which variable retums to scale (VRS) models are proposed – known as BCC concept), Färe et al. (1985), and others.

From the very beginning, the DEA method has been applied in various industries and segments of life. Färe, Grosskopf and Logan (1983) were the first authors who evaluated companies' efficiency using the DEA method in the power sector. Their research was conducted in the American state of Illinois between 1975 and 1979, and they found relative technical efficiency only in a few companies (compared to other companies). As mentioned before, the advantage of the DEA method is the fact that it provides additional information on the sources of inefficiency of production, which should be useful to decision makers and other stakeholders in general, not only in electric utilities. In this way, for example, regulatory authorities in electricity sector are able to formulate policies on liberalisation, privatisation or deregulation, and to determine the appropriate regulation on electric utilities in electric power transmission and distribution activities (Lam, Shiu, 2001). The major source of inefficiency was due to production 'inside' the isoquant, although there were another sources of inefficiency. Those results suggest that regulation does not necessarily result in efficient operation nor in good performance of electric utilities (Färe, et al., 1983).

There are numerous papers containing the DEA method in the electricity sector. Zhou et al. (2008) present a literature survey (with 100 publications) on the application of DEA to energy and environmental studies.

In each of the four main activities of the power sector, various studies and research were conducted using the DEA method, aimed to improve the functioning of the market. For example, in electricity generation activities, a research may be noted that measures the efficiency of 30 state-owned electric generation utilities/companies in India for the year 2007-2008 with a single input and two outputs (Jain, et al., 2010). Evaluation of the electricity companies using the DEA method, except in the production of electricity, is also carried out in regulatory activities. For example, efficiency of seven companies in Colombia was analysed in the transmission of electric power using "window analysis" for a period of four years (Cadena, 2009). In another regulatory activity, distribution of electricity, Bagdadioglu et al. (1996) find indication of relative efficiency among the Turkish distribution utilities offered for private franchise. In the process of transmission of electricity from the producer to the consumer, supply of electricity appears as the final stage before the consumption of electricity. Although it appears as a competitive business with many companies in the market, evaluation of efficiency using the DEA method is not performed to a large extent and scope in this activity of the electricity market. One can, however, cite a study that analysed the efficiency and performance of utilities and its effects on prices under the price-cap regulation in Hong Kong's electricity supply industry (Wang, et al., 2007).

Over the past decades, the importance of renewable energy resources has increased in the world due to both the rapid increase in energy demand and disadvantages of the fossil fuels (Yaniktepe et al., 2013). Increasing development and use of renewable energy sources caused the need for the application of the DEA analysis also in this segment of electricity production. As the world's fastest growing renewable energy source, wind power is an ideal technology for the development of electricity production and also represents a domestic source of energy http://www.renewableuk.com/en/renewable-energy/wind-energy/index.cfm, Ilkılıc, 2011). Although there are many papers on wind energy, intensive studies on efficiency of wind farms were not conducted until recently, by using various scientific methods, including the DEA method (Pestana Barros, Sequeira Antunes, 2011). Among the few studies in which efficiency of wind power plants was evaluated, there are studies by authors from Turkey (Sarıca, Or, 2007; Ertek et al., 2012) and Spain (Iglesias et al., 2010).

Sarıca and Or (2007) analysed and compared the performance of electricity generation plants of 65 thermal (natural gas-fired, coal-fired and oil-fired) and renewable (hydro and wind) power plants, owned by private and public sectors. Two efficiency indexes, reflecting operational and investment performance, have been defined and pursued. Also, various performance comparisons were conducted, and relationships between efficiency scores and various input/output factors were investigated and identified. The study has shown that wind power plants have the highest efficiency values in operational and investment performance models, which is a strong indication of their high future potential.

Ertek et al. (2012) conducted a data-centric analysis of commercial on-shore wind turbines and provided actionable insights through analytical benchmarking through DEA, visual data analysis, and statistical hypothesis testing. They measured the efficiency of 74 commercial on-shore wind turbines of the top ten wind turbine manufacturers in the world. Diameter, nominal wind speed (as the inputs) and nominal output (as the output) have been applied as attributes. In the research, the BCC Output Oriented model was selected as an appropriate model.

Iglesias et al. (2010) measured the productive efficiency of a group of 57 Spanish wind farms located in the region of Galicia that operated between 2001 and 2004 using the frontier methods DEA and SFA (Stochastic Frontier Analysis). The output of each wind farm is the quantity of electricity (measured in MWh) delivered to the distribution or transmission grid. Regarding the inputs, the capital factor is associated with the installed capacity (in MW) of the farms, which is obtained as the product of the number of wind turbines multiplied by the nominal power of each one. As for the labour factor, they used the number of full-time man-years employed in the tasks of operation, maintenance and control of the farms. Finally, the input fuel (measured in MWh) that feeds the facilities depends on the wind and is given exogenously by the nature. Research have shown that the average technical efficiency is very high, exceeding 75% in all cases. The results must be considered with caution given the limited number of wind farms and years studied.

3 ANALYSIS OF THE MODEL

In order to explore and evaluate whether there is an impact of financial results on the efficiency of wind power companies, a research was conducted using the DEA method on a sample of 29 companies, i.e. wind power plants that generated electricity in 2011. Their selection was random, from the “newer” EU Member States: Bulgaria, Croatia, the Czech Republic, Latvia, Poland, and Romania. Prior to the assessment of efficiency, it was necessary to select appropriate inputs and outputs used in the model, as well as to confirm the positive correlation between them. After formulating the inputs and outputs, the appropriate model is shown with respect to the constant or variable return to scale, and the direction of orientation, i.e. input or output-oriented model. The input and output data were downloaded from the Amadeus database (https://amadeus.bvdinfo.com/version-2014916/home.serv?product=amadeusneo) containing comparable financial information for public and private companies across Europe. Relative efficiency evaluation was conducted using the DEA method, whereby the software package DEA-Solver Professional Release 11.0. was used.

3.1 Selection and Correlation of Inputs and Outputs

In evaluating the efficiency of 29 wind power companies, „technical” and „economic” variables were used as the selection for inputs and outputs. “Technical” variables refer to technical values of an individual wind farm, while “economic” represent assets and profit. One of the important features of the DEA method is that inputs and outputs can be expressed in different values, and units of measurement (for example, euros, kilowatt, gigawatt hour, number of units, etc.). Inputs and outputs are of this size:

Inputs:

1. *Total assets* (in euros) are a fundamental economic size, and can be expressed as the sum of fixed assets and current assets.
2. *Power* (in kW) is installed capacity of one wind turbine.
3. *The number of turbines* multiplied by *power* is total nominal power of one wind farm.

Outputs:

4. *Operating profit* (in euros) is the main financial result of the company; it is defined as the difference between operating revenue and operating expenses.
5. *Estimated annual production* (in GWh) represents the generation of electricity if the capacities are maximised to 2300 hours per year.

Thereby, inputs are defined by 3 variables, while outputs consist of 2 variables. The following Table 1 presents statistics of the inputs and outputs data used in the DEA model.

Table 1. Statistics on input and output dana in 2011

	Total assets	Power	The number of turbines	Estimated annual production	Operating profit
Max	212.094.750	3.000	52	317	5.147.622
Min	3.147	800	1	2	2.558
Average	28.134.379	1.976	15	76	1.584.172
SD	45.127.219	730	14	83	1.822.500

Source: Author's calculation

Naturally, it is assumed that there is a certain positive correlation between these inputs and outputs. The above shows the relationship between the two variables, i.e. as the input value increases, so does the value of the output. Table 2 presents the correlation of the variables.

Table 2. Correlation coefficients of input and output variables

Input / Output Variable	Total assets	Power	The number of turbines	Estimated annual production	Operating profit
Total assets	1	0,405821	0,571284	0,678073	0,599161
Power	0,405821	1	0,315691	0,535742	0,158590
The number of turbines	0,571284	0,315691	1	0,932297	0,292068
Estimated annual production	0,678073	0,535742	0,932297	1	0,25701
Operating profit	0,599161	0,158590	0,292068	0,25701	1

Source: Author's calculation

As presented in the Table 2, all the variables have positive correlation coefficients. After showing the inputs and outputs of the model, as well as correlation coefficients, it is necessary to determine the DEA model with respect to the returns to scale.

3.2 Selection of the Model with Respect to Returns to Scale

Two models were presented earlier in the paper; the basic CCR model and the BCC model. CCR model works in conditions of constant returns to scale

(CRS), and the BBC model works under the assumption of variable returns to scale (VRS). CRS represent a situation where outputs increase proportionally for increase in inputs. On the other hand, VRS implies the situation where outputs do not increase proportionally for increase in inputs, i.e. they can increase more or less than the increase in inputs. It is impossible to predict under which conditions the analyzed companies, i.e. the DMU, will operate. For this reason, it is necessary to evaluate the efficiency using both methods, which is presented in the following table.

Table 3. Analysis result by CCR model and BCC model

Analysis result	CCR model	BCC model
No. of efficient DMUs	12	21
No. of inefficient DMUs	17	8
Average efficiency result	0,8431	0,9684
Maximum efficiency result	1	1
Minimum efficiency result	0,1905	0,7

Source: Author's calculation

Table 3 shows the results of the analysis of 29 DMUs (companies) conducted by CCR and BCC model. BCC model was used for evaluation of significantly more efficient DMUs than CCR model. It can therefore be concluded that it is more appropriate to use the BCC model in the analysis, i.e. that companies operate under conditions of variable returns to scale. At the end of the analysis of the model, orientation of the model should also be defined, as shown below.

3.3 Selection of the Model with Respect to Orientation

In the previous chapter of the paper, it was established that it is more appropriate to use the BCC model. The question is what kind of a BCC model should be regarding the orientation. "Oriented" models indicate the input or output orientation in evaluating efficiency, i.e. the main target of evaluation is either input reduction or output expansion. For example, input-oriented models aim to reduce input resources to the efficient frontier as far as possible while the output remains at the current level. On the other hand, output-oriented models maximize output levels in existing capacities of the input. "Non-oriented" models deal with input reduction and output expansion at the same time. In this paper, evaluation of efficiency is carried out using the BCC input orientation model. This means that the intention is to use, as much as possible, smaller amounts of input to achieve the appropriate level of output. Input orientation model is also used because of the fact that it is possible to perform translation invariance with respect to the outputs, but not on inputs. The following chapter, which also contains the main research in this paper, will cover this subject in more detail.

4 EMPIRICAL RESULTS

This chapter introduces the main part of the paper after the selection of inputs and outputs of the model, positive correlations between the variables were confirmed, and the model was selected with respect to returns to scale and orientation. The efficiency scores of 29 wind power companies were analysed and evaluated in the selected EU countries in 2011. Having obtained the efficiency results, the next step is analysing the impact of the financial result on companies' efficiency, i.e. these two categories are compared.

Using the best performance of multiple-inputs and multiple-outputs in the evaluation of efficiency, a DMU is efficient only if the efficiency score is equal to one ($\theta^* = 1$) and the slacks variable equal to zero ($s^{-*} = 0$, $s^{+*} = 0$). The non-zero slacks and the value of $\theta^* \leq 1$ identify the sources and amount of any inefficiencies that may be present. Analyzing 29 companies (DMUs) from 6 EU Member States, Table 4 shows the relative efficiency of wind power companies evaluated by the BCC input-oriented model as well as returns to scale (RTS) of projected DMU.

Table 4. The relative efficiency of 29 wind power companies and RTS of projected DMU in 2011

Rank	DMU	Country	Efficiency score	RTS of Projected DMU
1	Auseu-Borod	Romania	1	Constant
1	Băleni	Romania	1	Constant
1	BK Enerģija	Latvia	1	Increasing
1	Cernavoda	Romania	1	Constant
1	Cisowo	Poland	1	Constant
1	Darżyno	Poland	1	Constant
1	Dorobanțu	Romania	1	Constant
1	Drahany	Czech republic	1	Increasing
1	Elcomex EOL	Romania	1	Constant
1	Enercom Plus	Latvia	1	Increasing
1	Impakt	Latvia	1	Constant
1	Kaliakra Wind	Bulgaria	1	Constant
1	Karcino	Poland	1	Constant
1	Kardam	Bulgaria	1	Constant
1	Pchery	Czech republic	1	Increasing
1	Pestera	Romania	1	Constant
1	Raszków	Poland	1	Increasing
1	Shabla South	Bulgaria	1	Increasing
1	Suwałki	Poland	1	Decreasing
1	Topleț	Romania	1	Increasing
1	Trtar Krtolin	Croatia	1	Increasing
22	Baltnorvent	Latvia	0,9837	Increasing
23	Kisielice	Poland	0,9662	Increasing

24	Agighiol	Romania	0,9556	Increasing
25	Kamieńsk	Poland	0,9452	Increasing
26	Vetrocom	Bulgaria	0,8772	Increasing
27	Dobiesław	Poland	0,8584	Increasing
28	Czyżewo	Poland	0,7968	Increasing
29	Crno Brdo	Croatia	0,7	Increasing

Source: Author's calculation

According to the efficiency scores for 2011, there are 21 wind power companies locates in all 6 analyzed countries with the highest efficiency score (θ^* = 1). Only 8 companies were rated as inefficient (θ^* < 1); namely wind farms Baltnorvent, Kisielice, Agighiol, Kamieńsk, Vetrocom, Dobiesław, Czyżewo, and Crno Brdo. It should be noted that a Croatian wind power company named Crno Brdo was rated the worst with efficiency score of 0,7. Seven DMUs have the highest efficiency score, but they also have input slack placing them among the inefficient. These units are BK Enerģija, Drahany, Enercom Plus, Pchery, Shabla South, Suwałki, and Topleț. Slacks s^{-*} and s^{+*} represent the input excesses and output shortfalls (the superscript minus sign on input slack indicates reduction of inputs, while the superscript positive sign on output slacks require augmentation of outputs). It can be concluded from all of the above that there are 14 DMUs evaluated by the BCC input-oriented model as fully efficient.

It is visible from the preceding table that the BCC model that works in the conditions of variable returns to scale proved to be justified. Out of 29 DMUs, number of constant returns to scale is 12, but there is a prevailing number of units with variable returns to scale. Only one company (Suwałki) operates under conditions of decreasing RTS, while as many as 16 DMUs operate under conditions of increasing RTS. The BCC input-oriented model is also used because translation invariance is carried out with respect to outputs. For the BCC model, affine displacement of the data does not alter the efficient frontier and the classification of DMUs as inefficient or efficient is invariant to translation (Ali, Seiford, 1990). Therefore, the input-oriented BCC model is invariant to output translation (Cooper, Seiford, Tone, 1999). In this paper, therefore, the value of the *operating profit* output is changed for the value of 350000 units for all DMUs to overcome the negative profit, i.e. loss in the companies without affecting the efficiency frontier. By applying the DEA method, it is possible to determine a sub-group of the companies referred to as the efficiency reference set shown in the Table 5.

Table 5. Efficiency reference set and efficiency score of 29 wind power companies in 2011

Rank	DMU	Eff. score	Reference set
1	Auseu-Borod	1	Auseu-Borod (1)
1	Băleni	1	Băleni (1)
1	BK Enerģija	1	BK Enerģija (1)

1	Cernavoda	1	Cernavoda (1)
1	Cisowo	1	Cisowo (1)
1	Darżyno	1	Darżyno (1)
1	Dorobanțu	1	Dorobanțu (1)
1	Drahany	1	Drahany (1)
1	Elcomex EOL	1	Elcomex EOL (1)
1	Enercom Plus	1	Enercom Plus (1)
1	Impakt	1	Impakt (1)
1	Kaliakra Wind	1	Kaliakra Wind (1)
1	Karcino	1	Karcino (1)
1	Kardam	1	Kardam (1)
1	Pchery	1	Pchery (1)
1	Pestera	1	Pestera (1)
1	Raszków	1	Raszków (1)
1	Shabla South	1	Shabla South (1)
1	Suwałki	1	Suwałki (1)
1	Topleț	1	Topleț (1)
1	Trtar Krtolin	1	Trtar Krtolin (1)
22	Baltnorvent	0,98	Impakt (0,614), Cisowo (0,035), Raszkow (0,167), Toplet (0,184)
23	Kisielice	0,96	Kaliakra Wind (0,366), Trtar Krtolin (0,252), Cisowo (0,221), Cernavoda (0,1), Elcomex EOL (0,061)
24	Agighiol	0,95	Impakt (0,37), Cisowo (0,008), Baleni (0,548), Auseu-Borod (0,074)
25	Kamieńsk	0,94	Kaliakra Wind (0,007), Trtar Krtolin (0,177), Cisowo (0,705), Cernavoda (0,109), Elcomex EOL (0,002)
26	Vetrocom	0,87	Impakt (0,301), Cisowo (0,169), Cernavoda (0,44), Dorobantu (0,038), Elcomex EOL (0,051)
27	Dobiesław	0,85	Enercom Plus (0,325), Impakt (0,378), Karcino (0,012), Pestera (0,284)
28	Czyżewo	0,79	Enercom Plus (0,293), Impakt (0,659), Pestera (0,048)
29	Crno Brdo	0,7	Impakt (0,215), Cernavoda (0,048), Elcomex EOL (0,02), Toplet (0,717)

Source: Author's calculation

In DEA, the concept of the reference set can be used to identify best performing entities with which to compare a poorly (inefficient) performing DMUs (Beasley). For example, the Croatian wind farm Crno Brdo was found to have inefficiencies in direct comparison to four companies (Impakt, Cernavoda, Elcomex EOL, and Toplet). The value in parentheses in Table 5 represents the relative weight assigned to each reference set member to calculate the efficiency rating *(θ)*.

After surveying the efficiency score of evaluated DMUs, returns to scale of projected DMUs, and reference set to which entities were joined, the final part of the paper shows the impact of the size of operating profit on the level of efficiency of wind power companies. Table 6 shows the mentioned categories. Operating profit for each wind power company in this case has a positive value because of the above-mentioned translation invariance. Operating profit is one of the main financial results of a company, and it occurs as a result of performing the basic activities of the company, i.e. the company's core business.

Table 6. Comparison of operating profit and efficiency score of 29 wind power companies in 2011

Rank	DMU	Efficiency score	Operating profit
1	Karcino	1	5.147.622
1	Suwałki	1	5.003.336
1	Cisowo	1	4.791.882
1	Cernavoda	1	4.709.505
25	Kamieńsk	0,9452	4.170.412
1	Darżyno	1	4.036.303
1	Kaliakra Wind	1	3.767.423
23	Kisielice	0,9662	3.287.282
26	Vetrocom	0,8772	2.996.407
1	Trtar Krtolin	1	1.422.921
1	BK Enerģija	1	643.019
1	Pchery	1	615.926
29	Crno Brdo	0,7	587.971
22	Baltnorvent	0,9837	475.754
1	Topleț	1	446.533
1	Raszków	1	368.996
1	Drahany	1	350.193
1	Dorobanțu	1	349.782
1	Băleni	1	346.918
24	Agighiol	0,9556	341.911
1	Elcomex EOL	1	340.323
1	Shabla South	1	306.541
1	Enercom Plus	1	272.881
1	Impakt	1	264.439
1	Kardam	1	262.059
27	Dobiesław	0,8584	251.171
1	Auseu-Borod	1	212.964
28	Czyżewo	0,7968	167.947
1	Pestera	1	2.558

Source: Author's calculation

Data for efficiency scores and operating profit for each analyzed company do not show certain regularities in their ranking. It is obvious that, although some companies are inefficient, they have a very high level of operating profit. For example, the Kamieńsk company was only ranked 25th according to efficiency, but it had an extremely high operating profit compared with other companies and it was ranked fifth according to its maximum value. On the other hand, Pestera wind farm was rated efficient, but it had the lowest operating profit of only 2558 euros. The reasons for such a situation can be explained by the fact that the level of efficiency and profit need not be, i.e. are not interrelated. High (positive) profit does not necessarily imply a higher relative efficiency, nor does a lower financial result automatically imply a lower relative efficiency. In the evaluation of relative efficiency, financial results, i.e. operating profit and other financial indicators appear only as one variable among many and, although they participate in the evaluation, their size does not have a crucial impact on determining efficiency.

5 CONCLUSION

From the very beginning, the DEA method was used in various segments of the society and economy, as well as in the power sector. Färe, Grosskopf and Logan (1983) were the first authors who evaluated the efficiency of power companies using the DEA method. As renewable energy sources continued to develop and improve, in recent years, the DEA method has also been used in the generation segment of electricity production. Due to its multiple advantages in the electricity market, it is necessary to carry out various research in the field of wind energy. DEA method has proven a useful and appropriate methodology in assessing the relative efficiency of wind power companies. So far, the relative efficiency of wind farms was evaluated only in a few studies.

The subject of this paper is research and evaluation of the relative efficiency of wind power companies using the DEA method and to establish whether there is a significant correlation between the results of efficiency and financial results of the company. The research was conducted using the DEA methodology, whereby the BCC input-oriented model was used on the example of 29 wind power companies in selected EU countries in 2011. Half of the companies were rated fully efficient, i.e. in 14 wind power companies the efficiency score is equal to one ($\theta^*=1$) and the slacks variable is equal to zero ($s^{-*}=0$, $s^{+*}=0$). It is impossible to determine a specific correlation between the efficiency result and the financial result measured by operating profit, i.e. higher operating profit does not indicate higher company efficiency. It can therefore be concluded that high financial results have no impact on efficiency of wind power companies.

It is expected that measurements of relative efficiency of electricity companies, and therefore also wind energy companies, will be continued in future research using the DEA method, including various technical, financial or economic variables. This will further define the relationship and correlation between the variables and their impact on achieving company efficiency.

6 BIBLIOGRAPHY

1. Ali, A.I. and Seiford, L.M., 1990. Translation invariance in data envelopment analysis. *Operations research letters*, 9(6), pp. 403-405.
2. Bagdadioglu, N., Price, C.M.W. and Weyman-Jones, T.G., 1996. Efficiency and ownership in electricity distribution: A non-parametric model of the Turkish experience. *Energy Economics*, 18, pp. 1-23.
3. Banker, R.D., 1984. Estimating most productive scale size using data envelopment analysis. *European Journal of Operational Research*, 17, pp. 35-44.
4. Banker, R.D., Charnes, A. and Cooper, W.W., 1984. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 32, pp. 1078-1092.
5. Beasley, J.E., OR-Notes [online]. Available at: http://people.brunel.ac.uk/~mastjjb/jeb/or/dea.html.
6. Cadena, A., Marcucci, A., Pérez, J.F., Durán, H., Mutis, H., Taútiva, C. and Palacios, F., 2009. Efficiency analysis in electricity transmission utilities. *Journal of Industrial and Management Optimization*, 5(2), pp. 253–274.
7. Charnes, A., Cooper, W. and Rhodes, E., 1978. Measuring the efficiency of decision-making units. *European Journal of Operational Research*, 2, pp. 429-444.
8. Cooper, W., Seiford, L. and Tone, K., 1999. *Data Envelopment Analysis, A Comprehensive Text with Models, Applications, References and DEA-Solver Software*. Boston: Kluwer Academic Publishers.
9. Ertek, G., Tunç, M.M., Kurtaraner, E. and Kebude, D., 2012. Insights into the Efficiencies of On-Shore Wind Turbines: A Data-Centric Analysis, Innovations in Intelligent Systems and Applications. INISTA 2012 Conference, Trabzon, Turkey. (indexed in *IEEE Electronic Library*).
10. Färe, R., Grosskopf, S. and Logan, J., 1983. The relative efficiency of Illinois electric utilities. *Resources and Energy*, 5(4), pp. 349–367.
11. Färe, R., Grosskopff, S. and Lovell, C.A.K., 1985. *The Measurement of Efficiency of Production*. Kluwer-Nijhoff, Boston.
12. https://amadeus.bvdinfo.com/version-2014916/home.serv?product=amadeusneo
13. http://www.renewableuk.com/en/renewable-energy/wind-energy/index.cfm
14. Iglesias, G., Castellanos, P. and Seijas, A., 2010. Measurement of productive efficiency with frontier methods: A case study for wind farms. *Energy Economics*, 32, pp. 1199–1208.
15. Ilkılıc, C., Aydın, H. and Behcet, R., 2011. The current status of wind energy in Turkey and in the world. *Energy Policy*, 39, pp. 961–967.
16. Jain, S., Thakur, T. and Shandilya, A., 2010. Cost Benchmarking of Generation Utilities Using DEA: A Case Study of India. *Technology and Investment*, 1, pp. 229-234.
17. Lam, P.-L. and Shiu, A., 2001. A data envelopment analysis of the efficiency of China's thermal power generation. *Utilities Policy*, 10(2), pp. 75-83.
18. Mantri, J.K., 2008. *Research Methodology on Dana Envelopment Analysis (DEA)*. Universal-Publishers Boca Raton.
19. Pestana Barros, C. and Sequeira Antunes, O., 2011. Performance assessment of Portuguese wind farms: Ownership and managerial efficiency. *Energy Policy*, 39, pp. 3055–3063.
20. Sarıca, K. and Or I., 2007. Efficiency assessment of Turkish power plants using data envelopment analysis. *Energy*, 32, pp. 1484–1499.
21. Sorić, I., 2002. Analysis of the relationship between operating result and liquidity. *Economic Review*, 53(9-10), pp. 921-933.
22. Tavares, G., 2002. *A Bibliography of Data Envelopment Analysis (1978-2001)*. Rutcor Research Report

23. Wang, J.H., Ngan, H.W., Engriwan, W. and Lo, K.L., 2007. Performance based regulation of the electricity supply industry in Hong Kong: An empirical efficiency analysis approach. *Energy Policy*, 35, pp. 609–615.
24. Yaniktepe, B., Savrun, M.M. and Koroglu, T., 2013. Current status of wind energy and wind energy policy in Turkey. *Energy Conversion and Management*, 72, pp. 103–110.
25. Zhou, P., Ang, B.W. and Poh, K.L., 2008. A survey of data envelopment analysis in energy and environmental studies. *European Journal of Operational Research*, 189(1), pp.1-18.