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Possibilities of Applying the DEA Method in the Assessment of Efficiency of Companies in the Electric Power Industry: Review of Wind Energy Companies

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ABSTRACT: One of the fundamental tasks of modern power system is finding ways to produce stable and continuous electricity from scarce energy resources. One of the possible solutions is introduction, implementation and improvement of alternative forms of energy such as renewable energy sources, particularly wind energy as an increasingly important energy source which is expected to further increase its share in total electricity production. Numerous methods can be used in assessing the efficiency of wind energy companies, and in the focus of this research is the Data Envelopment Analysis method (DEA), a widely accepted methodology given its interdisciplinary approach and flexibility. This method represents a step forward in the field of renewable energy management, because it provides the possibility to compare the selected companies with the best in the industry (the most efficient) and the possibility of determining sources of inefficiency and, consequently, the possibilities of their elimination.

Keywords: efficiency; power sector; wind energy companies; DEA
JEL Classifications: C61; D24; Q42

1. Introduction

Power sector is one of the most complex technical and technological systems which consist of various power management processes. These core activities in the power sector are generation, transmission, distribution, and supply of electricity. By providing electricity to the customer, each of the activities in the electricity sector implies a certain level of costs. It is pointed out in the literature that the share of the electricity generation activity in the costs is 65%, electricity distribution 20%, power transmission 10%, and electricity supply amounts to only 5% of the total cost (Steiner, 2001). Generation of electricity is in the focus of this paper, given its major share in total electricity costs.

In the generation of electricity as a competitive activity on the market, as opposed to transmission and distribution of electricity, which have the features of a natural monopoly, it is necessary to analyse its performance and efficiency as one of the key indicators of business performance.

Renewable electricity sources, in addition to conventional forms, directly contribute to safe and reliable functioning of the power sector. The efficiency of each energy resource, including renewable energy, directly contributes to sustainability and improvement of efficiency of the entire power system. Wind energy companies, as one of the most important generators of renewable energy, are increasingly gaining importance, and evaluation of their efficiency requires full attention. Although a number of methods is available, the focus in this paper is on Data Envelopment Analysis

method (DEA), which can be used for measuring and evaluating the efficiency of wind energy companies that generate electricity.

Therefore, the main objective of this paper is to present the possibilities of using the DEA method in evaluating the efficiency in the electric power industry. Special emphasis is given to the evaluation of wind energy companies, which are developing extensively and are becoming increasingly important in the supply of electricity. This will contribute to a better understanding of the problems in measuring the efficiency of business units in the electric power industry.

2. The Historical Development, Importance and Role of Wind Energy in Electricity Generation

Renewable energy sources include solar energy, wind energy, hydropower, geothermal energy (heat of the Earth), energy derived from biomass (plant matter), and energy which can be divided into wave energy, tidal energy, or the energy of sea currents, and other (Armstrong and Hamrin, 2000). It is estimated that approximately 19% of total world energy consumption in 2011 was supplied from renewable energy sources (REN21, 2013).

Using renewable energy sources like *wind power* may be a suitable solution for many of the challenges and difficulties that are associated with the energy of today, such as adequacy, distribution, sustainability, and other influential factors. Wind energy occurs naturally in the atmosphere and cannot be spent. As a clean energy source, wind energy is the most appropriate and one of the most advanced and most promising renewable energy sources (Ilkılıc et al., 2011). Moreover, wind energy is currently considered the most exploited alternative energy source (Kabalci, 2013), and is listed as the fastest growing energy source with the share of as much as 30% per year (United Nations Development Programme, 2000).

The use of wind energy has played an important role during a long period in the history of mankind. Transformation of kinetic wind energy into useful mechanical energy has been applied ever since ancient times. This makes wind energy, along with the energy of the water flow, the oldest form of energy used by man. One of the earliest applications of wind energy was launching boats to sail on the Nile River in Egypt, pumping of water and running the irrigation pumps in China and the Middle East, and milling wheat in Iran and Afghanistan (Ilkılıc et al., 2011). Windmills with vertical and horizontal axes of rotation were constructed in the Middle Ages and mechanical operation of wind energy was exploited for a long time. The first windmill for electricity generation i.e. the first wind turbine was made by James Blyth in Scotland in 1887. Meanwhile, in 1888, Charles F. Brush designed and constructed the first self-managed wind turbine which generated electricity (Leung and Yang, 2012). From the beginning of the 20th century until the 1970s, development of wind turbines and associated wind industry was limited and very slow due to low prices and high availability of other energy resources, especially coal and oil. Increasing oil prices and the energy crisis of the 1970s resulted in a growing interest in the use of wind energy and therefore, domestic and agricultural wind turbines were gradually replaced with wind energy plants that began to be widely used in mass production of electricity. Strong development of wind industry initially took place in the American state of California, and by the end of the 20th century, northern Europe became the leader in manufacturing and installing wind turbines. In the 21st century, development of the wind industry took on unexpected proportions, the power of individual wind turbines increased by a hundred times in less than 20 years, and the size of wind turbines increased more than two times (Jerkić, 2010). Nowadays, wind energy is becoming one of the more common energy sources and is likely to have a competitive advantage in the production of electricity compared to other energy resources in the near future.

Due to the development of sophisticated technology in the wind industry, which aims to improve the production of electricity, wind energy is an important source of energy in highly developed countries, which is expected to further increase the share of wind energy in the total energy production (Ilkılıc et al., 2011). For example, Denmark, which is the leading country in the world when it comes to installed capacities of wind turbines in terms of the population, produces 20% of electricity from wind energy, 12% is produced in Portugal, and Germany gets as much as 7% electricity from wind energy companies (Lynn, 2012). Although the use of wind energy in the Republic of Croatia has been a subject of systematic research for over 30 years, and the first wind plant was installed in 1988, the first commercial wind plant for electricity production started operating in 2004 on the island of Pag. Analysing the total electricity produced from "newer" renewable energy sources, 62,38% of electricity was generated from wind energy in the Republic of Croatia in 2011

(Energy in Croatia, 2011). Therefore, wind farms are definitely predominant in the production of electricity from "newer" renewable energy sources in Croatia.

The use of wind energy in electricity production leads to many benefits, both environmental and economic. Using renewable energy sources like wind power, except for the fact that it leaves the possibility to use fossil fuels in the future, significantly contributes to the environmental aspect of sustainability, because it does not pollute the environment (Denona Bogović, et al., 2012). Although there may be aesthetic defects and a certain noise level, it is important to point out that wind farms do not cause negative environmental pollutions in terms of greenhouse gas emissions as one of the greatest environmental threats. Furthermore, the use of wind energy reduces import of energy and dependency on limited fossil energy resources, largely ensures diversification of production and the security of electricity supply, stimulates development of domestic industry, job creation, technological development, and can, ultimately, enhance the development of the national economy.

3. Measurement and Evaluation of the Efficiency of Companies in the Electric Power Industry

Measuring the efficiency, and thus productivity of the power sector, is carried out by different methods. Although such measurements existed in the early 20th century, they were particularly intensified in the 1960s (Lam and Shiu, 2001). In this early period, technological changes in the power sector were measured by studying and analysing the changes in production and production costs. Thus, for example, a research was conducted in the USA on the suitability of „output per unit of input" technique as a measure of changes in productivity of the electric power industry from 1929 to 1955 (Barzel, 1963). During the 1970s, empirical research of productivity were based on the effects of ownership structure on efficiency, within which, for example, investigating economic consequences of state ownership and regulatory measures in the electric power industry of the USA (De Alessi, 1974). A large number of researches refer to efficiency and/or productivity of the electric power industry in terms of public and private companies. Meyer (1975) evaluated and compared comparative efficiency of private and public, i.e. state power companies in the USA. On the other hand, Pescatrice and Trapani (1980) estimated the differences in productivity between private and public power companies. In their research, Pescatrice and Trapani (1980) concluded that the unit cost of a public company is 30% lower than that of a private company. The cause of inefficiency is the result of restrictions of the economic regulation method by rate of return that was imposed on private companies. Similar results were obtained also in the research conducted by Dilorenzo and Robinson (1982), while Atkinson and Halvorsen (1986) suggest that pricing inefficiency exists in both private and public American electric power companies.

Recently, marginal methods such as Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), Corrected Ordinary Least Squares (COLS) and others, are increasingly used to measure and evaluate the efficiency of companies in the electric power industry.

3.1. Application of the DEA Method as a Measure of Efficiency of the Power Sector

Data Envelopment Analysis method appeared for the first time in 1978 in the work of three authors (Charnes et al., 1978), and from 1978 to 1992, over 400 papers, books and other publications including the aforementioned method of measuring and evaluating efficiency in general were recorded (Charnes, et al., 1994). In early 2002, bibliography of Data Envelopment Analysis was published, which includes 3203 publications, of which 171 PhD theses (Tavares, 2002). Thus, a large number of works confirms the great interest in and importance of development of the methodology and its application. This is further enhanced by the fact that Data Envelopment Analysis is an interdisciplinary scientific method applied in various fields as well as in the evaluation of efficiency of various business units such as power plants, banks, insurance companies, schools, higher education institutions, hospitals, shopping facilities, business units in forestry, etc. Today, Data Envelopment Analysis is a widely accepted methodology in the scientific literature, with indications of further development. It is alleged that only in 2009; more than 700 papers applying this method were published (Liu et al., 2013).

Data Envelopment Analysis methodology allows comparison of selected companies with the best in the industry, i.e. with companies that achieve the highest level of efficiency. Also, it is important to point out that by this methodology; it is also possible to determine the sources of companies' inefficiency and to influence their elimination. This methodology provides the regulatory authorities, which are responsible for efficient and reliable operation of the power sector, the

opportunity to establish appropriate mechanisms, or measures and incentives to improve efficiency and hence business performance of the aforementioned sector.

In the early 1980s, there was recorded application of the DEA method in the field of measuring the level of productivity and efficiency of companies in the power sector. The first authors who used the DEA method in generating electricity were Färe et al. (1983) who evaluated the efficiency of electric power companies in the American state of Illinois between 1975 and 1979 and found that only a few companies were technically efficient in comparison with other companies. The same authors, who are considered top according to the number of publications that include Data Envelopment Analysis (Tavares, 2002), compared the efficiency of public and private companies in the power sector (Färe et al., 1985). Their research confirmed that public companies are more efficient than private companies and that companies' inefficiency is mainly due to lack of allocative efficiency. On the other hand, some studies show that there is no significant difference in efficiency between different forms of company ownership or economic organisations in the electricity generation activities in the OECD member states (Pollitt, 1995). Except for independent application of the DEA method, the Stochastic Frontier Analysis (SFA) is also commonly used in the research. Using the aforementioned methods, Coelli (1997) estimated the change in total factor productivity – TFP on the example of 13 coal-fired plants in Australia from 1981 to 1991. Empirical results indicated a 16% growth of total factor productivity in the above-mentioned period. The research conducted by a group of authors (Färe et al., 1990) should also be pointed out. These authors were among the first who used the Malmquist Productivity Index to analyse productivity growth in 19 power plants i.e. coal-fired plants in the state of Illinois between 1975 and 1981. They found that the average productivity growth rates were relatively stable, with the exception of the productivity slowdown in the course of 1976 and 1977 due to technological stagnation, and that the level of plant efficiency changes significantly affects growth of productivity.

It should be noted that the Data Envelopment Analysis method, as a linear programming method, is used in the production as well as in analysis of efficiency of other activities in the power sector such as transmission and distribution of electricity, as opposed to parametric methods which are mainly focused on the activity of electricity production. This is evidenced by numerous studies from which the most significant ones are those by authors Weyman-Jones (1991) and Miliotis (1992), who described the application of Data Envelopment Analysis methodology also in the activities of transmission and distribution of electricity.

Due to their specific characteristics, in terms of increasing growth and development of renewable energy sources, application of DEA methodology finds its place in the evaluation of the efficiency and this segment of electricity production. In this context, evaluating the efficiency of wind power companies or individual wind turbines implies a relative assessment and comparison of the analysed units and identification of sources of inefficiency in electricity production. One of the few studies of this type was conducted in Spain, prompted by the fact that in 2007, as much as 10% of the total demand for electricity was derived from wind energy (Iglesias et al., 2010). In the period between 2001 and 2004, by using marginal DEA and Stochastic Frontier Analysis method, production efficiency of a group of 57 wind farms was assessed in Spain, i.e. wind turbines connected to the transmission or distribution network. The research indicated that there is a high concordance between the results of technical efficiency obtained using both methods. High average technical efficiency was established, higher than 75% according to the results obtained by both methods. However, the results must be viewed with caution because of the limited number of the analysed wind farms and periods of research (Iglesias et al., 2010).

3.2. Features of the DEA Method in Evaluating the Efficiency of Wind Energy Companies

Data Envelopment Analysis is a reliable method for assessing the relative efficiency of comparable units that use similar business technology and operate in similar conditions. As a non-parametric method, it does not require knowledge of the functional relationship between inputs and outputs, as opposed to other approaches to assessment of efficiency as is the case, for example, with regression analysis method. The DEA method is considered to be very suitable for evaluating the efficiency of companies, i.e. comparing production units in general. In addition to reliability, simplicity and flexibility, its advantages are especially reflected in the following two characteristics (Mantri, 2008): 1) it is assumed that there is a connection between the selected variables, i.e. inputs and outputs of the model, that does not require analytical determination, but it should be confirmed; 2)

variables of the model may be expressed in different units of measurement. This method is often used in assessing the efficiency of electric power companies and, although it is most commonly used in evaluating the efficiency of production units that use traditional energy sources, it is considered that the selected method can, with modifications of certain attributes, find a wide application in the field of renewable energy, especially wind power companies.

Evaluating the efficiency of wind power units using the DEA method can be determined using several types or models of the DEA. They may vary according to the type of return to scale (models that relate to referring to constant or variable returns to scale), or the choice of path projection of an inefficient unit on the efficiency frontier in order to improve efficiency (models that are oriented on the reduction of input or increase in output). Although determination of efficiency is carried out under static conditions, i.e. at a given point in time, the dynamic component of efficiency is also often analysed in the research, i.e. change in efficiency over time, the so-called „window analysis". In addition to evaluating the change efficiency, it is also possible to determine the change in productivity by shifting the boundaries brought about by technological progress. Application of such productivity is most commonly measured by the Malmquist Index. Thus, in terms of changes in technological development, the DEA method can be complemented by the Malmquist Index, since it represents a kind of an upgrade of the DEA method. The above-mentioned indicator additionally contributes to the quality of the assessment of efficiency of wind power units, and represents a step forward in the field of renewable energy management.

Using the DEA method in the analysis of efficiency of electric power companies in the business of power generation, multiple inpuits and outputs are applied. Commonly used inputs are labour, capital, fuel, and technology, while produced electricity is used as output. For example, in their analysis, Lam and Shiu (2001) use capital (installed capacity of the plant), fuel (total consumption of different types of fuel), and labour (number of workers) as inputs, and electricity produced in plants as the only output. Athanassopoulos et al. (1999) apply the DEA method in the scenarios of setting targets for electricity companies and use multiple inputs and outputs. They cite fuel consumption, costs of labour and capital as inputs, while the outputs assume the values that apply to produced electricity and the achievement of set goals in the use of the plant. In the latest research, it is possible to include minimum values in the analysis, the so-called „bad outputs", and in the paper by the above-mentioned authors, they represent accidents and generated pollution.

In one of the few studies in the field of assessment of efficiency of wind farms in electricity generation activity, Iglesias et al. (2010) analyse three inputs (capital, labour and fuel) and one output (electricity production). Here, capital represents the installed capacity of wind power (power expressed in MW); labour refers to the number of workers employed full-time in the operation, maintenance, and control of the plant and fuel is actually the wind that is present in the area of the wind turbine rotor. Fuel per unit of time (measured in MWh) includes the number of wind turbines together with their unit area, air density and wind speed. Output represents the amount of electricity that is delivered to the transmission or distribution network (in MWh).

Acknowledging the contributions of previous research, the authors propose using the DEA method to include the amount of labour, plant capacity, wind characteristics, and investment in technology, i.e. research and development in the field of wind energy, in terms of inputs, and the actual amount of produced electricity transported in electricity network, in terms of output. It is expected that an additional qualitative dimension of using the Data Envelopment Analysis method would be ensured in the field of renewable energy management by the methodology of analysis of the efficiency of wind power companies set up in this manner, by increasing the number of variables, especially in the choice of technology, research and development.

4. Conclusion

Electricity market is one of the basic foundations for the functioning of the entire economy and the national economy. This market conditions economic progress, growth and development. The world today is unthinkable without sufficient availability of electricity. Attempts have been made to substitute conventional forms of energy, due to their scarcity and environmentally negative externalities, with alternative energy that will eventually become competitive to fossil energy resources. In recent years, renewable energy sources have assumed increasing momentum and are

used to a significant extent in developed countries. In the production of electricity, wind energy is especially significant and it is considered very suitable and promising energy solution.

Among the available scientific methods, Data Envelopment Analysis method has many advantages that allow the assessment of the level of efficiency of selected businesses. This method is particularly suitable for evaluating the efficiency of non-profit activities, but is increasingly used in the analysis of profit-generating production units. The method is used in almost all areas of human activity, and its application is becoming more common in the activities of the electricity sector, i.e. in generation, transmission, distribution, and supply of electricity. This allows regulatory authorities, and other interested market stakeholders involved in the system of functioning of the electricity sector to establish, but also to influence the efficiency of operations of each of the mentioned activities within the sector, and the efficiency of the sector as a whole.

By using the method of Data Envelopment Analysis in assessing the efficiency of wind energy companies in the business of power generation, it is possible to evaluate the efficiency level of observed businesses, compare it with the best in the industry, analyse critical points or bottlenecks, and directly influence elimination of the source of their creation.

Renewable energy sources, especially wind energy, are becoming more acceptable energy sources, primarily because of their environmental component, and limited fossil energy resources, and their level of efficiency directly implies the efficiency of the power sector in the field of renewable energy.

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