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The evaluation of renewable energy power using hybrid model of neural network and data envelopment analysis (neuro - DEA)

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A R T I C L E I N F O

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A B S T R A C T

Energy is essential parameter for economic – social development and quality of life. Sustainable energy is requisite for any economic growth. Nowadays, new options for producing energyand using technologies for its production are reproducible. So, the choice of technology is very important. In this article, 6 different renewable powers has evaluated using Hybrid model of Artificial-Neural Network (ANN) and data envelopment analysis base on economic- technical indicators. Because, the low number of inputs and outputs of decision making units, (DMUs), leading to a reduction a separable power of DMUs at traditional DEA, so the NEURO-DEA was used the simulation results shows that off-shore wind energy have high efficiency rather than other studied energy.

1. Introduction

Due to population growth and development of industrial areas, the demand for energy is increasing in the world. For this reason, the countries faced with energy scarcity and while even the greatest economic country in the world has been supplied by energy obtained from fossil fuels. This problem makes that the

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environment be polluted [1]. On the one hand, increasing the need for energy and the limitation of fossil fuel, on the other hand the increasing environmental pollution from burning these recourses has led to use renewable Energy instead of the others [2].

In today's world, not only environmental issues and climate change caused by fossil fuel, and Concentration of greenhouse gases, but also high cost of gases have provided the aspects of evolution in extensive use of renewable energy to achieve sustainable development [3].

Therefore, evaluation and selection of renewable energy power plants' technology is very important.

Charnes et al ([4] have introduced data envelopment analysis (DEA)to calculate the efficiency of decision-making unit (DMU), and this model was named CCR.

Some articles have been written about using of DEA in power industry. Liu et al [5] have examined the efficiency of electricity generation of power plants in Taiwan during 2004- 2006 by using DEA model.

Sozen et al, [6], have examined the performance of 15 power plants for power production in Turkey which they use different fuel by using DEA model.

Sueyoshi and Goto [7] measured the returns to scale for Coal power plants of USA, and they noted that these power plants in addition to the desired output have undesirable outputs too.

Azadeh et al [8] identified optimal locations for wind power plants in Iran. For this purpose, they use hierarchical data envelopment analysis.

One of the major problems of the common approaches of DEA is the lack of separable power for decision-making units. This problem mostly occurs due to the low number of units in comparison with the number of input and output of the model. The efficiency frontier obtained from DEA is sensitive than turbulence statistics and outliers caused by the measurement error or any other factor.

So, the basic models of DEA cannot rank the units. To resolve this issue, the power of generalize ability and estimation of non-linear relations in neural network are used. In this article has been attempted to combine neural network and DEA for measuring 6 technology' efficiency of renewable energy. Theses energy includes off shore wind energy, land-based energy, photovoltaic energy, Geo-thermal energy, solar Energy, small hydro power.

In this paper, the efficiency Evaluation of Renewable Energy Power using NEURO-DEA evaluated .then the results are compared with common DEA.

The paper is organized as follows: Section II briefly describes the data envelopment analysis (DEA). The neural network is reviewed in Section III. Section IV explains the proposed model (NEURO-DEA).The simulation results are shown in Section V, and Section VI concludes the paper.

2. Research background

2.1.Data Envelopment Analysis (DEA)

2.1.1. What is DEA?

DEA is a mathematical linear programming approach based on the technical efficiency concept; it can be used to measure and analyze TE of different entities: productive and non productive, public and private. Profit and non- profit seeking firms. It is a non-parametric approach that calculates efficiency level by doing linear program for each unit in the sample. DEA measures the efficiency of the decision-making unit by the comparison with best producer in the sample to derive compared efficiency. DEA submits subjective measure of operational efficiency to the number of homogenous entities compared with each other, through a number of sample’s units which from together a performance frontier curve that envelopes all observations. So, this approach is called Data Envelopment Analysis. Consequently, DMUs which lie on the curve are efficient in distributing their inputs and producing their outputs, while DMUs which do not lie on the curve are considered inefficient. [9].

So, DEA identifies the best-practice frontier as the envelope of the observed production possibilities. It can handle multiple input and multiple output models.

It also does not need the assumption of functional form for the relationship between the inputs and outputs of DMUs

2.2.Theoretical Construction of DEA System

As we have seen DEA is based on TE concept which is:

$$\text{Technical efficiency} = \frac{\sum \text{weighted output}}{\sum \text{weighted input}}$$

Mathematically we can express the above relation by the following formula:

$$E_k = \frac{\sum_{j=1}^{M} U_j O_{jk}}{\sum_{i=1}^{N} V_i I_{ik}} \qquad (1)$$

Where:

Data:

E_k: TE for the DMUK (between zero and one).

k : Number of DMUs in the sample $(k = 1,2, \dots, k)$.

N : Number of inputs used $(i = 1,2, \dots, N)$.

N : Number of outputs used $(j = 1,2, \dots, M)$.

O_{jk}: The observed level of output j from DMUk .

I_{ik}: The observed level of input i from DMUk .

Model's variables:

V_i: The weight of input i.

U_j: The weight of output j.

To measure TE for DMUs by using linear programming the following problem must be solved:

Max. TE

S.T

$E_k \leq 1 \qquad k = 1,2, \dots, K \qquad (2)$

Where TE is either maximizing outputs from given inputs, or minimizing inputs for a given level of outputs.

The above problem can be solved as stated because of difficulties associated with nonlinear mathematical programming. Charnes, Cooper and Rhodes have developed a mathematical transformation which converts the above nonlinear programming to linear one. Existing duality theory and simplex algorithms in linear programming are used to solve the transformed problem. For linear programming, there are two expressions which are dual to each other:

First problem: modified linear programming:

$$\mathrm{Max}\ \sum_{j=1}^{M} U_j O_{j\varepsilon}$$

s.t,

$$\sum_{i=1}^{N} V_i I_{i\varepsilon} = 1$$

$$\sum_{j=1}^{M} U_j O_{jk} \le \sum_{i=1}^{N} V_i I_{i\varepsilon}$$

$$U_j\ , V_i\ \ge\ \varepsilon \ge 0$$

Second problems: dual of modified L.P.

$$\mathrm{Min}\ \Theta - \varepsilon \sum_{j=1}^{M} S_j^+ - \sum_{i=1}^{N} S_i^-$$

s.t

$$\sum_{k=1}^{K} \lambda_k O_{jk} - \ S_j^+ = O_{j\varepsilon}$$

$$\sum_{k=1}^{K} \lambda_k I_{ik} - \ S_j^- = \Theta I_{i\varepsilon}$$

$$\lambda_k \ge 0$$

2.3.DEA conditions

We present some issues which are important in using DEA:

- Positively property: Generally the DEA formulation requires that the inputs, and outputs variables be positive (greater than zero)[9].
- isotinicity property :It is required that the functions relating inputs to outputs have mathematical property called isotonicity which means that an increase in any input results in some output increase and not a decrease in any output.
- Number of decision making units: A general rule is that there DMUs are required for input and output variables used in the model in order to insure sufficient degrees of freedom for a meaningful analysis [9].
- Homogeneity of DMUs: DEA requires a relatively homogenous set of entities. That is all entities included I the evaluation set should be have the same inputs and outputs in positive amounts [9].
- Window analysis: Window analysis generally assesses the performance of a DMU over time by treating it as a different entity in each period. This method allows for tracking the performance of a unit or a process [10]. In order to capture the variations of efficiency over time. Charnes proposed a technique called ‘Window Analysis’ in DEA. Window Analysis assesses the performance of a DMU over time by treating it as a different entity in each time period. This method allows for

tracking the performance of a unit or process. For example, if there are n units with data on their inputs and outputs measure in k periods, then a total of n_k units need to be assessed simultaneously to capture the efficiency variations over time [9].

- Control of weights: The weights U_j, V_i are determined by solving the DEA model [9].

These weights are computed in such that a way the organization under evaluation is placed in the best light possible relation to the other units in the data set. The weights developed via DEA may not represent the same relative subjective weights that management might apply as to the relative importance of the variables (especially the output variables) used in the DEA models.

3. Artificial-Neural Network (ANNs)

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information.

The computations of the brain are done by a highly interconnected network of neurons, which communicate by sending electric pulses through the neural wiring consistingof axons, synapses and dendrites. In 1943, McCulloch and Pitts modeled a neuron as a switch that receives input from other neurons and, depending on the total weighted input, is either activated or remains inactive.

The weight, by which an input from another cell is multiplied, corresponds to the strength of a synapse- the neural contacts between nerve cells. These weights can be both positive (excitatory) and negative (inhibitory). Using these concepts can be modeled as an artificial neuron. Figure 1 shows an artificial neuron.

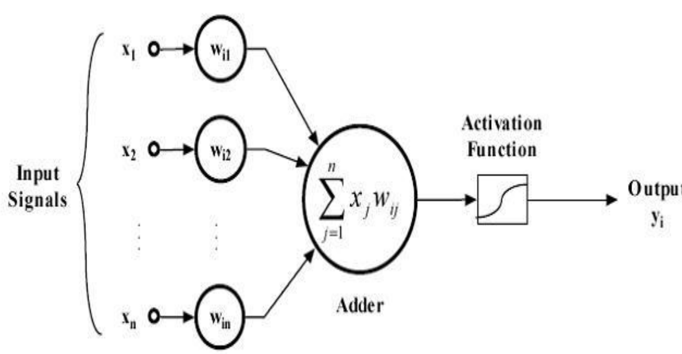

Figure 1 An artificial neuron

When combined input neurons for each a certain threshold, the neuron is stimulated and produces an output signal.

By comparing the obtained output of the neural network with the desired, the error vector is calculated. Using a special algorithm that Error Back-Propagation is known, and error vector, the neural network weights are corrected so that, the amount of error is reduced at next epoch. Various methods for training a neural network and the its weight has been proposed that can be found in [11,12].

3.1.Types of neural network training methods

Different methods of training neural networks can be classified into the following two categories:

3.1.1. supervised training

In supervised training, both the inputs and the outputs are provided. The network then processes the inputs and compares its resulting outputs against the desired outputs. Errors are then propagated back through the system, causing the system to adjust the weights which control the network. This process occurs over and over as the weights are continually tweaked. The set of data which enables the training is called the "training set." During the training of a network the same set of data is processed many times as the connection weights are ever refined.

3.1.2. Unsupervised Training.

The other type of training is called unsupervised training. In unsupervised training, the network is provided with inputs but not with desired outputs. The system itself must then decide what features it will use to group the input data. This is often referred to as self-organization or adaption.

3.2.Multilayer perceptron (MLP) neural network

Multi-layer neural network structure consists of an input layer, an output layer and one or more hidden layers.

One of the most widely used multi-layer neural networks is multilayer perceptron (MLP).

A MLP is a feed-forward artificial neural network model that maps sets of input data onto a set of appropriate outputs. An MLP consists of multiple layers of nodes in a directed graph, with each layer fully connected to the next one. Except for the input nodes, each node is a neuron (or processing element) with a nonlinear activation function. MLP utilizes a supervised learning technique called back-propagation for training the network. Figure 2 shows an MLP with one hidden layer [13].

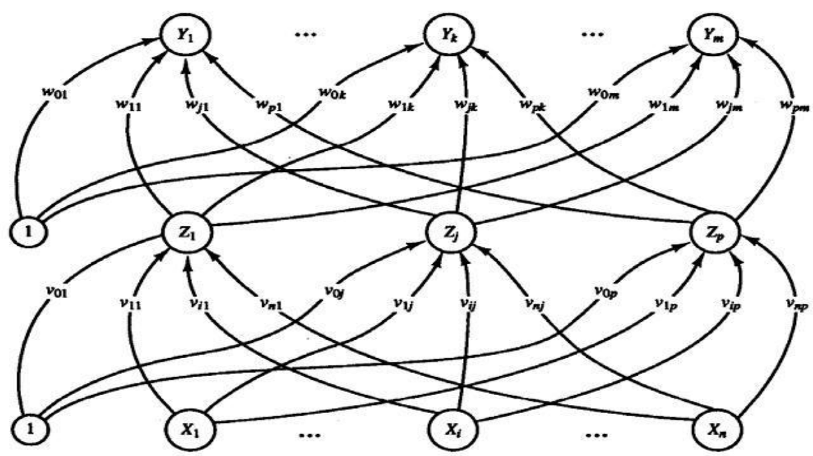

Figure 2 Structure of an MLP with one hidden layer [13].

4. Neuro- DEA

Neural Networks are suitable tools, because not only the DEA is a linear model, but also Neural Networks have high potential in the approximation of nonlinear functions.

There are many similarities between Neural Networks and DEA in the evaluation of performance [14]. For example:

1- None of the DEA and ANNs models have the basic assumptions about the relationship between inputs and outputs.

2- We are looking for a set of weights in DEA Model to maximize the efficiency, while ANNs Model follows a set of them, as the difference between actual output and the desired output is minimized. This (action) is done with the minimum of learning data.

The purpose of Neuro- DEA model is to minimize inputs than achieving to the desired output level.

4.1. Neuro-DEA structure:

MLP with a hidden layer is used for designing this model. In this structure, Network inputs include inputs and outputs of DMU. Network output represents the efficiency of each DMU. Neuro- DEA topology consists of the following steps:

Determination of inputs and outputs of any DMU;

Calculation of the DMUs' efficiency by using CCR model;

Selection of effective units for training neural network;

Normalization: The purpose of normalizing data is to insert the inputs in the range of (-1, 1).Because neural networks can act better in bipolar.

Calculation of the DMU efficiency by using trained neural network;

5. Simulation results

In this article, 6 different technologies has evaluated by using Neuro- DEA model. These technologies include: offshore wind, onshore wind, solar power, Geo-thermal power, small hydropower, photo voltaic power.

Two main decision criteria are economic and technical criteria. Economic criteria include Investment cost, Fixed & variable O&M cost and Progress ratio. Technical criteria were divided into four sub-criteria; Construction period, Technical lifetime, Capacity factor and Maximum availability. These criteria have selected based on previous researches [15].

Simulation is done in MATLAB software with the mentioned method. The Variable Learning Rate (or "traingdx") algorithm in MATLAB neural network toolbox [16], was employed to train the MLP neural networks. Less sensitive to the noise of input data is the advantage of this algorithm.

Reference data for the simulation is listed in [15]. Table 1 show that the results obtained from conventional DEA and Neuro- DEA.

Table 1 results obtained from conventional DEA and Neuro- DEA

Renewable technology	Off-shore wind	On-shore wind	Geo-thermal power	solar power	Photo-voltaic power	Small hydro-power
results obtained from DEA	1	1	1	0.7854	1	1
results obtained from Neuro- DEA.	1	0.9030	0.8467	0.7677	0.9085	0.9517

6. Conclusions

In this paper, the performance renewable energy based on DEA and Hybrid Model of Neural Network and Data Envelopment Analysis (Neuro- DEA) was investigated. Simulation results showed that the combined model has higher ability. Therefore, where the basic model can't measure efficiency of DMUs, using neuro-dea can solve the problem. It should be noted that training neural networks and number of neuron in each layer is very important. This research also showed that based on criteria considered, off-shore wind energy more effectively.

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