DECISION SCIENCES INSTITUTE

Analyzing the Efficiencies of Renewable Energy Sources with Data Envelopment Analysis

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ABSTRACT

In this paper, we compare the efficiencies of the eight major renewable energy sources that generate electricity. We use Data Envelopment Analysis (DEA) to determine the most efficient renewable energy source. We apply four different analytical approaches to rank these energy sources with respect to their efficiency scores. According to our DEA analysis, biomass and geothermal are the most efficient and solar technologies (photovoltaics technologies and solar thermal) are the least efficient renewable energy sources. We also find out land requirement is very important input to determine the efficiency scores of these technologies.

KEYWORDS: Data Envelopment Analysis (DEA), Multi-Criteria Decision Making, Renewable Energy, Efficiency

INTRODUCTION

During the Industrial Revolution, there were fundamental changes occurred in agriculture, textile, metal manufacture, and transportation besides economic and social structure of Europe. The invention of the steam engine increased the labor efficiency, and it provided an opportunity for the mass production that has important socio-economic effects: Urbanization (Vries, 1984), child labor (Nardinelli, 1990), economic growth (Jones, 2001).

During the last two decades, we have been realized that industrial revolution has also significant effects on the environmental issues that we are highly concerned (Clapp, 2014). According to Houghton (2005), human activities like large-scale deforestation and burning of fossil fuels (coal, oil, and gas) starting with the industrial revolution, are the most important causes of global warming which is the average temperature increase of Earth’s surface, air and oceans. Global warming was first recognized by Fourier (1827), and Arrhenius (1896) developed the earliest model for the relationship between carbon dioxide concentration and the temperature of the ground. However, its perceived effects on human beings become more detectable and measurable last fifty years.

According to the IPCC the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, the average global surface temperature is increased 0.74 ± 0.18^0C (1.33 ± 0.32^0F) because of irrepressible increase of the concentration of greenhouse gases such as carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons. According to this report, if we will be successful to keep the level of the concentration of the greenhouses gases constant, the global average surface warming would be about 0.2^0C for a decade which may lead very serious problems on ecosystems all over the world. According to the scenario projections in this report, when the warming exceeds 2^0C increase, approximately 25% of the plant and animal species will be in danger of extinction. In addition, crop productivity will be decreased, and it leads to having food scarcity in many regions of the world. Millions of people will have health problems because of increase in malnutrition. In addition deaths, diseases and injuries will increase due to severe weather conditions. Climate change leads to rising on sea level significantly, which leads small islands in Asia, Africa and Caribbean will become vulnerable to storms surge, inundation, and erosion. This will also cause of some island will be vanished. According to this report, by 2020, climate change will cause of between 75 and 250 millions of people will have a fresh water problem in Africa. Shortly, climate change would cause many severe problems if the global warming is not restrained. Therefore global warming and climate change becomes the most important environmental and political issue between the countries. A total of 192 countries have signed and ratified the Kyoto Protocol which delimits the production of greenhouses gas (GHG) emissions to fight global warming and climate change.

According to the United States Environmental Protections Agency (EPA) data, there are five main sources of GHG emissions in the United States: electricity production 31%, transportation 27%, industry 21%, commercial and residential 12%, and agriculture 9%. These values are consistent with the worldwide data of IPCC, where the electricity production has the highest contribution to the total of GHG emissions. The U.S. Energy Information Administration data shows that in 2015, 67% of electricity was generated by burning of fossil fuels (coal 33%, natural gas 33%, and petroleum 1%) which are the primary sources of GHG emissions for the electricity production, and only 13% of electricity is generated by renewable energy sources, which produce negligible amount of GHG emissions, in the United States.

Renewable energy is a kind of energy which is produced and replenished by natural resources such as sunlight, wind, tides, and rain. There are five primary sources of renewable energy: wind power, solar, geothermal, biomass, and hydropower. Approximately, twenty percent of the total energy consumption is produced by these renewable energy sources which have positive effect on global warming with reduction of GHG emissions. According to Owen (2004), the annual growth rate of the market share of the renewable energy is about two percent, during the last two decades. According to Prindle et al. (2007), the synergies between energy efficiency and renewable energy sources are the twin pillars of sustainable energy policy that reduce GHG emissions which show us the importance of these technologies. However, each renewable energy source has significant advantages and disadvantages. Therefore how we are going to decide, which renewable energy source is the most efficient one? In this study, we model a linear programming model to compare the efficiencies of these eight major renewable energy sources that generate electricity. We evaluate the efficiency scores of each renewable energy source with Data Envelopment Analysis (DEA), which is multi-criteria decision-making tool, to determine the most efficient renewable energy source.

The remainder of this paper is organized as follows: Section 2, provides detailed literature review for DEA-related articles for the energy sectors. The third section of this paper provides an overview of the DEA framework with the four different ranking approaches that we use in this paper. Section 4, describes the model in detail with input and output variables. We also present each one of the renewable energy sources in detail in this section. Section 5, reports the results of each approaches that we consider in DEA framework; while concluding remarks and research agenda are discussed in Section 6.

LITERATURE REVIEW

Data Envelopment Analysis (DEA), which was developed by Charnes et al. (1978), is a very popular management tool for evaluating and improving the efficiency of both manufacturing and service operations. The DEA has been studied by a large number of researchers for more than four decades. According to Emrouznejad et al. (2008), there is an exponential growth in DEA –

related articles that published over the past two decades. Moreover each year more than 300 DEA – related articles are published in various journals with various applications such as education (Bessent and Bessent, 1980), bank (Favero and Papi, 1995), transport (Gillen and Lall, 1997), health (Grosskopf Valdmanis, 1987), and environment (Kao et al. 1993).
In the literature, there are more than thirty DEA – related articles for the energy sectors. Bagdadioglu et al. (1996) applied DEA to discover the relationship between privatization and ownership on the efficiency of Turkish electricity supply industry. Sueyoshi and Goto (2001) studied the performance of the electric power in Japan. Many researchers applied DEA to find out the efficiency of electricity distribution of various countries. For example, Miliotis (1992) looked at Greece electricity distribution districts, Forsund and Kittelsen (1998) compared electricity distribution companies in Norway, with using DEA efficiency scores. Chen (2002) studied the cross efficiency of the electricity distribution sector in Taiwan, Pacudan and Guzman (2002) looked at the efficiency of electricity distribution in the Philippines. Resende (2002) studied Brazilian electricity companies, and Korhonen and Syrjanen (2003) studied the efficiency of electricity distribution in Finland. Although there are established literature on the efficiency of electricity distribution, there are only a few articles that aim to determine the most efficient energy source with DEA framework.

Boyd and Pang (2000) studied the linkage between energy efficiency and productivity in two segments of the glass industry. They compared the level of electricity and fossil fuel intensity by using regression analysis. They also showed that there is a strong correlation between energy intensity and productivity. Ramanathan (2001) applied DEA to the comparative risk assessment of eight different energy supply technologies. He concludes that solar photovoltaic and nuclear power are the most efficient energy sources. After he excludes these two energy sources, windmill becomes the most efficient energy source according to his analysis. Jha and Shrestha (2006) used DEA to measure the efficiency of hydroelectric plants in Nepal. Chien and Hu (2007) apply DEA to the 45 OECD and non-OECD economies to determine the effects of renewable energy sources on the technical efficiency. They used macroeconomic data such as labor, capital stock, and energy consumption for the input variables where the real GDP is the only output variable. They concluded that there is a positive correlation between use of renewable energy and technical efficiency and there is a negative correlation with the traditional energy. Jayanthi et. al. (2009) applied DEA to U.S. photovoltaic industry. More recently, Cristobal (2011) applied DEA to evaluate the efficiency of the renewable energy sources in Spain.

DATA ENVELOPMENT ANALYSIS (DEA)

Charnes et al. (1978) introduced the DEA framework, which is a very powerful technique for the evaluating and improving the efficiency of both manufacturing and service operations. It is a non-parametric, multi-factor relative efficiency measure which is based on linear programming procedure. Charnes et al. (1978) calculated the relative efficiency score with the division of the weighted sum of outputs and weighted sum of inputs to obtain decision-making units (DMU). Equation 1 formulates the scenario where we have *N* number of maximized DMUs, which are obtained by *s* number of output and *m* number of input variables.

$$\begin{aligned} & max \quad E_e = \frac{\sum_{k=1}^{s} v_{ke} y_{ke}}{\sum_{i=1}^{m} u_{ie} x_{ie}} \\ & s.t. \quad \frac{\sum_{k=1}^{s} v_{ke} y_{kj}}{\sum_{i=1}^{m} u_{ie} x_{ij}} \leq 1; \;\; j = 1, 2, 3, \dots, n \\ & v_{ke}, u_{ie} \geq 0; \; k = 1, 2, 3, \dots, s; \;\; i = 1, 2, 3, \dots, m \end{aligned} \tag{1}$$

where, E_e is the maximized efficiency score which belongs to the e^{th} DMU. Hence this set of equations can be easily converted to a linear programming problem by fixing the denominator equals to one:

$$\begin{aligned} & max\ E_e = \textstyle\sum_{k=1}^{s} v_{ke} y_{ke} \\ & s.t.\ \ \textstyle\sum_{k=1}^{s} v_{ke} y_{kj} - \sum_{i=1}^{m} u_{ie} x_{ij}\ \le 0;\ \ j = 1, 2, 3, \dots, n \\ & \textstyle\sum_{i=1}^{m} u_{ie} x_{ie} = 1 \\ & v_{ke}, u_{ie} \ge 0;\ k = 1, 2, 3, \dots, s;\ \ i = 1, 2, 3, \dots, m \end{aligned} \tag{2}$$

This formulation provides only two groups of results, efficient DMUs, and inefficient DMUs. However, this formulation doesn't provide any ranking information besides of these two groups. Therefore we use different approaches to find out the most efficient renewable energy source. In addition, we rank all of them according to their total efficiency scores which will be obtained by these different approaches. In this paper, we apply following ranking methods to determine the most efficient power plant: (1) the benchmark ranking model, (2) the super efficiency model, (3) the cross-efficiency model, and (4) the virtual model.

Benchmark Ranking Approach

One of the most popular ranking methods is benchmark ranking method which focuses on inefficient DMUs. This approach has been used in the DEA framework to rank the DMUs (e.g. Torgersen et al. 1996). This ranking method aims to improve inefficient DMUs with benchmarking of the efficient DMUs. The benchmarks are obtained by dual problem of the linear programming problem. The total number of benchmarks determine the rank of efficient DMUs, and the most referenced efficient DMU ranks first, and inefficient DMUs rank equally.

Super-Efficiency Approach

Super-efficiency approach was developed by Andersen and Petersen (1993) for ranking efficient DMUs. In this approach, linear programming problem is relaxed with omitting the unity constraint. This relaxation creates inefficient DMUs which are greater than 1, for originally efficient DMUs. Then the ranking is obtained by ordering of these inefficient DMUs.

Cross-Efficiency Approach

Another popular ranking method is the cross-efficiency approach which was developed by Sexton et al. (1986). The cross-efficiency method evaluates the performance of each DMU with respect to the optimal input and output weights of other DMUs. The cross efficiency matrix is constructed by peer evaluation, and then the ranking is obtained by the simple average of each DMUs' efficiency score.

Virtual DMU Approach

Golany and Roll (1994) developed the virtual DMU approach by selecting the best values of each input and output variables. The original model run one more time for each DMU with including new virtual DMU. After this process, virtual DMU becomes only efficient one, and the ranking is obtained by descending order of inefficient DMUs.

THE MODEL

In this study, we want to determine the most efficient renewable energy source(s) by using pre-determined input and output variables. This paper evaluates 8 major renewable energy sources: Wind Power (both onshore and offshore), Photovoltaic (both crystalline and thin film), Solar Thermal, Geothermal, Biomass, and Hydropower. In the next subsection, we look at each one of the renewable energy sources in detail. We also provide detailed information for each input and output variables in this section. The data is presented at the end of this section.

DEA Evaluations

Wind Power:

Wind power is one of the most expanded renewable and sustainable energy source in worldwide. Electricity is generated by the conversion of kinetic energy of wind by using a wind generator. According to the World Wind Energy Association data, over 300 GW of wind power would have been installed worldwide. There are two types of wind farms that we consider in this study: An onshore wind farm is located on a land, where an offshore wind farm is located in the water. We consider both of these two wind farms in our analysis because of the fact that both of them has comparative advantages. Although onshore wind farms have much cheaper total system levelized cost with respect to the offshore wind farms, they need very large areas for construction where offshore wind farms has no actual land requirements. That’s why we include both of these two technologies into our DEA analysis.

Solar Photovoltaic:

The solar photovoltaic technology generates electrical power by converting sunlight into direct current electricity. Photovoltaic is one of the fastest growing power-generation technology that reaches about 200 GW total installation in the world. In this study, we consider two different types of photovoltaic technology because of the tradeoff between total levelized cost and land requirements: (1) solar photovoltaic crystalline and (2) solar photovoltaic thin film. One of the most important advantages of solar photovoltaic crystalline technology is lack of land requirements because they can easily install to rooftops of the buildings.

Solar Thermal:

Solar thermal technology is a renewable energy source, which generates solar power from solar energy by using solar thermal collectors. There are three major categories of solar thermal technology: (1) low-temperature collectors for heating and cooling systems; (2) medium temperature collector provides hot water for both residential and commercial areas, and (3) high-temperature collectors to generate electricity. Although it creates high construction and installation costs, the efficiency of these technologies is very high also.

Geothermal:

Geothermal energy is one the oldest renewable energy source which is almost emission free. Geothermal energy is generated and stored in the Earth, and it has been used for residential needs for thousands of years. Although the amount of geothermal energy is enormous but only a very small fraction may be profitably exploited. Therefore the total installation of geothermal power is about 10,715 megawatts.

Biomass:

Biomass is widely available and naturally distributed renewable energy source which is derived from distinct energy sources like garbage, wood, waste, landfill gases, and alcohol fuels. There are various different applications of biomass energy such as direct burning, electricity generation, gasification, biofuels and anaerobic digestions to obtain heat, electricity, or another form (bio-fuel, bio-gas). Total installation of biomass power is about 5 percent of the U.S. electricity supply.

Hydropower:

Hydropower is both renewable and sustainable energy source. It is derived from the force of falling or fast moving water which produces electrical power. Hydroelectricity and marine energy are the two main component of hydropower which is one of the most major renewable energy sources of the U.S. electricity supply.

The Inputs

In this study, we consider two input variables for the DEA analysis: (1) the total system levelized cost (TSLC), and (2) land requirements. Table 1 presents the related data for these input variables.

Total System Levelized Cost (TSLC):

Total system levelized cost is one of the most important input variables which combines different cost values, with electricity generation capacity, and life cycle of the system as well. The total system levelized cost has four components: (1) the total investment expenditures, (2) total operations and maintenance expenditures, (3) total fuel expenditures, (4) total amount of electricity generation. We also take into account discount rate which is associated with inflation estimates, and life cycle of the system. Therefore the total system levelized cost is calculated as follow:

$$TSLC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (3)$$

where;

I_t: Investment expenditures in the year t
M_t: Operations and maintenance expenditures in the year t
F_t: Fuel expenditures in the year t
E_t: Electricity generation in the year t
r: Discount rate
n: Life cycle of the system

Land Requirement:

Land requirement is another critical input variable for this DEA analysis because of the fact that some power plant requires extensive land area, and some of them require none. That’s why it is very critical input to calculate the efficiency scores of renewable energy sources. The unit of this input variable is measured by hectare per megawatt.

The Outputs

In this study, we consider three output variables for the DEA analysis: (1) the plant size, (2) the capacity factor of each power plant, and (3) greenhouse gas (GHG) emissions. Table 1 presents the related data for these output variables.

<u>Plant Size:</u>

In this DEA framework, we use unit values for each power plant when we are calculating the total levelized system cost and land requirements to produce 1-megawatt electricity. That's why plant sizes are constant, and they are all equal to 1 for each energy source. The plants size unit is measured by megawatt.

<u>Capacity Factor:</u>

In this DEA analysis, capacity factor is very important output variable, which is the ratio of the actual output of a power plant and the total energy that plant would have produced at full capacity.

<u>Greenhouse Gas (GHG) Emissions:</u>

Greenhouse gas (GHG) emissions are the most important output variable to find out the most efficient renewable energy source due to the fact that they are the main source of global warming and climate change. The unit is measured by kilogram per megawatt.

The Data

Table 1 presents all of the input and output variables for DEA analysis. According to the U.S Energy Information Association Annual Energy Outlook 2011 data set, we construct TSCL and capacity factor columns. The land requirements and GHG emissions of each power plant are obtained by the U.S. Department of Energy.

Table 1: Power Plants Data with Input and Output Variables

Power Plant	Inputs		Outputs		
	TSLC ($/MW)	Land Req. (ha/MW)	Plant Size (MW)	Capacity Factor (%)	GHG Emissions (kg/MW)
Wind-Onshore	97.0	18.0	1.0	34.0	19.0
Wind-Offshore	243.2	0.0	1.0	34.0	14.0
Solar PV-Crystalline	291.0	0.0	1.0	25.0	53.0
Solar PV-Thin Film	254.0	2.5	1.0	25.0	62.0
Solar thermal	311.8	3.7	1.0	18.0	58.0
Geothermal	101.7	3.2	1.0	92.0	12.0
Biomass	112.5	0.7	1.0	83.0	72.0
Hydropower	86.4	6.6	1.0	52.0	5.0

DEA RESULTS

We model the linear programming problem for each one of the renewable energy sources by using the coefficients of input and output variables that are presented in Table 1. We run these models with LINDO 10 which is a comprehensive software that is designed to build and solve linear optimization models quickly and efficiently.

Table 2 presents the DMU values of each renewable energy sources. According to the Table 2, wind-offshore, geothermal, biomass and hydropower are efficient energy sources because they reached the maximum efficiency score, 1.0. On the other hand, wind-onshore, solar pv-crystalline, solar pv-thin film and solar thermal plant are inefficient renewable energy sources because their efficiency scores are less than one. According to these results, land requirement is very important input variable for the efficiency scores of these power plants. Although wind-onshore plant's TSLC is much less than wind-offshores', because of land requirements, wind-offshore reached the maximum efficiency score where wind-onshore has an inefficient score.

Table 2 also includes the reference sets of the benchmark ranking approach. According to these results, wind-offshore and geothermal energy sources have the highest reference score because of the fact that inefficient energy sources benchmarked these two power plants three times. According to this approach, wind-offshore and geothermal energy share the highest rank, and then biomass and hydropower follow them. Inefficient DMUs share the lowest rank according to the benchmark ranking method.

Table 3 shows the cross-efficiency matrix of these 8 power plants. This is an *nxn* matrix where *ij* represents the efficiency score of j^{th} power plant with the weights of i^{th} power plant. The highest average efficiency score represents the most efficient power plant with respect to its peers. According to these averages of these cross-efficiency scores, biomass has the highest average efficiency score, which refers to the most efficient renewable energy source. The solar thermal energy source has the lowest average efficient score which refers to the least efficient (or inefficient) renewable energy source according to the cross-efficiency method.

Table 2: Efficiencies Index of 8 Power Plants and their reference sets.

No	Power Plants	Efficiency Score	Efficiency	Inefficiency	References
1	Wind-onshore	0.4309		×	6,8
2	Wind-offshore	1.0000	×		*
3	Solar PV-Crystalline	0.6145		×	2
4	Solar PV-Thin Film	0.1778		×	2,6,7
5	Solar thermal	0.1193		×	2,6,7
6	Geothermal	1.0000	×		*
7	Biomass	1.0000	×		*
8	Hydropower	1.0000	×		*

Table 4 shows the super efficiency and virtual efficiency score of these 8 different power plants. According to the super efficiency approach, biomass has the highest efficiency score, which refers to the most efficient renewable energy source. Therefore the ranking is (1) biomass, (2) wind-offshore, (3) geothermal, (4) hydropower and (5) the rest of the other power plants.

Table 3: Cross-Efficiency Values of 8 Power Plants								
Power Plants	Wind-onshore	Wind-offshore	SPV-Crystalline	SPV-Thin Film	Solar thermal	Geo-thermal	Bio-mass	Hydro-power
Wind-onshore	0.8907	0.3553	0.2969	0.3402	0.2771	0.8496	0.7680	1.0000
Wind-offshore	0.0664	1.0000	0.8357	0.3247	0.2328	0.3307	1.0000	0.1745
Solar PV-Crystalline	0.0664	1.0001	0.8358	0.3247	0.2328	0.3307	1.0001	0.1745
Solar PV-Thin Film	0.6553	0.4745	0.3965	0.4355	0.3518	0.9968	0.9999	1.0000
Solar thermal	0.6553	0.4745	0.3965	0.4355	0.3517	0.9968	0.9999	0.9999
Geothermal	0.8197	0.3269	0.2614	0.2995	0.2354	1.0000	0.8734	1.0000
Biomass	0.6562	0.4710	0.3931	0.4321	0.3487	0.9999	0.9999	1.0000
Hydropower	0.6562	0.4710	0.3931	0.4321	0.3487	1.0000	1.0000	1.0000
Average	**0.5583**	**0.5717**	**0.4761**	**0.3780**	**0.2974**	**0.8131**	**0.9551**	**0.7936**

According to the virtual efficiency approach, hydropower is the most efficient power plant because it has the highest virtual efficiency score. In general, we expect that all efficiency scores are less than 1 for the virtual efficiency method. However, Table 4 shows that the virtual efficiency score of hydropower is equal to 1 because of the fact that the constraint of virtual DMU is not binding. Therefore the ranking of the power plants should be as follow: (1) hydropower, (2) wind-onshore, (3) geothermal, (4) biomass, (5), wind-offshore, (6) solar photovoltaics-thin film, (7) solar photovoltaics-crystalline, and (8) solar thermal plant.

Table 4: Super Efficiency and Virtual Efficiency Scores for Power Plants.		
Power Plants	Super Efficiency	Virtual Efficiency
Wind-onshore	*	0.8907
Wind-offshore	1.6273	0.3553
Solar PV-Crystalline	*	0.2969
Solar PV-Thin Film	*	0.3402
Solar thermal	*	0.2771
Geothermal	1.2261	0.8496
Biomass	2.6125	0.7680
Hydropower	1.1607	1.0000

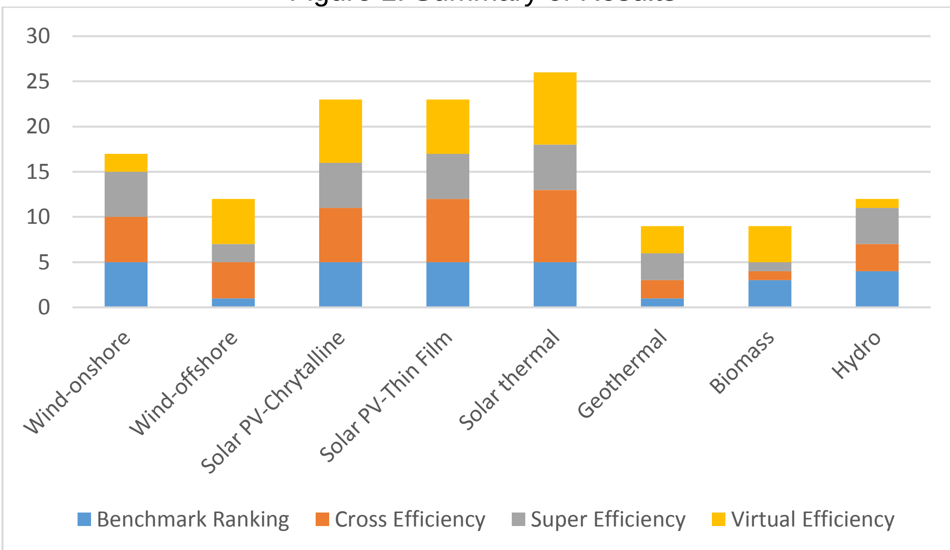
Table 5 shows the summary of the ranking of power plants with respect to benchmark ranking, super efficiency, cross efficiency and virtual efficiency approaches. The final ranking is obtained by the cumulative scores of each power plant.

Table 5: Comparison of Various Approaches						
Power Plants	Benchmark Ranking	Cross Efficiency	Super Efficiency	Virtual Efficiency	Cumulative Score	Ranking
Wind-onshore	5	5	5	2	17	5
Wind-offshore	1	4	2	5	12	3
Solar PV-Crystalline	5	6	5	7	23	6
Solar PV-Thin Film	5	7	5	6	23	6
Solar thermal	5	8	5	8	26	8
Geothermal	1	2	3	3	9	1
Biomass	3	1	1	4	9	1
Hydropower	4	3	4	1	12	3

SUMMARY AND CONCLUSION

In this paper, we want to determine the most efficient renewable energy source(s), with pre-determined input and output variables. We construct DEA framework to find efficient scores of each power plant. We apply four different analytic approaches, benchmark ranking, cross-efficiency, super efficiency and virtual efficiency. We rank each power plant by using these approaches, and then we calculate the cumulative scores. Therefore we rank these power plants according to their cumulative scores. Figure 1 and Table 5 summarizes the results.

Figure 1: Summary of Results



According to the results, biomass and geothermal are the most efficient renewable energy sources, where wind-offshore plant and hydropower follow these two plants. According to the DEA framework, they are all labelled as efficient renewable energy sources. Wind-onshore is ranked 5, where solar photovoltaics technologies share the sixth place, and solar thermal is the most inefficient renewable energy source. Figure 1 summarizes the contribution of each analytic techniques to the cumulative scores of each plant.

This study also shows that land availability has a really key role in this ranking and the efficiency scores of these renewable energy sources as well. Wind-offshore technology, which doesn't require any land, performs much better than wind-onshore technology, even though TLSC of wind-onshore is about 40% of TLSC of wind-offshore. These findings suggest that offshore wind farms should be more preferable because they don't have any land requirement. In addition, biomass, which requires a very small land for its operation, is one the most efficient renewable energy source as well according to our DEA analysis.

Another important finding of our DEA analysis is; although photovoltaic technology is one of the fastest growing power-generation, they are the least efficient technologies with solar thermal technology with respect to the other renewable energy sources. However in the future, the advancements in these technologies, may make them more preferable with the reduction of cost functions.

Lastly, policymakers should encourage and subsidy these technologies to reduce greenhouses gas (GHG) emissions which are it the main source of global warming and climate change. According to the EIA data, with the expansion of these renewable energy sources, GHG emissions started to decline in the United States in last five years.

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