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Comparative Analysis of Efficiencies for Renewable Energy Capacities across ISO Regions

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Abstract

This study investigates the renewable energy adoption across regions covered by Independent System Operators (ISOs) in the U.S. The study employed a deterministic model in the form of Data Envelopment Analysis (DEA) to determine the performance of ten ISO regions over a five-year period from 2013 to 2017. Inputs into the model include the Renewable Portfolio Standard (RPS) targets, fossil fuel capacity additions and the costs of capacity additions. Outputs from the model include renewable energy capacity additions and CO_2 emissions per MWh of generated electricity. The results show the regions covered by CAISO, ERCOT, NE-ISO, SPP and the NON-ISO to be on the efficient frontier. For the regions not on the efficient frontier, the results identify their limitations and provide projections both for reductions in excess inputs and improvements in outputs to be on the efficient frontier. For example, we see that the regions covered by NY-ISO and PJM would require, on average, renewable energy capacity expansions of 593.65MW and 230.24MW, respectively, to be on the efficient frontier. These regions would require their average fossil capacity expansions to be limited to 234.83MW and 365.4MW respectively. These findings offer some guidance on approaches to improving the performance of these markets.

Keywords: Renewable Energy, Data Envelopment Analysis, Independent Systems Operators

1. Introduction

The debate surrounding climate change and efforts to limit global temperature rise has continued to attract varying levels of social and political concerns across the globe. A recent assessment of the annual global temperatures has ranked the year 2019 to be second hottest recorded in a 140-year long climate record at 2.07° F (1.15° C) above preindustrial conditions [1]. The most recent records on energy-related CO_2 emissions in the US also show that the Electric Power sector was responsible for about a quarter of the energy-related CO_2 emissions in 2018 with 64% of the total generation emanating from fossil fuel sources and only 17% from renewable energy sources [2]. Several policies have been introduced to stimulate the growth and development of renewable energy across regions in the U.S. [3, 4], however, the effectiveness of these policies at achieving this, still remain a source debate [5]. One of such policies is the Renewable Portfolio Standard (RPS) that represents policy mandates across states requiring that a certain percentage of the total electricity sales from utilities across states be sourced from renewable energy. As more states continue to strengthen the profile of their RPS targets, it is expected that technology investment in renewable energy capacity additions as opposed to fossil fuel technology investments would be on the rise. While most of these policies are located across state lines, the electricity grid system traverses across multiple state boundaries [5]. In this regard, ISOs are saddled with the objective of overseeing the multi-state electric grid system.

This paper evaluates the renewable energy adoption efficiency across ISOs regions in the U.S. We refer to a region's renewable energy efficiency as to how effectively the region is able to maximize its renewable energy capacity growth and minimize its fossil fuel capacity also taking into consideration certain policies implemented to stimulate renewable energy growth within the region. The study employs Data Envelopment Analysis (DEA), a non-parametric linear programming approach that evaluates the efficiencies of different units containing multiple inputs and outputs. The study found five regions to be efficient and five to be inefficient. For each of the inefficient regions, the study identified possible projections in input and output variables which could be implemented to improve their efficiencies. The findings from these study are useful for energy planners across regions in deciding on renewable energy capacity addition requirements and also for policy makers in understanding the effectiveness of certain policies.

2. Model

The DEA approach involves evaluating relative efficiencies across several Decision Making Units (DMUs). The approach was developed by Charnes et al. [6] based on the frontier analysis approach proposed by Farrell [7]. The model calculates a weighted sum of inputs and outputs for each DMU and calculates efficiency scores based on the ratio of the weighted outputs to weighted inputs or vice versa. DMUs are then grouped into efficient and inefficient units based on their efficiency scores. This paper employs the DEA model in determining the regional renewable energy efficiencies across ISOs regions in the United States. Considering a scenario with *n* productive units, each with *s* number of outputs and *m* number of inputs. With θ being the efficiency of the qth DMU. The CCR (Charnes, Cooper and Rhodes) output-oriented model [6] is as shown in model (1) :

$$\max D = \theta$$

$$s.t. \ \sum_{j=1}^{n} \lambda_j X_{ij} + S_i^- = X_{iq}\,, \quad (i = 1,2, \ldots \ldots m)$$

$$\sum_{j=1}^{n} \lambda_j Y_{rj} - S_r^+ = \theta Y_{rq}, \qquad (r = 1,2, \ldots \ldots s)$$

$$\lambda_{j,}\, S_i^-, S_r^+ \geq 0 \tag{1}$$

For the purpose of this study, each DMU represents the ISOs. Table A1 in the Appendix shows the distribution of each DMU along state lines. Y_{rj} represents the vector of the *r*-th output of the *j*-th ISO, X_{ij} represents the vector of the *i*-th input of the *j*-th ISO. λ_j represents the weight assigned to the *j*-th ISO, S_i^-represents the negative slacks of the input constraints and S_r^+ represents the positive slacks of the output constraints. An ISO region is said to be an efficient unit if the optimal value, $\theta^* = 1$ and all slacks are zero. Inefficient units on the other hand would have values of $\theta^* \leq 1$. Furthermore, input and output targets (X'_{iq} and Y'_{iq}) which represent projections from the inefficient ISO region to the efficient frontier can be calculated for each inefficient region as shown

$$X'_{iq} = \sum_1^n \lambda_j^* X_{ij} = X_{iq} - S_i^- \ and \quad Y'_{iq} = \sum_1^n \lambda_j^* Y_{rj} = \theta^* Y_{rq} + S_r^+ \tag{2}$$

Where λ_j^* represents the optimal assigned weights of each ISO region. The study involves a total number of 10 ISO regions and 5 input/output variables consisting of data collected over the periods of 2013 to 2017. Three variables were selected as inputs into the model. The first input is the average annual fossil fuel capacity additions into each region in MW (FS). These data consist of annual generator-level data on the fossil-fuel plants which were newly installed within each region averaged over the time horizon. The data was obtained from the Energy Information Administration (EIA-860) database. The second input was the average annual construction cost of total capacity additions (AVC) into each region in \$. This value was calculated by finding the product of the average construction cost/kW of installed capacity for each technology and the annual capacity additions in kW for each technology. The result was then summed up for each year to get the total cost and averaged across the time period. The data on average cost per technology for each year was also obtained from the EIA-860 database. The final input into the model is the average Renewable Portfolio Standard (RPS) percentage targets across each region. It is expected that the strength of RPS policies across regions would drive the production of renewable energy. Data on the actual RPS targets for each period was obtained from the RPS database of the Lawrence Berkeley National Laboratory (LBNL). These data was averaged over the time period for each region to get the average RPS targets over the selected period.

Two output variables were selected for the study. The first is the average annual renewable energy capacity addition (RE) into each region in MW. These consist of the annual generator-level data on renewable energy plants which were newly installed across each region averaged over the time horizon. These data was also obtained from the Energy Information Administration (EIA-860) database. The final output variable was the average CO_2 emissions per MWh of generated electricity across each region. This was modelled as an undesirable output by finding the inverse of this value [8]. Data on the average CO_2/MWh of electricity generated was calculated for each region from values obtained from the EIA electricity analysis and projection database.

The summary statistics and correlation matrix of the input and output variables are shown in Table 1. To draw insights on regional efficiencies with respect to each input variable, an initial performance assessment was done on the regions to evaluate how each region performed taking into consideration only one of the input variables at a time. Further analysis was then performed considering all input and output variables in the same model. For the multiple input-output scenario, an output oriented DEA model as shown in (1) was selected because the study aims to determine how much renewable energy capacity expansions would be required by inefficient regions to operate at the efficient frontier.

Table 1: Summary statistics and correlation matrix of the input and output variables. (0)-Output, (I)-Input

	Mean	*SD*	*(O) RE (MW)*	*(O) CO_2 (Kg/MWh)*	*(I) AVC($'Millions)*	*(I) FS (MW)*	*(I) RPS (%)*
(O) RE (MW)	598.11	898.75	1				
(O) CO_2 (Kg/MWh)	189.90	153.75	0.7135	1			
(I) AVC ($'Millions)	200.00	261.00	0.9925	0.7164	1		
(I) FS (MW)	995.17	1248.09	0.8599	0.8401	0.8675	1	
(I) RPS (%)	10.73	6.53	0.0743	-0.1515	0.1314	-0.1122	1

3. Results

The results of the single input evaluation is shown in Figures 1, 2 and 3 for input variable FS, AVC and RPS, respectively. Figures 1 and 2 show that when average fossil capacity additions and average cost of total capacity additions are considered as inputs in separate cases, NE-ISO and SPP both lie on the efficient frontier. This implies that for these scenarios, only these two regions are efficient while other regions are inefficient. The results also show that the least efficient regions for both cases are MISO, NY-ISO and PJM. For the case where RPS targets are considered as inputs, the efficient regions are the NON-ISO regions and ERCOT. The results again show that for this scenario, the least efficient DMUs are the NY-ISO and MISO regions.

Figure 4 shows the efficiency scores of the multiple input-output analysis. The results show a total of five regions to be efficient and five inefficient. The efficient DMUs include four regions which were efficient in the single input analysis (SPP, NON-ISO, NE-ISO, ERCOT) and the CAISO region. The inefficient DMUs in the order of decreasing efficiency score include the regions covered by MISO&SPP, PJM, MISO&PJM, NY-ISO and MISO. Using (2) the projections of each inefficient DMU was calculated. This represents the improvements or targets each inefficient region needs to attain to be at the efficient frontier.

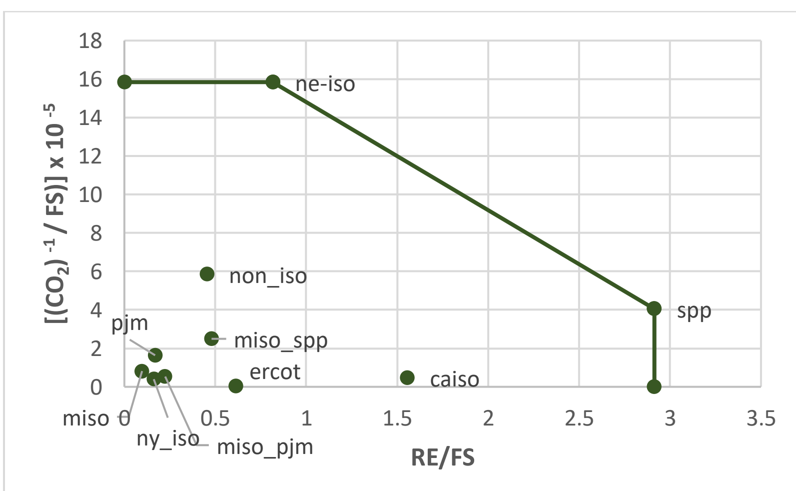

Figure 1: Frontier analysis with FS as input

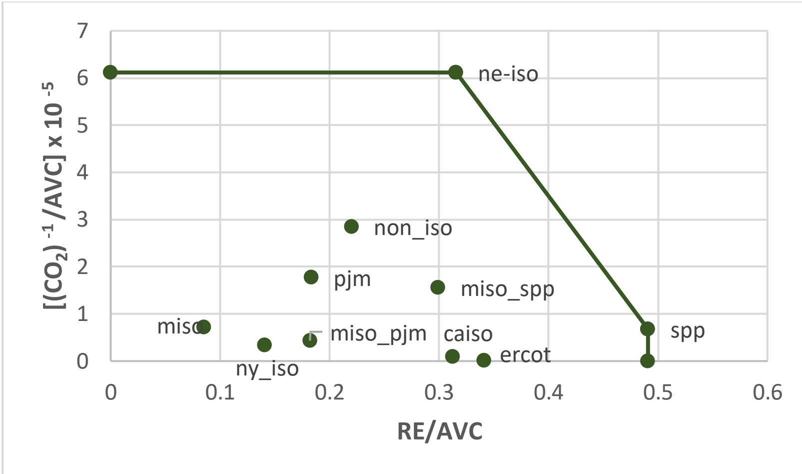

Figure 2: Frontier analysis with AVC as input

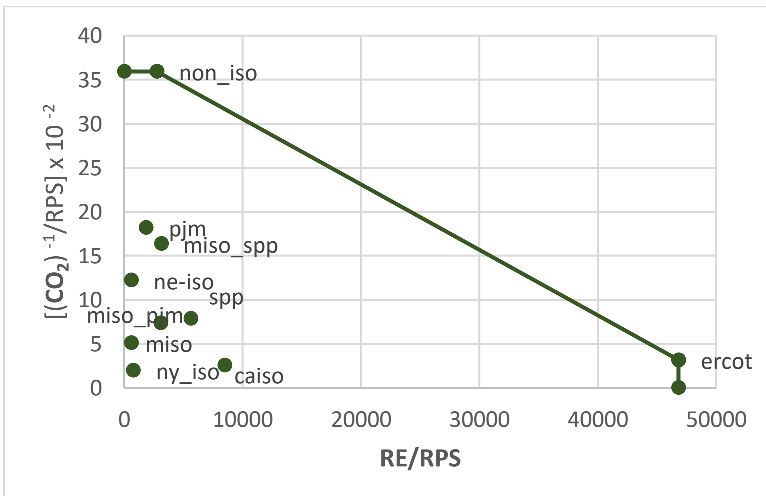

Figure 3: Frontier analysis with RPS targets as input

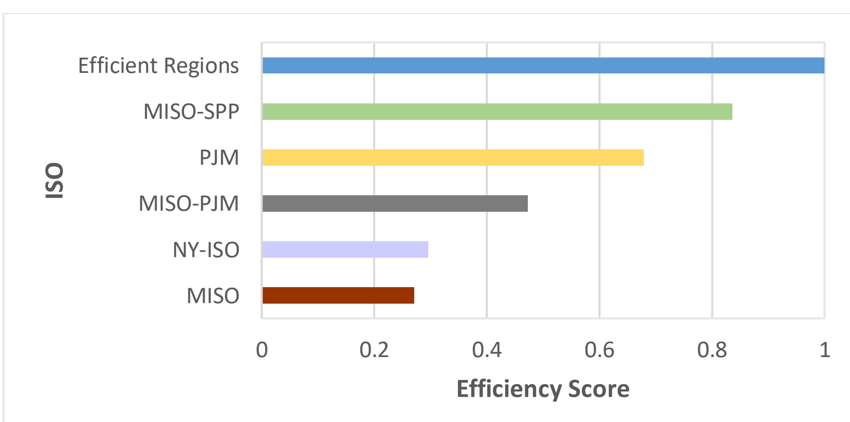

Figure 4: Regional Efficiency Scores

The projection results are shown in Figure 5. The percentage required reduction in fossil input is represented on the horizontal axis while the percentage reduction in Kg of CO_2/MWh is represented on the vertical axis. The size of the bubble for each inefficient region represents the percentage increase in additional renewable energy capacity required by each of the DMUs to reach the efficient frontier. The results show that the greatest percentage reduction in fossil capacity additions (78%) is required in the regions covered by NY-ISO, while the least is required in the regions by covered MISO&SPP (48%). For the CO_2/MWh of electricity, the results show that the highest percentage reductions are required in the regions covered by MISO and NY-ISO (73% and 70% respectively) while the least percentage reduction of (16%) is once again required in the regions covered by MISO&SPP.

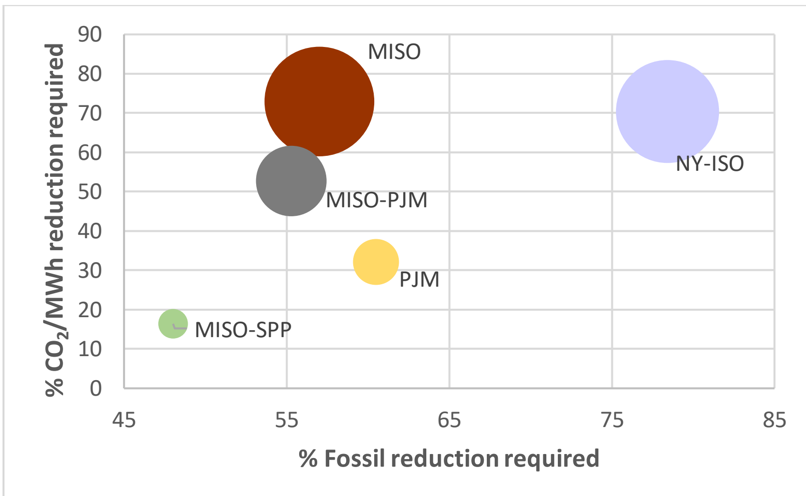

Figure 5: Input and output targets for inefficient regions

The analysis of the renewable energy capacity targets show that the regions MISO and NY-ISO require the greatest percentage increase in RE capacity additions to reach the efficient frontier. In a similar vein, the results also show that the regions covered by MISO&SPP require the least RE capacity additions to be on the efficient frontier. Table 2 shows the actual renewable energy capacity additions required by the inefficient regions and also shows that the efficient regions require no improvements.

Table 2: Average Renewable Energy capacity projections required by each DMU

DMU	*caiso*	*ercot*	*ne-iso*	*miso*	*miso-pjm*	*miso-spp*	*non-iso*	*ny-iso*	*pjm*	*spp*
Average RE (MW)	1808.14	2685.66	103.81	38.91	202.64	211.93	171.36	175.74	156.26	426.65
Required RE (MW)	1808.14	2685.66	103.81	143.78	428.60	253.55	171.36	593.65	230.24	426.65

4. Conclusions

This study applied the DEA method to determine the regional renewable energy adoption across ISOs in the U.S. For the multiple input-output analysis, the results obtained showed the regions covered by SPP, NON-ISO, NE-ISO, ERCOT and CAISO to be efficient while those covered by MISO&SPP, PJM, MISO&PJM, NY-ISO and MISO to be inefficient. For both efficient and inefficient regions, the study assessed how RPS policies across these regions have over the years influenced the growth of renewable energy. By evaluating the effectiveness of this policy alongside other input-output indices, the study is able to shed some light on how efficiently such policies contribute to renewable energy capacity growth within each region over the time frame. Considering the regions covered by NY-ISO, the average RPS target was 22% over the period but the region had a relatively low average renewable energy capacity addition over the period when compared to other regions such as ERCOT and the NON-ISO region which had average RPS targets of 5.7% and 6.2% respectively through the period. RPS could be ineffective across regions due to poor designs in the policies, inadequate enforcement mechanisms and the use of Renewable Energy Certificates (RECS) [5]. RECS for instance may not guarantee that the certificate purchased have actually displaced any fossil fuel source. As a result of this, policies such as RECS would not necessarily drive the growth of renewable energy across regions. The study also identified areas of improvement in input and output variables across inefficient regions. Specifically, the study showed actual projection targets which could be implemented for each of the identified input and output variables. In these regard, these findings can serve as a guide or decision making tool for policy makers and energy planners in these regions in deciding how much renewable energy capacity expansions are required to increase renewable energy adoptions in comparison to an efficient unit.

This study makes use of input and output variables across regions averaged over a time frame from 2003 to 2017. An extension of this study, would be to evaluate the regional renewable energy efficiencies across ISOs taking into consideration the stochastic nature or uncertainties in input and output variables over the time frame.

References

[1] NOAA, "2019 was 2nd hottest year on record for Earth say NOAA, NASA | National Oceanic and Atmospheric Administration," *National Oceanic and Atmospheric Administration/News*, 2020. https://www.noaa.gov/news/2019-was-2nd-hottest-year-on-record-for-earth-say-noaa-nasa (Jan. 16, 2020).

[2] EIA, "What is U.S. electricity generation by energy source? - FAQ - U.S. Energy Information Administration (EIA)," *U.S EIA*, 2018. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3 (Jan. 16, 2020).

[3] F. Pourahmadi, S. H. Hosseini, P. Dehghanian, E. Shittu, and M. Fotuhi-Firuzabad, "Uncertainty Cost of Stochastic Producers: Metrics and Impacts on Power Grid Flexibility," *IEEE Trans. Eng. Manag.*, pp. 1–12, 2020, doi: 10.1109/TEM.2020.2970729.

[4] I. DeLuque and E. Shittu, "Generation capacity expansion under demand, capacity factor and environmental policy uncertainties," *Comput. Ind. Eng.*, vol. 127, pp. 601–613, Jan. 2019, doi: 10.1016/j.cie.2018.10.051.

[5] O. Ogunrinde, E. Shittu, and K. K. Dhanda, "Investing in Renewable Energy: Reconciling Regional Policy With Renewable Energy Growth," *IEEE Eng. Manag. Rev.*, vol. 46, no. 4, pp. 103–111, Dec. 2018, doi: 10.1109/EMR.2018.2880445.

[6] A. Charnes, W. W. Cooper, and E. Rhodes, "Measuring the Efficiency of Decision Making Units," *Eur. J. Oper. Res.*, vol. 2, no. 6, pp. 429–444, 1978, doi: 10.1016/0377-2217(78)90138-8.

[7] M. J. Farrell, "The Measurement of Productive Efficiency," *J. R. Stat. Soc.*, vol. 120, no. 3, pp. 253–290, 1957, doi: http://doi.org/10.2307/2343100.

[8] B. Golany and Y. Roll, "An application procedure for DEA," *Omega*, vol. 17, no. 3, pp. 237–250, Jan. 1989, doi: 10.1016/0305-0483(89)90029-7.

Appendix

Table A1: ISO and States

ISO	STATES
CAISO	California
ERCOT	Texas
MISO	Mississippi, Wisconsin
MISO&PJM	Illinois, Indiana, Kentucky, Michigan
MISO&SPP	Arkansas, Iowa, Louisiana, Minnesota, Missouri, Montana, North Dakota, South Dakota
NE-ISO	Connecticut, Maine, Massachusetts, New Hampshire, Rhode island, Vermont
NON-ISO	Alabama, Alaska, Arizona, Colorado, Florida, Georgia, Hawaii, Idaho, Nevada, Oregon, South Carolina, Utah, Washington
NY-ISO	New York
PJM	Delaware, District of Columbia, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia
SPP	Kansas, Nebraska, New Mexico, Oklahoma, Wyoming