

# MEASURING THE OPERATING EFFICIENCY OF SOLAR CELL COMPANIES IN TAIWAN WITH DATA ENVELOPMENT ANALYSIS

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## ABSTRACT

This study discusses the Data Envelopment Analysis (DEA) approach to measure the operating efficiency of solar cell companies. With active and constructive advancement of the government, competition in the solar cell industry became even tenser. When drawing up the competitive strategies, one firm should identify the key indicators of its operating efficiency. This study incorporates three inputs (the number of employees, fixed asset, operating expenses) and three outputs (fund and investment, shareholders equity, sales revenue, gross margin) to measure the operating efficiency of 12 DMUs (solar cell companies) to provide reference for these companies in determining competitive strategies. Data are gathered from the market observation post system in Taiwan. The result indicates that there are six efficient DMUs and six inefficient DMUs. For the relatively inefficient DMUs, a slack variable analysis is performed and the efficiency scores to understand the usage of inputs and performance improvement of inefficient DMUs. The findings could benefit company operators seeking performance improvement in which they could benchmark practices being adapted by the most efficient companies. Together with Malmquist productivity index analysis, companies are able to assess the productivity change of DMUs over time. Finally, managerial implications are provided.

**Keywords:** Data Envelopment Analysis (DEA), Slack Variable Analysis, Malmquist Productivity Index (MPI), Operating Efficiency, Solar Cell Industry

## 1. INTRODUCTION

The global energy industry has been affected by the dramatic rise in the price of fossil fuels, a general shortage of energy resources and the crisis brought about by environmental pollution. With sharp increases in the world population and economic growth, the need for energy has increased and this in turn has led to a sustained rise in the international price of oil. However, since fossil fuel resources will eventually be depleted, prices will inevitably increase in the long term. In addition, humans have overused the traditional fossil fuels and this has resulted in the increased carbon dioxide in the atmosphere, which has worsened the

global warming problem and caused serious damage to the natural environment (Tseng *et al.*, 2011).

Of all of the green energies, solar energy has experienced the most vigorous growth and its energy consumption continues to rise. Due to the rapid growth of the photovoltaic market, the demand for solar cells has increased significantly. In recent years, Taiwan's government has been putting active implementation which has caused even tenser competition in the solar cell industry.

Taiwan's Ministry of Economic Affairs (MOEA) announced its final feed-in tariffs for renewable energy for year 2011 on May 2 2011. Together with weak demand from the solar cell market and market price

moving to cost price, a number of PV companies in Taiwan had faced with gross loss recently. In order to compete with such difficulty, liberalization and internationalization will be necessary for Taiwan's solar PV companies. Before setting up competitive strategies, one company should identify its relative operating efficiency in the industry and try to find out benchmarks first. Hence, how to improve the operating efficiency in order to gain more competitive advantages has become an essential issue to PV companies.

Traditionally, a company's performance is usually evaluated by a set of financial ratios which provide a simple description about a company's performance in comparison with that of previous periods and help to identify improvement directions. However, every single indicator may have different importance. The DEA approach can be applied to solve this problem.

This study considered the DEA method for performance assessment. The DEA approach not only takes into account input-output variables but also proves to be useful for efficiency analysis. Hence, this study has the main purposes as follows. First, the operating efficiency of 12 solar cell companies in Taiwan is analyzed with CCR and BCC models. Efficient companies are identified. Second, provide improvement directions in business operations. Second, slack variable analysis was used to find the critical variables that can improve the efficiency. Third, Malmquist productivity measurement, productivity rate of growth for each company can be further analyzed to understand their progress or regression during a specific period.

## 1.1. Literature Review

### 1.1.1. Taiwan's PV Industry

Photon International has released the results of its annual cell production survey, noting that global solar Photovoltaic (PV) cell output increased 118% in 2010 to 27.2 GW, with a global production capacity of 36.6 GW at the end of the year. The report also noted the increasing dominance of China in cell manufacturing, where 47.8% of all cells were produced in 2010 and Taiwan also outpaced Germany and Japan, where 12.7% of all cells were produced in 2010.

Taiwan's PV industry started with the production of amorphous silicon cells in 1987. The industry experienced an investment boom in 2003 because of market demands from Europe and Japan. Startup companies covered various fields of supply chain in the

solar industry, such as wafers, cells, modules and system installation.

As shown in **Fig. 1**, cell production from Taiwan reached 3,448.5 MW in 2010, which is a significant growth compared with that of 2009. Taiwan has shown remarkable performance in the global market as the second largest producing country in the global PV cell production. Among Taiwan-headquartered cell makers, Motech Industrial Inc. is currently the largest one. It had jumped back to the top 10 cell producer in 2010, landing at No. 7. A total of 945 MW solar cells were produced in 2010 compared to 360 MW of production in 2009, meaning that Motech posted a huge annual growth of 163%.

Since 1980, Taiwan's government has allocated budgets for the development of PV technology and considered PV as a major development target. Subsidy programs for PV installation were executed since 2001 to encourage the development in the domestic market. Set by the Executive Yuan, the PV installation is targeted to reach 1 GW in 2025. Since Renewable Energy Development Act has been legislatively approved in June 2009, feed-in-tariff was implemented accordingly. PV industry and the system installation were stimulated. According to Taiwan's feed-in tariff announcement on February 7 2012, the rate now changes twice a year as opposed to annual changes in the past. In addition, aggressive programs have been kicked off to enhance Taiwan's global competitiveness in PV industry.

## 1.2. Data Envelopment Analysis (DEA)

Building on the ideas of Farrell (1957) and Charnes *et al.* (1978) applied linear programming to estimate an empirical production technology frontier for the first time in their use of multiple inputs to produce multiple outputs. Since then, there have been a large number of books and journal articles written on DEA or applying DEA on various sets of problems.

There are two popular DEA models: CCR model and BCC model. DEA can be used to measure the efficiency of each similar firm or Decision-Making Unit (DMU) and it is a powerful tool to determine whether DMUs perform efficiently or inefficiently on the efficiency performance. Additionally, multiple input and output variables can be calculated simultaneously in DEA. Although previous studies developed various DEA methods, the CCR model and the BCC model are two of popular DEA methods (Chen and Chen, 2011).

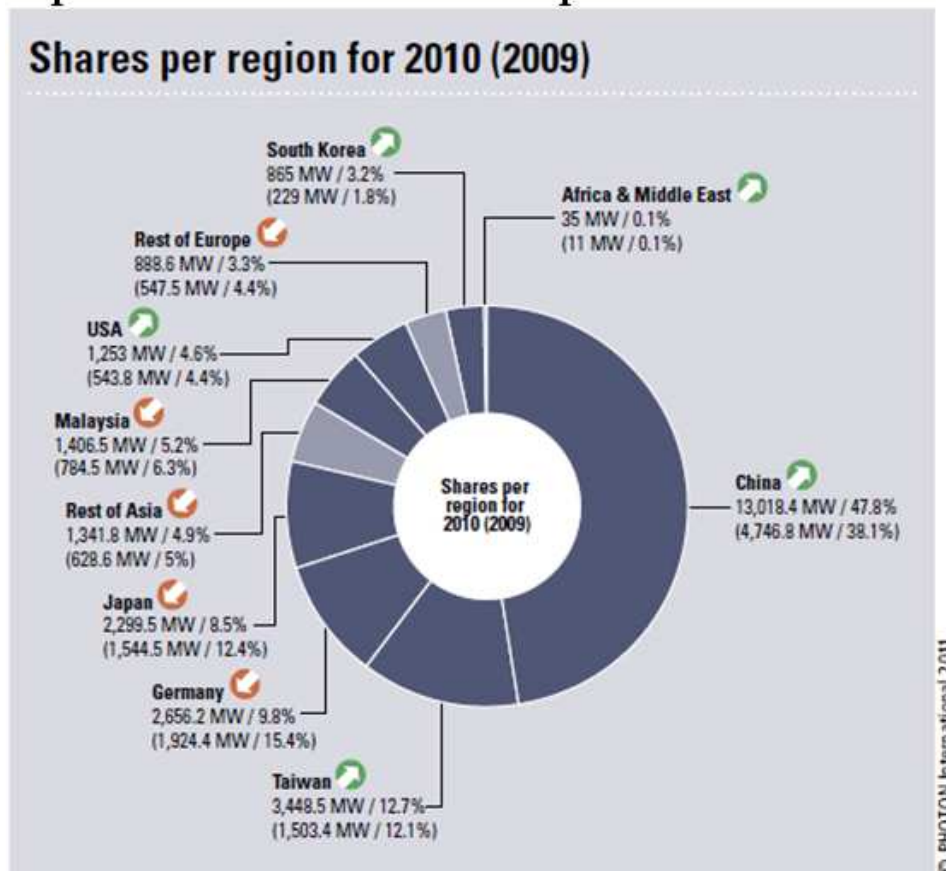


Fig. 1. PV cell market share per region for 2010(2009) (Source: Photon International’s Cell Production Survey, 2011)

### 1.3. CCR Model

Building on Farrell’s ideas, Charnes *et al.* (1978) expanded Farrell’s efficiency measurement concept of multiple inputs and single output to the concept of multiple inputs and multiple outputs. They utilized linear combination to convert it to single virtual input and output, estimated efficiency frontier from the ratio of two linear combinations and measured the relative efficiency of each DMU in CRS, which is between 0 and 1 and can determine whether a DMU is in constant, increasing or decreasing returns to scale.

### 1.4. BCC Model

Banker *et al.* (1984) widened the CCR model ratio concept and application scope in both Farrell and CCR models; efficiency was supposed to measure in CRS, but inefficiency might not have allocative efficiency,

proper scale and technical efficiency. Therefore, BCC changed CCR to Variable Returns to Scale (VRS) hypothesis, broke down technical efficiency into pure technical efficiency and scale efficiency and measured its efficiency and returns to scale.

### 1.5. DEA Application in Solar PV Studies

DEA has attracted much attention as a relatively new and efficient approach to studying efficiency matters in many fields, for example in high-tech manufacturing studies (Lee and Pai, 2011; Chen and Chen, 2011), in automobile studies (Yousefi and Hadi-Vencheh, 2010) and in tourism studies (Assaf, 2012).

With natural resource scarcity and environmental protection, solar energy is a promise of clean and plentiful energy. There have been a number of studies measured the performance of solar PV industry by DEA. Lee *et al.* (2010; 2012) integrated Data Envelopment

Analysis (DEA) and Analytic Hierarchy Process (AHP) to evaluate the business efficiency of Taiwan’s photovoltaic companies. Productive efficiency, technical efficiency and scale efficiency are calculated to provide directions for further improvement in business operations for PV companies.

From the review of past studies, DEA has been proven to be a successful evaluation approach for operating efficiency. Hence, this study would like to further apply DEA method to measure the operating efficiency in the solar cell industry.

## 2. MATERIALS AND METHODS

### 2.1. Methodology

This research applied a non-parametric DEA approach to measure the operating efficiency of selected solar cell companies in Taiwan.

### 2.2. Decision Making Units (DMUs)

A decision making unit is any entity that is to be assessed by its abilities to convert inputs into outputs (Charnes *et al.*, 1978). The study selected 12 solar cell companies in Taiwan for assessment as shown in **Table 1**.

### 2.3. Inputs and Outputs

In selecting the inputs and outputs for evaluating the operating efficiency of DMUs, we chose 6 variables (3 inputs and 3 outputs) to be incorporated in this study based on reviewed literature and the availability of the data. Inputs are number of employees, fixed assets and operating expenses, while outputs are fund and investment, shareholders’ equity and sales revenue. The combination of the measured indicators ensures adherence to the DEA convention that the number of DMUs should be at least twice the number of inputs and outputs to allow DEA to produce a decent level of discrimination (Thomas *et al.*, 1987). Moreover, by calculating the correlation coefficients between inputs and outputs, a significant correlation was found as illustrated in **Table 2**. The requirement of DEA model is fulfilled and thus the input and output variables can be used for this research to measure the operating efficiency.

Hence, we chose 12 solar cell companies as DMUs and collected the data of 3 inputs and 3 outputs from the Market Observation Post System in Taiwan. **Table 3** represents 12 DMUs and Q3 input/output data in 2011.

**Table 1.** List of solar cell companies

DMU	Companies	DMU	Companies
1	Arima	7	Shin Zu Shing
2	E-Ton	8	Danen
3	Gintech Energy	9	Giga
4	Green Energy	10	Tainergy
5	Solartech Energy	11	Sino-American Silicon Products
6	Tynsolar	12	Motech

**Table 2.** Correlation matrix between inputs and outputs

Inputs/ outputs	No. of employees	Fixed assets	Operating expenses
Fund and investment	0.469	0.226	0.493
Shareholders’ equity	0.946	0.842	0.930
Sales revenue	0.897	0.938	0.956

**Table 3.** Original Input and Output Data of DMUs

DMU	No. of employees	Fixed assets	Operating expenses	Fund and investment	Shareholders’ equity	Sales revenue
1	92	313,201	56,152	3,977,615	2,355,476	29,659
2	925	5,210,001	252,076	273,464	9,624,273	6,405,830
3	1,704	11,783,316	419,937	487,660	15,299,896	14,674,583
4	1,539	14,143,325	647,165	3,019,715	14,298,712	15,802,760
5	853	7,402,858	359,872	2,953,040	8,612,503	10,747,677
6	184	239,058	40,563	0	520,736	678,939
7	1,729	11,057,452	494,942	155,955	16,217,637	17,550,581
8	522	4,634,786	82,331	11,021	5,101,652	3,583,885
9	129	224,502	199,128	75,992	3,281,139	2,542,176
10	556	2,355,483	131,606	570,650	3,549,269	3,418,578
11	1,742	7,453,611	508,676	8,752,517	18,896,934	13,397,593
12	3,212	9,589,808	653,985	5,175,717	20,960,858	17,414,870

Source: Market Observation Post System [http:// mops.tse.com.tw](http://mops.tse.com.tw)

## 3. RESULTS

### 3.1. Empirical Results

#### 3.1.1. Efficiency Analysis

Overall efficiency scores evaluated using the CCR and BCC models are given in **Table 4** the CCR model assumes constant returns to scale while the BBC model allows for variable returns to scale.

During the observation period, DMU 1, 5, 7, 8, 9 and 11 are efficient in CCR model while DMU 2, 3, 4, 6, 10 and 12 are inefficient. In addition, the scale efficiency indicates that the DMU is on the optimum production scale when the score equals one. From the scale efficiency analysis, the study found that DMU 1, 5, 7, 8, 9 and 11 maintained efficient during the observation period, whereas DMU 2, 3, 4, 6, 10 and 12 had no scale efficiency. However, some of the SE inefficient DMUs had efficiency value of 1 in the BCC model, such as DMU 3, 4, 6 and 12. This phenomenon implies that their inefficiency is possibly from the influence of scale inefficiency. It is observed that DMUs 2, 3, 4 and 12 exhibited increase in returns

to scale indicating that a further expansion of input or output may be productive, while DMUs 6 and 10 exhibited decrease in returns to scale indicating that a further contraction of input or output may be productive.

### 3.2. Slack Variable Analysis

In regard to inefficient DMUs, slack variable analysis was used to analyze 3 inputs and 3 outputs in order to find the critical variables that can improve the efficiency. Results of slack variable analysis are shown in **Table 5**. Taking DMU 3 with an overall technical efficiency of 95.95% for example, the improvable spaces are (21.47, 0, 0) for its inputs and (0, 128244.48, 0) for its outputs respectively. That is, to enable such DMU to utilize resources so efficiently as other DMUs with the overall technical efficiency values of 1 do, its “number of employees” has to decrease by 48 [1,704\*(1-0.9595)-21.47 = 47.54], its “operating expenses” has to cut by 17,007. [419,937\*(1-0.9595)-0 = 17,007.45] and its “shareholders’ equity” has to increase by 128,244. DMU 3 will become a relatively efficient DMU.

### 3.3. Malmquist Productivity Index Analysis

Finally, Malmquist Productivity Index (MPI) was used by this study to measure the productivity change of DMUs over time (Year 2009 and Year 2010). Since DMU 6, 9 and 10 had no data during this observation period, 9 DMUs retained for Malmquist productivity index analysis in order for consistency. **Table 6** shows the TSE, IEI, MI and MPI of different DMUs.

**Table 4.** Production efficiency, technical efficiency and scale efficiency

DMU	CCR efficiency <sup>a</sup>	BCC efficiency <sup>b</sup>	Scale efficiency	Returns to scale
1	1	1	1	Constant
2	0.9359	0.9442	0.9912	Increasing
3	0.9595	1	0.9595	Increasing
4	0.8647	1	0.8647	Increasing
5	1	1	1	Constant
6	0.9369	1	0.9369	Decreasing
7	1	1	1	Constant
8	1	1	1	Constant
9	1	1	1	Constant
10	0.853	0.9031	0.9445	Decreasing
11	1	1	1	Constant
12	0.9944	1	0.9944	Increasing

<sup>a</sup>: CCR efficiency stands for Technical Efficiency (TE). CCR efficiency = BCC efficiency × scale efficiency; <sup>b</sup>: BCC efficiency represents pure technical efficiency

**Table 5.** Slack variable analysis results

DMU	TE	Inputs			Outputs		
		No. of employees	Fixed assets	Operating expenses	Fund and investment	Shareholders’ equity	Sales revenue
1	1.0000	0.00	0.00	0	0.00	0.00	0
2	0.9359	0.00	0.00	0	4086809.72	0.00	0
3	0.9595	21.47	0.00	0	0.00	128244.48	0
4	0.8647	0.00	969306.07	0	3674162.57	0.00	0
5	1.0000	0.00	0.00	0	0.00	0.00	0
6	0.9369	123.48	0.00	0	13935.08	244553.67	0
7	1.0000	0.00	0.00	0	0.00	0.00	0
8	1.0000	0.00	0.00	0	0.00	0.00	0
9	1.0000	0.00	0.00	0	0.00	0.00	0
10	0.8530	118.55	0.00	0	0.00	71420.64	0
11	1.0000	0.00	0.00	0	0.00	0.00	0
12	0.9944	1265.70	0.00	0	761350.06	0.00	0

**Table 6.** Malmquist productivity index

DMU	TSE <sup>1</sup>	TSE <sup>2</sup>	IEI <sup>1→2</sup>	IEI <sup>2→1</sup>	MI <sub>t</sub> <sup>2</sup>	MPI <sub>t</sub> <sup>2</sup>
1	1.000	1.000	1.608	1.330	0.910	0.910
2	0.892	0.758	0.839	1.164	1.278	1.086
3	1.000	0.960	0.796	1.423	1.364	1.309
4	1.000	0.745	1.055	1.097	1.181	0.880
5	0.918	0.950	0.788	1.371	1.296	1.341
7	0.855	1.000	0.593	1.580	1.509	1.764
8	0.518	1.000	0.372	1.267	1.328	2.563
11	1.000	1.000	1.028	1.626	1.258	1.258
12	1.000	1.000	0.788	1.643	1.444	1.444

TSE = Technical and Scale Efficiency; IEI = Intertemporal Efficiency Index; MI = Malmquist Index; MPI = Malmquist Productivity Index

According to **Table 6**, 6 DMUs have exhibited a decline in  $IEI^{1 \rightarrow 2}$  which means improvement is required.  $MPI = \text{Technical Efficiency Change} \times \text{Technical change}$ . Technical efficiency change measures the change in efficiency between current (t) and next (t+1) period, while technological change captures the shift in frontier technology. A value of technical efficiency change greater than 1 represents an improvement in efficiency and a value less than 1 indicates a decline. A value of technological change greater than 1 represents a progress in technology and a value less than 1 indicates a regression in technology. As for intertemporal efficiency index, DMU 1 identified technology progress while DMU 8 identified no technology progress.

#### 4. DISCUSSION

This study conducted efficiency analysis, returns to scale analysis, slack variable analysis and Malmquist productivity index analysis to assess the efficiency of 12 solar cell companies in Taiwan. The results are summarized as follows:

- Efficiency analysis: DMU 1, 5, 7, 8, 9 and 11 are efficient in CCR model
- Scale efficiency analysis: DMU 2, 3, 4, 6, 10 and 12 had no scale efficiency
- Slack variable analysis and return to scale analysis: DMU 2, 3, 4 and 12 are IRS while DMU 6 and 10 are DRS
- Malmquist productivity index analysis: As for intertemporal efficiency index, DMU 1 identified technology progress while DMU 8 identified no technology progress

#### 5. CONCLUSION

DEA approach proves to provide constructive suggestions to enhance resource allocation. It is known from slack variable analysis, DMU 3 for example, shall decrease its "number of employees" by 48, decrease its "operating expenses" by 17,007 and increase its "shareholders' equity" by 128,244 in order to become a relatively efficient DMU. The findings could benefit company operators seeking performance improvement in which they could benchmark practices being adapted by the most efficient companies. Together with Malmquist productivity index analysis, companies are able to assess

the productivity change of DMUs over time. This also helps managers to evaluate whether or not there is a progress at different times.

In addition, Taiwan's government has been putting a lot of efforts to encourage enterprises to conserve energy and to reduce carbon emission. A survey on the operating efficiency of solar cell companies will be guidance for the government to design appropriate policies whether to better manage these companies or to provide subsidies.

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