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Using DEA to Evaluate Operation Efficiency of Top 10 Global Solar Photovoltaic Companies

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***Abstract*--Experts indicates that fossil fuel depletion may happen in the next 6 decades. People start to think of the possibilities of developing alternative energy. Among different alternative energy, solar offers the most adaptable application and converts sunlight directly into electrical energy with the highest efficiency. Lots of enterprises then start to launch resources to develop solar photovoltaic (solar PV) technique and thus create fierce competition. Therefore, the importance of operation efficiency in solar PV industry has been highlighted. In this research, we incorporate four-year' financial records of global top 10 solar PV companies and use DEA that includes technical efficiency, scale efficiency, and evaluation of returns to scale to evaluate each firm's operation efficiency. Results show that only 17.5% of the firms reaches the ideal efficiency. Marketing and management expense should be reduced most. Solar PV companies may scale it down and then invest in the vital part of solar PV industry, R&D. Most of the problems of solar PV industry could be solved with technical improvement. This paper renders a global view of operation efficiency evaluation that results from the top global solar PV companies, and thus makes the results more applicable and are worth of referring.**

I. MOTIVATION AND OBJECTIVES

A. Motivation

Resource problem has become the critical issue to people's survival in such an overpopulation era. According to US census bureau, total amount of world population has exceeded seven billion [18] in 2013. As everyone knows, escalation of world population boosts the need of resources. However, resources on the planet is not infinite. On the contrary, the resources that people can share on earth has become less and less as time passed. One of the resources that has become fewer and fewer but has been widely-used in almost every kind of transportation and production in people's daily lives is fossil fuel. Fossil fuel is the resource which can't be produced but can only be consumed. In other words, this is the so-called unrenewable resource. The bad news is, according to BP's (British Petroleum) Statistical Review of World Energy, total amount of fossil fuel that can be used by people can only last for approximately 52.9 years [3]. Here comes the serious problem, if we lose the main raw material for transportation and production of our daily lives, how can we still survive? As a consequence, people start to think of the possibilities of generating alternative energy, such as wind, geothermal, biomass, and solar [16]. Among all of the previous alternative energies, solar (photovoltaic technology) offers the most widely adaptable applications and converts sunlight directly into electrical energy with the highest efficiencies [14]. Perceive the problem of fossil fuel exhaustion, lots of businesses start to launch their resource to develop the technique of generating energy from solar power. However, the overall production efficiency of solar power industries is still unfavorable due to the inevitable energy loss during the conversion process from solar power to another kind of energy, for instance, electricity. Most importantly, the expense of developing such new energy generating technique requires incredibly high expense. Therefore, the control of expense seems to be rather important in solar power industry. If we could find the proper way to control the expense of production through efficiency analysis of solar power industry, this industry will very possibly become more prosperous than now as well as generating more renewable energy, e.g. solar power energy. In this way, there is no need for people to be afraid of running out of fossil fuel anymore and can more likely to realize the ideal of sustainability.

B. Objectives

Conversion efficiency of the energy that comes from solar power to electricity is still too unfavorable to support daily usage. Resulting from the principles of thermodynamics of materials, the efficiency loss between conversions of different types of energy is inevitable. This is the reason why we can only have the efficiency conversion rate of approximately 6-30% from solar power to electricity. Despite of the uncontrollable conversion loss from solar power to electricity, managers of solar industries can focalize on the things that could make solar industry more prosperous and is allowed human's control at the same time, that is, manufacturing expense adjustment. With the purpose to find out the possible improvement and deduction room of different expense of inputs, we are going to adopt DEA methodology to analyze usage condition of each firm's inputs through the comparisons with the effective sample firms. Under the comparisons with effective firms, we can know the exact deduction or increase room of each inputs, and thus make the best adjustment of each input to pursue a brighter future of solar power industry as well as the sustainability of human beings.

II. LITERATURE REVIEW

A. Overpopulation Era

Resources insufficiency that comes from overpopulation may probably become a serious concern in the coming few decades. Thanks to the great achievements in medicine and technology, lifespan of people has been extended a lot than before. It is estimated that the total amount of world population will escalate to 9.6 billion in 2050 according to World Population Prospects: The 2012 Revision. As a result of the achievements of medicine and technology, population still grows despite the fact that birth rate has generally decreased in most of the areas in recent decades. However, excessive amount of people may somehow become a burden for the whole environment since the demand of each kind of resources climbs as well as the expansion of population. Unfortunately, one of the resources that people widely apply in transportation and production is fossil fuel. Fossil fuel is the also the so-called non-renewable resource. According to Prof. Fred Magdoff, non-renewable resource is the resources that "the rate of use can be no greater than the rate at which renewable resources can be substituted for these nonrenewable resources—that is, the sustainable use of nonrenewable resources is dependent on investment in renewable resources that can replace them [13]."

B. Malignant Effects of Fossil fuel Overuse

Among many different types of non-renewable resources, we would like to put the emphasis on fossil fuel that is widely used in generating energy, production, and transportation. Overuse of fossil fuel may result in many problems such as global warming because of the excessive emission of CO_2 while using fossil fuel [11]. Global warming causes rise of sea level and will endanger some of the coastal countries which are at the low altitude, for example, one of the most beautiful islands in Indian Ocean, Maldives. Maldives is said to disappear from the world in the next one hundred years [1]. In addition, global even engenders climate changes such as more unexpected floods, droughts, heat waves, hurricanes, and tornadoes [10].

In addition to the environmental damages, overdependence of fossil fuel in most of the production and transportation in our lives can easily lead to soar of consumption price. In 1970s, only 5% decrease of fossil fuel extraction caused 5 times increase of global consumption price. Annual Energy Report from British Petroleum indicates that only 10%-15% decrease of fossil fuel extraction will very possibly lead to a paralysis of industrialized countries [19].This is because fossil fuel has been applied to so many aspects in our lives, the amount of fossil fuel extraction determines many different aspects of prices in people's lives. However, people should better quit this dependence on fossil fuel and start thinking of the practicability of alternative energy.

BP Statistical Review of World Energy indicates that fossil fuel depletion may probably happen in 52.9 years. In other words, it is vital for us not to keep relying on fossil fuel for our energy sources. From the perspective of business, the company that takes the lead in developing the techniques of generating alternative energy should become the pioneer in the industry and thus can make considerable profits from developing the new way of generating energy.

C. Solar Photovoltaic Industry overview

As the results of technological improvement, cost reductions in materials, and government support for renewable-energy-based electricity production, development of solar PV technology has grown tremendously in the recent decades. Photovoltaic plays an important role to utilize solar energy for electricity production worldwide. Nowadays, PV market grows swift around the world around 23.5 GW in 2010 and is at an annual rate of 35–40%. This figures further disclose the fact that solar photovoltaic has been one of the fastest growing industries. It is even predicted that photovoltaic electricity will provide approximately 345 GW by 2020 and 1081 GW by 2030 [7].

Efficiency of solar cell is one of the important parameters which determines the establishment of this technology in the market. In order to make this technology more attainable, there have been heap of research work that focalize on efficiency improvement of solar cells for commercial use [17].

III. RESEARCH METHODS

A. DEA

The beginning of DEA methodology could be traced back to an article of Farrell (1957), "The Measurement of Productive Efficiency." Farrell (1957) was motivated by the need for developing better methods and models for evaluating productivity. He contended that current ways in 1905s to evaluate productivity of certain industry usually produced complex measurements of some or all inputs and outputs. However, those solutions were quite limited because they are not capable to combine those complex measurements into an overall point of view of efficiency of the target industry [8].

Responding to these inadequacies, Farrell proposed an activity analysis approach that could more adequately deal with the problem of productivity evaluation. His measures were intended to be applicable to any productive organization; in his words, '… from a workshop to a whole economy'. In the process, he extended the concept of "productivity" to the more general concept of "efficiency."

Data Envelopment Analysis (DEA) was later developed by Charnes, A., W. Cooper, and E., Rhodes in 1978. After the initial study by Charnes, Cooper, and Rhodes, there had appeared 2000 articles in the literature. Such rapid growth and widespread (and almost immediate) acceptance of the methodology of DEA was testimony to its strengths and applicability. Researchers in a number of fields had quickly recognized that DEA is an excellent methodology for modeling operational processes, and its empirical orientation and minimization of a priori assumptions has resulted in its use in a number of studies involving efficient frontier estimation in the nonprofit sector, in the regulated sector, and in the private sector [6].

The DEA method is based on a model of linear programming in order to define the technical efficiency levels, in cases of constant or variable returns to scale [15].

Technical efficiency that is defined by the DEA method for no matter constant returns to scale or variable returns to scale can both be calculated on either output oriented or input oriented. When it is with the premise of output orientation, it establishes a model that proposes to maximize outputs with the current amount of inputs. On the other hand, technical efficiency of DEA can also be based on input orientation and thus will generates a model whose objective is to minimize inputs but keep the current amount of outputs constant [5].

1) CCR

The initial DEA model, as originally presented in Charnes, Cooper, and Rhodes's (CCR) (1978) "Measuring the Efficiency of Decision Making Units," built on the earlier work of Farrell (1957). Farrell's empirical work had been confined to single-output cases and his sketch of extensions to multiple outputs did not supply what was required for applications to large data sets. In order to meet the need of computationally implementable form, Charnes, Cooper and Rhodes developed the dual pair of linear programming problems that were modeled in their model, i.e. CCR model.

The dual problems devised by Cooper and Rhodes readily extended the Farrell's(1957) ideas to multiple outputs and multiple inputs in ways that could locate inefficiencies in each input and each output for every DMU. Since CCR model is developed, DEA has become a multi-factor productivity analysis model for measuring the relative technical efficiencies of a homogenous set of decision making units (DMUs).

The efficiency index, in the presence of multiple input and output factors, is defined as the ratio of the sum of outputs to the sum of inputs that have been weighed with weighted factors.

$$\mathrm{TE} = \frac{\text{Weighted Sum of Outputs}}{\text{Weighted Sum of Iutputs}} \qquad (1)$$

One of the characteristics of DEA is that DEA gives separate weights to each input and output, and the weights are extracted after all possible linear combinations of peer DMUs (which produce at least the same result as the Decision Making Unit examined) have been checked.

Suppose we have n DMUs, m inputs and s outputs of each. The level of relative efficiency of one of them (even of p DMU) arises as a result of the solution of the following model, described by [4]:

$$\max \ \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \ , \ \mathrm{s.t}\ \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \le 1 \qquad \forall\ \mathrm{i} \quad v_k\ , \ u_j\ \ge 0,\ \forall\ \mathrm{k,j} \qquad (2)$$

k= 1, 2, 3,…, s

j= 1, 2, 3,…, m

i= 1, 2, 3,…, n

y_{ki} = amount of output k produced by $\mathrm{DMU_i}$,

x_{ji} = amount of input j utilized by $\mathrm{DMU_i}$,

u_k = weight given to output k,

u_j= weight given to output j

This model is for constant returns to scale. The weighted ratio of outputs to inputs is between 0 and 1 for all the DMUs of the model.

2) BCC

In 1984, Banker, Charnes and Cooper added the constraint of $\sum_{j=1}^{m} u_j\, x_{jp} = 1$ into (2), and they also acknowledge the hypothesis of variable returns to scale and thus results in the BCC model.

$$\sum_{k=1}^{s} v_k y_{kp} \ , \quad \mathrm{s.t}\ \sum_{j=1}^{m} u_j\, x_{jp} = 1 \ , \quad \sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j\, x_{ji} \ \le 0,\ \forall \mathrm{i}\ \ v_k,\ u_j\ \ge 0,\ \forall \mathrm{k,j} \qquad (3)$$

Slightly different from technical efficiency (TE) of CCR model, the efficiency index which is derived from BCC mode is called pure technical efficiency (PTE) [8]. We can obtain scale efficiency (SE) by dividing TE by PTE [2]. Scale efficiency can be a good reference of determining whether the target company should enlarge or dwindle their inputs.

However, it's insufficient for us to understand what condition of returns to scale of each DMU is in. As a result of this, Fare et al (1994) change the constraint $\sum_{j=1}^{m} u_j\, x_{jp} = 1$ in BCC to $\sum_{j=1}^{m} u_j\, x_{jp} \le 1$. With the adjusted constraint, we can get a new technical efficiency which is under the constraint of non-increasing returns to scale, we call this technical efficiency as $\mathrm{TE_{NIRS.}}$ Comparing $\mathrm{TE_{NIRS}}$ with $\mathrm{TE_{VRS}}$ (pure technical efficiency), we can get the idea of whether the DMU is in increasing returns to scale or decreasing returns to scale. In addition, constant returns to scale could be obtained by comparing $\mathrm{TE_{CRS}}$ and $\mathrm{TE_{VRS.}}$ DMU is in constant returns to scale when $\mathrm{TE_{CRS}}=\mathrm{TE_{VRS.}}$

Here we conclude a simple development history from CCR model to BCC model, and clarify the relationships and appearance sequence among different kinds of efficiency in DEA.

TABLE 1

Comparison between $\mathrm{TE_{NIRS}}$ and $\mathrm{TE_{VRS}}$	Condition of returns to scale
$\mathrm{TE_{NIRS}}=\mathrm{TE_{VRS}}$	DRS
$\mathrm{TE_{NIRS}}<\mathrm{TE_{VRS}}$	IRS
Comparison between $\mathrm{TE_{CRS}}$ and $\mathrm{TE_{VRS}}$	Condition of returns to scale
$\mathrm{TE_{CRS}} =\mathrm{TE_{VRS}}$	CRS

Sources: Fare et al (1994)

TABLE 2

Farrel, 1957	• Under condition of constant returns to scale, overall efficiency is obtained. • Total economic efficiency here= price efficiency × technical efficiency
1978 CCR	• Developed by Charnes, Cooper, and Rhodes with the hypothesis of constant returns to scale, tecnical efficiency is obtained • As a result of the same premise as Farrel, constan returns to scale, technical efficiency that results from CCR could also be called as Farrle's overall efficiency
1984 BCC	• Banker et al. added one more variable to change CRS into **VRS** and figured out the efficiency index here, which is called as pure technical efficiency (PTE). Addicntionally, SE (Scale Efficiency)=$\frac{TE_{CCR}}{PTE_{BCC}}$ • TE = PTE × SE (Scale efficicncy) • Since TE is the product of PTE and SE, the inefficient DMU can owe its inefficiency to either PTE or SE, and thus we can obtain the idea of the improvement direction.

Sources: Organized by the authors of this research

3) Sensitivity Analysis

DEA uses unknown production function to estimate efficiency. The production frontier that is derived from DEA are enveloped by the most efficient decision making units. In other words, frontier of DEA represents the optimal production condition of all of the involved decision making units [8]. As a result of the efficiency that is evaluated by DEA is the comparative efficiency, variation of the number of decision making units, inputs, and outputs; or the change of values of each input or output will all influence the comparative efficiency, and thus will affect the shape and position of production frontier. This is the reason why DEA methodology is sensitive to changes of inputs or outputs, hence we can use this character to find out the most influential input or output of the decision making firms and make some adjustments to meet the strategic needs of each organization. Through the sensitivity analysis of DEA, we can attain a clearer picture of each firm's competitive or inferior inputs and outputs.

B. Homogeneity of Decision Making Units

DEA is a research method which evaluates the comparative efficiency among different decision making units (DMUs), this results in the importance of the homogeneity of the DMUs. Suppose the entities of the DMUs are all different, i.e. the DMUs are in different industries, the comparison and the following comparative efficiency evaluation will become meaningless. Therefore, the adoption of DEA method should be based on the premise that all of the DMUs that are going to be evaluated in DEA are with the similar entities, for instance, they are in the same industry or the organization goals and performance indicators they have are similar [9]. According to the above, the DMUs we adopt in this research are the global companies which are all in photovoltaic solar industry.

With the purpose to establish an inspection of global solar photovoltaic industry, we select the world's top ten solar photovoltaic companies that are worth of referring from the United States of America, China and Taiwan. In these ten companies, two are from the United States of America, i.e. First Solar, Sun Power. Five of those are from the one of the countries which rapidly develop solar photovoltaic industry in the recent decade, China, i.e. Ja Solar, Suntech, Yingli Solar, Trina and Canadian Solar Incorporation (CSI). The other three are from Taiwan, a mature area which is developed in solar photovoltaic relevant industries, e.g. semiconductor and panel industries. The three of ten of the top global solar photovoltaic companies in Taiwan are Gintech, Motech and Neo Solar Power Corporation (NSP).

We would like to understand potential improvement room of each different company through Data Envelopment Analysis, and thus we take operating cost, expense of research and development, expense of promotion and administration and total assets as inputs. There will be only one output here in the present research, that is, net sales. Operating cost is defined as cost per unit of a product or service, or the annual cost incurred on a continuous process. Promotional expense is the expense on promotion activities, including website development, advertising and public relations. Administrative expenses are the money spent in operating a business (rent, salaries, telephone charges, etc.). Total asserts is the final amount of all gross investments, cash and equivalents, receivables, and other assets as they are presented on the balance sheet. Net sales stands for the amount a company receives from the sale of its products, after deducting discounts, returns of products by customers, and damaged, missing, or stolen products. All of the data are obtained from each firm's financial statements which are available for the public online.

C. Selection of DEA mode

Start from the point of generating suggestions for the firms in solar photovoltaic industry, we are not the firms themselves and thus we are incapable of changing the output, i.e. revenue. As a result of this, we make this DEA-based research into an input-oriented one, that is, seek to minimize inputs to produce the same outputs.

We mainly adopt CCR mode and its technical efficiency (TE) as the analysis base in the present research. In addition, we take pure technical efficiency which results from BCC mode as references to further discuss scale efficiency and the different conditions of returns to scale of DMUs. Frontier Analyst is adopted in this research.

IV. RESULTS

A. Efficiency Analysis

1 means that the DMU attains the comparative optimum efficiency, whereas the number which is less than 1 means that it still have room to be advanced. Among 40 DMUs, only 17.5% of the DMUs reach the comparative ideal efficiency, 1, the left 82.5% DMUs' fail to reach the comparative ideal efficiency and their comparative efficiency are less than 1.

Two of the 7 comparative efficient DMUs are 2008 Sun Power and 2011 Sun Power. Sun Power has been leading global solar innovation and manufactures the world's highest efficiency solar cells featuring Sun Power Maxeon cell technology. According to Lee, Chen, & Kang, advanced solar cell technologies including new materials introduction (such as nano and microcrystalline silicon thin-film solar cell), advanced devices (such as laser scriber), and new methods (such as extremely thin absorber and multiple excitation generation) will also help increase solar conversion efficiency, reduce production expenses, and extend life-cycle period [12]. With one of the important and leading techniques in solar photovoltaic industry, Sun Power earns comparatively higher efficiency than all the others. Sun Power's cutting-edge techniques of solar cell could be other DMUs' role model.

B. Pure Technical Efficiency and Scale Efficiency

Efficiency that results from CCR mode is technical efficiency. Technical efficiency also stands for the overall efficiency of the decision making unit. The efficiency that comes from BCC model is pure technical efficiency [8] and it expounds the effectiveness of the use of each DMU's inputs' set. 30% of the DMU achieves technical efficiency. In other words, there are 30% of the DMU uses their input combination effectively. However, there are still 70% of the DMU fail.

In accordance with Table 2 mentioned in the previous page, we derive scale efficiency from dividing total efficiency by pure technical efficiency. In other words, $\mathrm{TE} = \mathrm{PTE} \times \mathrm{SE}$.

Therefore, when the DMU comes out to be technical inefficient, we can get the idea about whether the inefficiency is resulted from pure technical efficiency or scale efficiency. The higher the scale efficiency is, the better DMU's scale is and thus it suggests the higher productivity of the DMU.

22.5% of the 40 DMUs attains scale efficient and is under constant returns to scale. The condition of constant returns to scale and scale efficient stand for the fact that 2008 CSI, 2008 Sun Power, 2011 Sun Power, 2008 Gintech, 2009 NSP, 2008 Motech, 2009 Gintech, 2009 Motech, and 2010 Gintech are under the optimum operation scale. In other words, there is 77.5% of the DMUs fail to achieve optimum operation. 52.5% of the DMUs is under decreasing returns to scale, and it means that these DMUs need to reduce their inputs. The other 25% DMUs is under increasing returns to scale. Generally speaking, the DMUs which are under the condition of increasing returns to scale would be suggested to increase their inputs to generate higher income. As to the problem of what inputs to increase or decrease, slack variable analysis of DEA provides some suggestions which are worth of being taken for reference.

C. Slack Variable Analysis

Slack variable analysis of DEA should be the most fascinating trait if it is compared with other analytical methods. It provides detailed improvement information for each DMU's input.

Since the current research is an input-oriented one, i.e. a research which seeks to minimize inputs to produce the same outputs, slack variable analysis of DEA here only provides exact range (specific amount of percentage) to lower different inputs but does not incorporate advice on outputs (revenue) in the discussion. In Table 4, we know what and how much percent of input should each specific DMU should decrease.

We adopt four inputs in this research, the expense of operation, expense of marketing and management, expense of R&D, and total asset. Among four of the inputs, expense of marketing and management needs to be reduced 26.8% on average, and is the expense that is necessary to be cut down the most.

TABLE 3

Ranking of TE	DMU	TE	PTE	SE	RTS
1	2008 CSI	1	1	1	CRS
2	2008 SunPower	1	1	1	CRS
3	2011 SunPower	1	1	1	CRS
4	2008 Gintech	1	1	1	CRS
5	2009 NSP	1	1	1	CRS
6	2008 Motech	1	1	1	CRS
7	2010 Gintech	1	1	1	CRS
8	2008 Trina	0.9907	1	0.9907	DRS
9	2009 SunPower	0.9686	0.9829	0.985	IRS
10	2008 NSP	0.9675	0.9676	0.9998	DRS
11	2011 NSP	0.9631	0.9682	0.995	IRS
12	2009 Gintech	0.9488	0.9488	1	CRS
13	2010 NSP	0.9482	0.9985	0.95	IRS
14	2010 JA solar	0.9416	0.9417	0.999	DRS
15	2010 SunPower	0.939	1	0.939	DRS
16	2010 CSI	0.9323	0.9357	0.996	DRS
17	2010 Motech	0.928	1	0.928	DRS
18	2009 Trina	0.9157	0.9376	0.977	DRS
19	2009 Motech	0.9026	0.9026	1	CRS
20	2010 Trina	0.8965	0.8987	0.998	DRS
21	2008 JAsolar	0.8945	0.8952	0.999	DRS
22	2011 CSI	0.8867	0.8887	0.998	DRS
23	2011 Gintech	0.8699	0.8799	0.989	IRS
24	2009 CSI	0.8588	1	0.859	IRS
25	2008 Yingli	0.8293	0.8616	0.963	IRS
26	2010 Yingli	0.7976	1	0.798	DRS
27	2011 Motech	0.7699	0.7704	0.999	IRS
28	2009 First Solar	0.7534	0.7574	0.995	DRS
29	2011 JAsolar	0.7527	0.7529	0.999	DRS
30	2008 First Solar	0.7375	0.7178	1.027	DRS
31	2011 Trina	0.7321	0.7333	0.998	DRS
32	2008 Suntech	0.7256	0.7278	0.997	DRS
33	2010 First Solar	0.7103	0.7127	0.997	DRS
34	2011 Suntech	0.6795	0.6803	0.999	DRS
35	2009 JAsolar	0.6529	0.6572	0.993	DRS
36	2010 Suntech	0.6465	0.6663	0.97	DRS
37	2009 Suntech	0.6313	0.695	0.908	DRS
38	2011 Yingli	0.601	0.8323	0.722	IRS
39	2011 First Solar	0.5848	0.5795	1.009	IRS
40	2009 Yingli	0.5481	0.7622	0.719	IRS

Sources: Organized by the authors of this research

TABLE 4 SLACK VARIABLES ANALYSIS

	TE	Reduced Operating Cost%	Reduced Promotional and Administative Expense%	Reduced R&D Expense %	Reduced Total Asset%
2008 CSI	1	0	0	0	0
2008 SunPower	1	0	0	0	0
2011 SunPower	1	0	0	0	0
2008 Gintech	1	0	0	0	0
2009 NSP	1	0	0	0	0
2008 Motech	1	0	0	0	0
2010 Gintech	1	0	0	0	0
2008 Trina	0.9907	-0.9	-65.3	-0.9	-21.8
2009 SunPower	0.9686	-3.1	-3.1	-28.1	-18.1
2008 NSP	0.9675	-3.2	-3.2	-3.2	-9.6
2011 NSP	0.9631	-19.8	-3.7	-3.7	-9.1
2009 Gintech	0.9488	-12.2	-5.1	-5.1	-37.6
2010 NSP	0.9482	-5.2	-5.2	-52.9	-12.1
2010 JA solar	0.9416	-5.8	-12.4	-5.8	-5.8
2010 SunPower	0.939	-6.1	-6.2	-6.1	-6.1
2010 CSI	0.9323	-6.8	-60.6	-11.4	-6.8
2010 Motech	0.928	-7.2	-7.2	-63.3	-18.3
2009 Trina	0.9157	-8.4	-61.3	-8.4	-45.6
2009 Motech	0.9026	-9.7	-9.7	-9.7	-30.8
2010 Trina	0.8965	-10.3	-33.5	-10.3	-10.3
2008 JAsolar	0.8945	-10.5	-31.3	-10.5	-29.8
2011 CSI	0.8867	-11.3	-69.6	-64.8	-11.3
2011 Gintech	0.8699	-13	-13	-13	-26.1
2009 CSI	0.8588	-14.1	-71.1	-14.1	-44.2
2008 Yingli	0.8293	-17.1	-35.8	-17.1	-30.6
2010 Yingli	0.7976	-20.2	-34	-20.2	-43
2011 Motech	0.7699	-23	-23	-69.8	-42.5
2009 First Solar	0.7534	-24.7	-24.6	-54.4	-24.7
2011 JAsolar	0.7527	-24.7	-24.7	-24.3	-31.1
2008 First Solar	0.7375	-26.3	-30.4	-31.4	-26.3
2011 Trina	0.7321	-26.8	-57	-55.2	-26.8
2008 Suntech	0.7256	-27.4	-45.1	-27.4	-43.6
2010 First Solar	0.7103	-29	-28.3	-54.1	-29
2011 Suntech	0.6795	-32.1	-62	-32.1	-32.1
2009 JAsolar	0.6529	-34.7	-34.7	-38.1	-65.2
2010 Suntech	0.6465	-35.3	-35.3	-47.1	-42.4
2009 Suntech	0.6313	-36.9	-36.9	-54.8	-55.2
2011 Yingli	0.601	-39.9	-55.3	-39.9	-39.9
2011 First Solar	0.5848	-41.5	-41.5	-71.2	-41.5
2009 Yingli	0.5481	-45.2	-45.2	-59.1	-46.6
	Average reduced Expense	-15.81	-26.8825	-25.1875	-24.0975

Sources: Organized by the authors of this research

D. Sensitivity Analysis

DEA is the method that analyzes comparative efficiency among all of the tested DMUs. As a result of the efficiency that is evaluated by DEA is comparative efficiency, variation of the number of decision making units, inputs, and outputs; or the change of values of each input or output will all influence the comparative efficiency. Therefore, we are going to perceive the change of TE by excluding different inputs. If the TE of certain DMU changes a lot after excluding a certain input, it means that the excluded input is the competitive or less competitive input as to the DMU, and thus we can know which input the DMU should pay more attention to.

The efficient DMUs' TE that are with score 1 doesn't change much after excluding certain inputs. For instance, TE of 2008 CSI, 2008 Gintech, 2009 NSP, 2008 Motech, and 2010 Gintech change nothing at all after excluding the expense of operation. However, TE of 2008 Sun Power drops 44.13%, and TE of 2011 Sun Power drops 42.85% after excluding operation expense. Drop of Sun Power's TE in 2008 and 2011 expounds the fact that operation expense is the competitive input compare with other efficient DMUs. It suggests that expense of operation is the input that is worth of Sun Power's development and investment.

Marketing and management should be NSP's comparative competitive input because NSP's TE decreases 21.43% after excluding the expense of marketing and management. This means that NSP is doing a great job in their marketing and management, so that they attain efficiency when they own this input while becomes inefficient when they can't implement this input.

As to the aspect of R&D, most of the DMUs' TE don't change a bit after excluding this input. However, 2009 CSI and 2009 Trina are the two extinguished DMUs among all of the other DMUs. 2009 CSI's TE shrinks 31.63% after the input, R&D is gone. On the other hand, TE of 2009 Trina also falls 31.11% when there is no R&D input anymore. It means R&D is the input that makes these two DMUs competitive in the industry or their efficiency won't diminish in such a dramatic scale when they don't have it in the comparison. R&D ability result in technique advancement which helps to reduce production expenses for the DMU [12]. Therefore, if Trina and CSI can sustainably develop their competitive ability, research and development, they can defense their TE in the long run.

Obvious changes of DMUs' TE aren't be seen after putting total asset aside except for 2011 CSI and 2011 Trina. It means 2011 CSI and 2011 Trina possess comparatively better asset than other DMUs. As a result of this, they can think of the possibilities to make use of their asset to improve other comparatively inferior inputs, e.g. R&D, marketing and management or operation.

TABLE 5 SENSITIVITY ANALYSIS

Unit name	Delete Operating Cost	Delete Promotional and Administrative Expense	Delete R&D Expense	Delete Total Assets
	Change of TE	Change of TE	Change of TE	Change of TE
2008 CSI	0.00%	0.00%	0.00%	0.00%
2008 SunPower	-44.13%	0.00%	0.00%	0.00%
2011 SunPower	-42.85%	0.00%	0.00%	-8.95%
2008 Gintech	0.00%	0.00%	-2.28%	0.00%
2009 NSP	0.00%	-21.43%	0.00%	0.00%
2008 Motech	0.00%	-4.02%	0.00%	0.00%
2010 Gintech	0.00%	0.00%	0.00%	0.00%
2008 Trina	-26.38%	0.00%	-13.47%	0.00%
2009 SunPower	-52.11%	0.00%	0.00%	0.00%
2008 NSP	-0.72%	-13.41%	-0.96%	0.00%
2011 NSP	0.00%	-18.67%	-3.29%	0.00%
2009 Gintech	0.00%	-12.34%	-4.25%	0.00%
2010 NSP	-11.25%	-4.57%	0.00%	0.00%
2010 JA solar	-8.22%	0.00%	-0.10%	-2.39%
2010 SunPower	-43.39%	0.00%	-0.01%	-5.47%
2010 CSI	-7.85%	0.00%	0.00%	-3.19%
2010 Motech	-17.18%	-7.74%	0.00%	0.00%
2009 Trina	-50.67%	0.00%	-31.11%	0.00%
2009 Motech	-0.62%	-20.04%	-0.13%	0.00%
2010 Trina	-20.35%	0.00%	-0.09%	-12.21%
2008 JAsolar	-28.22%	0.00%	-7.17%	0.00%
2011 CSI	-7.79%	0.00%	0.00%	-26.42%
2011 Gintech	-0.41%	-22.93%	-0.18%	0.00%
2009 CSI	-38.31%	0.00%	-31.63%	0.00%
2008 Yingli	-30.78%	0.00%	-9.38%	0.00%
2010 Yingli	-45.32%	0.00%	-8.74%	0.00%
2011 Motech	-5.86%	-16.24%	0.00%	0.00%
2009 First Solar	-33.34%	0.00%	0.01%	-5.87%
2011 JAsolar	-16.83%	0.17%	0.00%	0.00%
2008 First Solar	-35.31%	0.00%	0.00%	-10.10%
2011 Trina	-21.31%	0.00%	0.00%	-23.84%
2008 Suntech	-35.18%	0.00%	-10.12%	0.00%
2010 First Solar	-32.82%	0.00%	0.00%	-5.31%
2011 Suntech	-20.87%	0.00%	-0.10%	-11.51%
2009 JAsolar	-56.79%	-2.36%	0.00%	0.00%
2010 Suntech	-30.81%	-7.90%	0.00%	0.00%
2009 Suntech	-45.51%	-16.08%	0.00%	0.00%
2011 Yingli	-28.07%	0.00%	-0.43%	-9.25%
2011 First Solar	-33.05%	-0.36%	0.00%	-3.74%
2009 Yingli	-32.62%	-2.35%	0.00%	0.00%

Sources: Organized by the authors of this research

V. CONCLUSION AND SUGGESTIONS

In the era which focalizes on environment protection and energy sustainability more and more, green industries has become further prosperous more than ever. Among all of the green industries, solar photovoltaic has become the most expecting and competitive one because it offers the most widely adaptable applications and converts sunlight directly into electrical energy with the highest efficiencies [14]. Fierce competition further draws out the importance of efficiency analysis in solar photovoltaic industry. In order to establish a convincing analysis for solar photovoltaic firms to improve the needed ability and to invest worthwhile resources in, we take four-years input and output data from the top ten global solar photovoltaic firms as samples to conduct a DEA analysis.

Our results show that expense of marketing and management is the input that is

required to be reduced most. Consequently, we propose that the inefficient solar photovoltaic companies should scale down the budget of expense of marketing and management, and then change the use of budget to the vital part of PV industry, research and development. For the 25% inefficient DMUs which are in the condition of increasing returns to scale, they can invest more resources especially in research and development to pursue better efficiency. As to the other 52.5% inefficient DMUs which are in the condition of decreasing returns to scale, they should try to decrease their inputs but leave the most resources for R&D simultaneously.

For the future researches, we have few suggestions as follows:

1. The data that are being evaluated in research is only quantitative ones. If you would like to establish a more radical efficiency analysis, you may try to incorporate qualitative data which is harder to get but is also relevant and significant to the operation efficiency of the company, e.g. brand equity of the company, organization culture, leadership, HR quality etc.
2. The data of the current research is retrieved from the finance report of each company's finance report. With the purpose to construct a more penetrable operation efficiency analysis, you may try to incorporate some more detailed results that comes from the interviews with the firms, i.e. what are the contradictions between what they actually know what to do but is hard to execute. For instance, firms know that R&D investment is important. However, they don't have enough money to support the huge investment. In addition, the human resources to conduct R&D is not easy to find and cultivate. Try to find the way to balance the ideal expectation and real implementation, and you can obtain an analysis that is more approachable to the fact, and its practicability will also bring more sustainable help to solar photovoltaic firms.

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