
**AN EVALUATION OF ENERGY EFFICIENCY IN CEMENT PLANTS
USING DATA ENVELOPMENT ANALYSIS APPROACH**

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Abstract

The cement industry is one of energy-intensive industries. The industry needs energy (thermal and electricity) including coal and solar. In particular, the increase in consumption of fossil-based energy may increase the amount of pollutants besides its availability is increasingly limited. Energy consumption is one important indicator in sustainable manufacturing of the cement industry. This study aims to evaluate energy efficiency rate and to propose potential energy savings in cement plants. The study was conducted in a cement manufacturer in Indonesia. The main data is secondary data that took from the monthly performance report of PT X. The efficiency rate was measured by the non-parametric Data Envelopment Analysis (DEA) approach. The input-oriented DEA-CCR model used to see how efficient the plants in using energy resources. There are three evaluated plants (A, B, and C) during 12 months in year X. There are four indices of input ; electricity consumption (in KWH / ton cement), heat consumption (in kcal/ kg clinker), coal consumption (in ton/ ton clinker), solar consumption (in liter), and one indice of output ; amount of cement produced (in ton). The solving of DEA models were solved by DEAP version 2.1 that gives all of DMU's efficiency values. The result of the study indicates plant C has the highest efficiency of 86,7%, followed by plant A of 63,1 % and plant B of 61,5%. The overall efficiency of plants is at sub-optimal level of 70,4% on average which needs to be further improved. The study also provides an overview of the potential ways to improve energy efficiency of cement plants by referring to the literatures.

Key words : *efficiency, energy, cement plants, input oriented, DEA-CCR*

1. INTRODUCTION

The cement industry is one of energy-intensive industries (Sattari and Avami, 2007; Garcia-Gusano, et al., 2015; Rahman, et al., 2013). The industry needs energy (thermal and electricity) including coal and solar. The coal is used mainly during the burning process in the kiln process to produce clinker as main ingredient of cement (Galitsky, et al., 2007). Although electricity is using widely during the cement plant, milling is the most electrical consuming section (Sattari and Avami, 2007). Unfortunately, increasing in fossil based energy consumption may increase the amount of by-products (pollutants) that have negative impact on the environment and besides its availability is increasingly limited. Energy efficiency is a potential KPI for cement plant performance (Rahman, et al., 2013). Energy and fuel consumption are important indicators in sustainable manufacturing of the cement industry (Amrina and Vils, 2015).

There have been some prior researchs that related to energy efficiency in the cement industry. Galitsky, et al. (2007) conducted study on efforts to improve efficiency in the cement kiln while reducing the amount of pollutants, and estimated economic parameters. Sattari and Avami (2007) did study on energy consumption of cement industries through real auditing and identifying technological opportunities in order to decreased energy consumption rate. Ansari and Seifi (2013) used a system dynamic model to analyzed energy consumption and CO₂ emission in cement industry. Wang and Han (2012) studied the current strategies of energy efficiency improvement in cement industry.

Efficiency can be defined as the demand that the desired goals are achieved with the minimum use of the available resources (Martic et al., 2009). In the measurement of efficiency is known with two approaches, parametric and non-parametric. Non-parametric DEA method has been widely used in energy efficiency related literatures (Khoshroo et al., 2013). DEA involves the use of linear programming method to construct a non-parametric piece-wise surface (or frontier) over the data. Efficiency measures are then calculated relative to this surface (Coelli et al., 2005).

Farell measured efficiency empirically for the first time in 1957. Then Charnes et al. (1978) developed Data Envelopment Analysis (DEA) by generalizing the concept of single input, single output technical efficiency measure of Farrell's to the multiple inputs and multiple output case. Next, the model was known as the DEA-CCR (refer to Charnes, Cooper, Rhodes). The DEA approach has been used in various types of industries including sugarcane plant (Junior et al., 2014), pulp and paper industry (Anwar & Soetjipto, 2012), thermal power plant (Wang & Tian, 2013), and cement industry (Mandal & Madheswaran, 2009).

In this study we evaluate energy efficiency of three cement plants using the DEA model and provides an overview of the potential ways to improve the energy efficiency of cement plants with reference to some literatures.

2. METHODOLOGY

This study was a descriptive study with case study at a cement manufacturer in Indonesia. The main data was secondary data that obtained from the monthly performance report in year X. Table 1 shows the variables used in the calculation of energy efficiency.

Table 1. Variables that are used as input and output data

Variables	Units	Classification
Electricity consumption	KWH/ ton cement	input
Coal consumption	ton/ ton clinker	input
Heat consumption	kcal/ kg clinker	input
Solar consumption	liters	input
Cement production	tons	output

We use non-parametric DEA as method of analysis where it does not require any assumptions about type of production function. Data Envelopment Analysis (DEA) is a linear programming technique for measuring the relative efficiency of a set of decision making units (DMUs) or units of assessment in the use of multiple inputs to produce multiple outputs (Ramli and Munisamy, 2013). DMU will refer to individuals in the evaluation group (Azadeh et al., 2007). In DEA method, the technical efficiency is calculated relatively by comparing a DMU (plant) to the most efficient plant as its benchmark. The input-oriented DEA model used in this study due to we focus to see how efficient the plants use energy resources.

The plants have been operating in some decades. We considered that the plants have been operating in optimal scale so that we used constant returns to scale (CRS) assumption. CRS states that an increase in inputs will result in a proportional increase in outputs (Azadeh et al., 2007). Furthermore, this DEA model is known as the input oriented DEA-CCR model. We will evaluate three plants of a cement manufacturing company (named A, B, and C) in year X. The Decision Making Unit (DMU) amounted to 36 units (3 plants x 12 months). This is done to see the efficiency level in cross plants and time throughout the DMU's are homogeneous units.

According to Azadeh et al. (2007), CCR model evaluates relative efficiencies of n DMUs ($j=1, \dots, n$), each with m inputs and s outputs denoted by $x_{1j}, x_{2j}, \dots, x_{mj}$ and $y_{1j}, y_{2j}, \dots, y_{sj}$ respectively. This is done so by maximizing the ratio of weighted sum of output to the weighted sum of inputs :

$$\begin{aligned} \text{Max } \theta &= \frac{\sum_{r=1}^s u_r y_{r0}}{\sum_{i=1}^m v_i x_{i0}} \\ \text{s. t } & \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \leq 1, \quad j=1, \dots, n, \quad r=1, \dots, s \\ & u_r, v_j \geq 0, \quad i=1, \dots, m, \quad r=1, \dots, s \end{aligned} \quad (1)$$

In model (1), efficiency of DMU_0 is θ and u_r and v_i are factor weights. For computational convenience, fractional programming model (1) re-expressed in linear programming (LP) form as

$$\begin{aligned} \text{Max } \theta &= \sum_{r=1}^s u_r y_{r0} \\ \text{s. t } & \sum_{r=1}^s u_r y_{rj} - \sum_{i=1}^m v_i x_{ij} \leq 0, \quad j=1, \dots, n, \end{aligned}$$

$$\sum_{i=1}^m v_i x_{i0} = 1 \quad (2)$$

$$u_r, v_i \geq \varepsilon, \quad i = 1, \dots, m, \quad r = 1, \dots, s$$

Where ε is non-Archimedean infinitesimal introduced to ensure that all the factor weights will have positive values in the solution. The model (3) evaluates the relative efficiencies of n DMUs ($j=1, \dots, n$), respectively, by minimizing inputs when outputs are constant. The Dual of LP model for input oriented CCR is as follows :

$$\begin{aligned} & \text{Min } \theta \\ & \text{s. t } \theta x_{i0} \geq \sum_{j=1}^n \lambda_j x_{ij}, \quad i = 1, \dots, m, \\ & \quad y_{r0} \leq \sum_{j=1}^n \lambda_j y_{rj}, \quad r = 1, \dots, s, \\ & \quad g \lambda_j \geq 0 \end{aligned} \quad (3)$$

The solving of LP equations that have many constraints by Lingo software would be time consuming and exhausting due to the efficiency value of each DMU have to be counted one by one. Therefore, we used the Data Envelopment Analysis Program (DEAP) version 2.1 that developed by Coelli et al. (2005) to find out the solutions where computation for all DMU's efficiency values can be done simultaneously. However we give a sample program for input oriented DEA-CCR model of DMU in Lingo version 10 on Appendix 1. It refers to the example given by Agarwal et al. (2014).

3. RESULTS AND DISCUSSION

The following Table 2 describes the descriptive statistics of data include mean, standard deviation, maximum, and minimum.

Table 2. The descriptive statistic of actual output and inputs in year .

Statistic	Cement (tons)	Electricity (KWH/ton cement)	Heat (kcal/ kg clinker)	Coal (ton/ ton clinker)	Solar (liters)
Mean	183.213	101	878	0,206	51.466
S.D	46.186	11	57	0,009	46.311
Max	278.151	122	958	0,231	229.150
Min.	127.331	83	798	0,180	6.050

Source : Company X, own calculatons (2016)

The following Table 3 presents the energy efficiency rate of all DMU's (Plant A, B and C during 12 months in year X).

Table 3. The monthly energy efficiency rate of the cement plants

Plant	Month												Average
	1	2	3	4	5	6	7	8	9	10	11	12	
A	0,424	0,775	0,725	0,391	0,479	0,816	0,495	0,524	0,836	0,890	0,472	0,740	0,631
B	0,567	0,463	0,715	0,774	0,600	0,470	0,548	0,552	1,000	0,621	0,558	0,515	0,615
C	0,646	0,872	1,000	0,856	1,000	0,895	0,705	0,861	0,888	0,923	0,861	0,899	0,867

Source : DEAP output (2016)

The plant C achieves the highest efficiency of 86,7% on average, followed by plant A of 63,1% and plant B of 61,5%. The overall efficiency of plants is at sub-optimal level of 70,4% on average which needs to be further improved. The efficiency level trend can be seen in Figure 1 below.

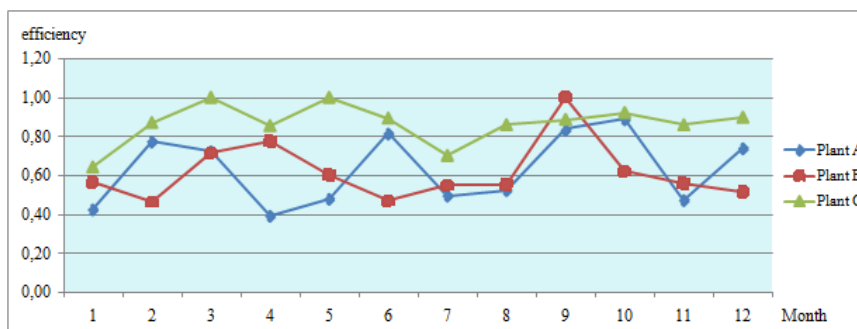


Figure 1. Energy efficiency trend in year X.

The energy efficiency rate of all plants shows a fluctuating trend during 12 months in year X. The efficiency level of Plant C is above the two other plants. Plant A has the highest efficiency point in October (DMU A-10) of 89% and the lowest in April of 39.1% (DMU A-4). Plant B has the highest efficiency point in September (DMU B-9) of 100% and the lowest in February of 39.1% (DMU B-2). Plant C has the highest efficiency point in March and April (DMU C-3 and DMU C-4) of 100% and the lowest in January of 64.6% (DMU C-1). The output of DEAP also displays the slack input values as can be seen in the following Table 4.

Table 4. The slack input values

Plant/ month	Electric	Heat	Coal	Solar	Plant/ month	Electric	Heat	Coal	Solar	Plant/ month	Electric	Heat	Coal	Solar
A-1	8,7	0,0	0	1856	B-1	9,2	0	0	4398	C-1	4,9	0	0,001	132450
A-2	12,0	31,2	0	0	B-2	3,7	0	0	14322	C-2	3,1	0	0,003	34937
A-3	11,3	1,7	0	0	B-3	1,4	8,8	0	0	C-3	0,0	0	0	0
A-4	5,6	0	0	11903	B-4	0,2	0	0	0	C-4	0,8	0	0,002	40417
A-5	9,7	15,5	0	0	B-5	3,5	0	0	18117	C-5	0,0	0	0	0
A-6	6,9	10,1	0	0	B-6	4,0	0	0	28324	C-6	2,7	0	0,005	3276
A-7	6,9	9,9	0	0	B-7	6,0	0	0,002	816	C-7	8,9	0	0,007	96555
A-8	7,6	25,2	0	0	B-8	9,7	23,5	0	0	C-8	8,9	0	0	74374
A-9	4,8	0	0,003	0	B-9	0	0	0	0	C-9	2,3	0	0,002	49599
A-10	10,1	13,0	0	0	B-10	1,5	8,6	0	0	C-10	7,0	0	0,004	38905
A-11	10,1	1,7	0	14078	B-11	2,2	0	0	4512	C-11	6,4	0	0,003	28240
A-12	14,5	6,6	0	0	B-12	13,4	14,3	0	0	C-12	12,2	0	0,004	30659

Source : DEAP output (2016)

Based on Table 4 above, the efficient DMU’s have no slack value (zero), only inefficient DMU’s which have slack value. This slack value can be used to set targets or projections of the input level that can be lowered to achieve the maximum efficiency. Then, the following Table 5 presents peer(s) of each DMU in calculating efficiency.

Table 5. Peer(s) of each DMU

Plant/ month	Peer (s)	Plant/ month	Peer (s)	Plant/ month	Peer (s)			
A-1	C-3	B-1	C-5	C-3	C-1	B-9	C-3	
A-2	C-5	C-3	B-2	C-3	C-5	C-2	B-9	
A-3	C-3		B-3	C-5		C-3	C-3	
A-4	C-3	B-9	B-4	B-9	C-3	C-4	C-3	B-9
A-5	C-5	C-3	B-5	C-3	C-5	C-5	C-5	C-3
A-6	C-3		B-6	C-3		C-6	C-3	
A-7	B-9	C-3	B-7	C-5	C-3	C-7	C-5	
A-8	B-9	C-3	B-8	C-3		C-8	C-5	C-3
A-9	C-3		B-9	C-3		C-9	C-3	
A-10	C-3	C-5	B-10	C-3	B-9	C-10	B-9	C-3
A-11	C-3	B-9	B-11	C-5	C-3	C-11	C-5	C-3
A-12	C-3		B-12	C-3	15	C-12	C-3	

Source : DEAP output (2016)

Based on Table 5 above, the efficient DMU (C-3, B-9, and C-5) become peer (benchmark) for other inefficient DMU's.

The efforts to improve energy efficiency in cement plants can refer to the literatures. Wang and Han (2012) proposed to increase energy efficiency through technology updates and waste heat recovery. Rahman et al. (2013) discussed the usage of alternative fuels that cover all non-fossil fuels and waste from other industries including tire-derived fuels, biomass residues, sewage sludge and different commercial wastes. Galitsky et al. (2007) explained improvements on cement kiln by implementation ; improved refractories, energy management and process control systems, and adjustable speed drives for the kiln fan. Next, Sattari and Avami (2007) described electrical saving potential and thermal saving potential in cement plant. In fact, the cement manufacturer had been tried to found the ways to reduced energy consumption. As example through blending of coal where this option is technically and environmentally feasible, but this option resulted in long return on invesment. The other option is through the refractory lining where this option can not be done because it resulted in the cessation of production run.

4. CONCLUSION

This study presented DEA approach for evaluating of energy use in cement plants. The overall efficiency of plants is at sub-optimal level of 70,4% on average which needs to be further improved. We also provides an short overview of the potential ways to improve the energy efficiency of cement plants by referring to some literatures. This study has limitations which does not consider undesirable output (by-product) due to data unavailability. The obtained efficiency values can be over-estimated if the number of by-product outputs were significant. The further research is needed to apply the DEA model by considering unsiderable outputs include emissions of CO₂, NO_x, and SO₂ which have negative impact on the environment.

5. ACKNOWLEDGEMENT

The authors would like to thank the company for accessing to the data provided, to our institution for funding the publication of this article, and to anonymous reviewer for his/her constructive suggestions.

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APPENDIX 1. A Sample Program for Input Oriented DEA-CCR Model of DMU A-1 in Lingo 10

Min = theta;

$$118.4*w1 + 113.5*w2 + 116.9*w3 + 116.1*w4 + 113.2*w5 + 104.8*w6 + 108.7*w7 + 105.6*w8 + 105.5*w9 + 112.4*w10 + 122.3*w11 + 119.5*w12 + 109*w13 + 102.3*w14 + 92.7*w15 + 94.0*w16 + 97.7*w17 + 102.3*w18 + 100.5*w19 + 103.2*w20 + 98.9*w21 + 90.2*w22 + 98*w23 + 117.3*w24 + 89.6*w25 + 86.5*w26 + 83.4*w27 + 84.5*w28 + 85.1*w29 + 86.2*w30 + 95*w31 + 94.5*w32 + 87.7*w33 + 90.8*w34 + 91.2*w35 + 97*w36 <= 118.4*theta ;$$

$$952*w1 + 958*w2 + 952*w3 + 955*w4 + 929*w5 + 916*w6 + 929*w7 + 924*w8 + 935*w9 + 951*w10 + 948*w11 + 950*w12 + 885*w13 + 891*w14 + 872*w15 + 881*w16 + 881*w17 + 887*w18 + 875*w19 + 869*w20 + 916*w21 + 857*w22 + 891*w23 + 907*w24 + 798*w25 + 802*w26 + 807*w27 + 808*w28 + 798*w29 + 807*w30 + 801*w31 + 822*w32 + 830*w33 + 811*w34 + 813*w35 + 811*w36 <= 952*theta ;$$

$$0.231*w1 + 0.211*w2 + 0.220*w3 + 0.216*w4 + 0.214*w5 + 0.209*w6 + 0.213*w7 + 0.208*w8 + 0.219*w9 + 0.215*w10 + 0.213*w11 + 0.218*w12 + 0.206*w13 + 0.205*w14 + 0.201*w15 + 0.205*w16 + 0.206*w17 + 0.204*w18 + 0.215*w19 + 0.198*w20 + 0.209*w21 + 0.200*w22 + 0.205*w23 + 0.210*w24 + 0.195*w25 + 0.197*w26 + 0.195*w27 + 0.198*w28 + 0.180*w29 + 0.201*w30 + 0.203*w31 + 0.198*w32 + 0.203*w33 + 0.200*w34 + 0.200*w35 + 0.200*w36 <= 0.231*theta ;$$

$$33213*w1 + 8872*w2 + 12114*w3 + 84015*w4 + 31550*w5 + 10923*w6 + 38619*w7 + 20130*w8 + 9819*w9 + 8560*w10 + 83741*w11 + 11968*w12 + 47672*w13 + 75114*w14 + 14205*w15 + 12347*w16 + 68391*w17 + 104343*w18 + 27989*w19 + 27847*w20 + 6050*w21 + 31787*w22 + 52268*w23 + 30694*w24 + 229150*w25 + 64373*w26 + 24440*w27 + 71709*w28 + 45586*w29 + 28100*w30 + 161154*w31 + 112299*w32 + 80960*w33 + 66705*w34 + 57416*w35 + 58666*w36 <= 33213*theta ;$$

$$139004*w_1 + 138880*w_2 + 149833*w_3 + 127331*w_4 + 147617*w_5 + 156880*w_6 + 154367*w_7 + 133794*w_8 + 157450*w_9 + 159661*w_{10} + 152054*w_{11} + 151345*w_{12} + 171742*w_{13} + 141047*w_{14} + 150490*w_{15} + 154569*w_{16} + 181060*w_{17} + 142612*w_{18} + 165226*w_{19} + 157095*w_{20} + 158582*w_{21} + 179873*w_{22} + 169972*w_{23} + 155793*w_{24} + 177723*w_{25} + 240933*w_{26} + 278151*w_{27} + 238277*w_{28} + 271975*w_{29} + 248930*w_{30} + 194726*w_{31} + 243864*w_{32} + 254179*w_{33} + 258047*w_{34} + 241301*w_{35} + 251289*w_{36} \geq 139004 ;$$
$$w_1 \geq 0; w_2 \geq 0; w_3 \geq 0; w_4 \geq 0; w_5 \geq 0; w_6 \geq 0; w_7 \geq 0; w_8 \geq 0; w_9 \geq 0; w_{10} \geq 0; w_{11} \geq 0; w_{12} \geq 0; w_{13} \geq 0; w_{14} \geq 0; w_{15} \geq 0; w_{16} \geq 0; w_{17} \geq 0; w_{18} \geq 0; w_{19} \geq 0; w_{20} \geq 0; w_{21} \geq 0; w_{22} \geq 0; w_{23} \geq 0; w_{24} \geq 0; w_{25} \geq 0; w_{26} \geq 0; w_{27} \geq 0; w_{28} \geq 0; w_{29} \geq 0; w_{30} \geq 0; w_{31} \geq 0; w_{32} \geq 0; w_{33} \geq 0; w_{34} \geq 0; w_{35} \geq 0; w_{36} \geq 0;$$

END