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EFFICIENCY ASSESSMENT OF MALAYSIAN COAL-FIRED POWER PLANT: A CIRCULAR ECONOMY PERSPECTIVE

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Abstract

Coal-fired power generation is expected to grow over the next 10 years and become the most important source of electricity in Malaysia. As the coal usage for electricity generation continues, there is a critical need to assess the circular economy development and the reduction of emissions. So far, in Malaysia, such study for coal fired plant has not been further investigated. In this paper, a survey on a coal fired plant in Peninsular Malaysia is conducted to focus on evaluating the relative plant efficiency using a circular economy concept. Using the survey field data, a DEA or Data Envelopment Analysis method is employed to evaluate the coal plant performance. The simulation result infer that the DEA model can be used to help government to reveal the relative efficiency and inefficiency unit of the coal fired plant which needs to be improved. Also, the result recognized several unit of plants as the benchmark of circular economy for enhancing the performance of the electricity generation in Malaysia.

Keywords: Efficiency, coal-fired power plant, circular economy, data envelopment analysis.

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1. Introduction

Electricity is the foundation that spurs the socio-economic growth in the country. In 2015, Malaysia's total installed capacity was 30,439 MW, an increase of 0.6% from 29,974 MW in 2014. About 75% of the installed electricity capacity is located in Peninsular Malaysia, 16% in Sarawak and remaining 8% in Sabah (Suruhanjaya Tenaga, 2016). Currently, coal is the biggest energy source for electricity generation in Malaysia. As the economy continues to progress, the demand for energy is inevitably on the rise and the use of coal for power generation is projected to grow as well from 53% in 2015 to 56% by 2026 (Suruhanjaya Tenaga, 2017). Within the last ten years, Malaysia's emissions has increased almost 12.3% from 281.15 Million tonnes in the year 2005 to 315.69 Million tonnes in the year 2014, of which,; about 40% is from the power generation, that is mainly from coal-fired plants (Bekhet & Mat Sahid, 2016). The coal combustion emit significant CO_2 emissions and pollutants into the atmosphere such as sulfur dioxide (SOx), nitrogen oxides (NOx), etc (Zhao et al., 2017).

As the CO_2 emissions growth has becoming important global issue, many countries, including Malaysia, have undertaken active roles in the effort for energy conservation and emissions reduction. As part of global environmental commitment, in 2015 during the 21th Conference of Parties (COP21), Malaysian government is pledged to reduce its CO_2 emissions intensity by 45% by 2030 as compared to the 2005 emissions intensity level. This reduction consists of 35% on an unconditional basis and a further 10% conditional upon receipt of technology transfer, finance and capacity building from developed countries (Begum et al., 2015). Consequently, as the environmental issues of coal-fired plants has been increasingly important, it has become a top priority for mitigation and appropriate policies need to be implemented as to achieve the CO_2 emissions reduction target (Baris et al., 2016; Mokthar et al., 2014). For instance, the Malaysian government has initiated a push for renewable energy (RE) as a cleaner alternative solution for emissions reduction in the power generation (Mustapa et al., 2010). In terms of coal-fired technology, the ultra-supercritical technology has been introduced in the country for new coal plant that aims to promote higher efficiency of coal plant for less requirement of coal per electricity generation. Efficiency improvement of coal-based power plants through this technology would enhance the performance of power industries. It would increase consumer benefits through cost reduction, while enhancing energy security and assist to reduce CO_2 emissions through more efficient of coal use (Malek et al., 2013).

The circular economy assessment has been widely used as an effective means to improve the energy efficiency and the resource utilisation rate, especially in the waste system (Michelini et al. 2017; Sanzes et al., 2017; EPU, 2016). The circular economy aims to reduce resources input and emissions output. It presents a new pattern of economic operations which build upon a concept of reduce, reuse and recycle (3Rs) which offers enormous opportunity to improve the energy efficiency and resource utilization as well as reducing CO_2 emissions (Heshmati, 2016). Using the circular economy concept, this paper attempts to assess the coal plant efficiency in Malaysia. To date, such study has not been further investigated in Malaysia. It has however, been studied in other countries (Liu et al., 2017; Zeng et al., 2009; Zeng & Zhang, 2011; Sozen et al., 2010). Hence, we wish to fill the gaps in this study.

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2. Problem Statement

Coal-fired power generation is expected to grow over the next 10 years and become the most important source of electricity in Malaysia. This is a challenge for Malaysia due to the fact that the increment of coal-based plant installation in the country would cause the CO_2 emissions level to increase as well. Improving the coal plants efficiency would improve the power industries performance and the CO_2 emissions will also reduce through efficient coal utilisation. Besides, the government is completing the amendments in emissions standards for heat and power generation sectors under an Environmental Quality Regulation (Mokhtar et al, 2014), which implies power sector to invest for emission control improvement as compliance to the regulations will be mandatory by June 2019. Therefore, there is a critical need to assess the efficiency improvement of the coal-fired plant. Builds on the recent regulation commitment and country's target for CO_2 emissions reduction by 2030, this paper attempt to shed light on to operational performance and relative efficiency of coal-based power plant through measuring, improving and benchmarking procedure.

3. Research Questions

The main research questions are as below:

- What is the relative efficiency of coal plant using the circular economy concept?
- What is the benchmark to improve the efficiency of coal plant?

4. Purpose of the Study

The purposes of the study are as below:

- To assess the coal plant relative efficiency using circular economy concept.
- To rank and improve the efficiency of coal plant based on DEA model.

5. Research Methods

5.1. DEA Method

DEA is a non-parametric method of linear programming which is commonly employed to empirically evaluate the efficiency and relative performance of decision making units (DMUs). The DMUs is homogenous in the sense it uses the same inputs to produce the same outputs (Amin & Toloo, 2007).There are mainly two DEA models which can be divided into CCR model or BCC model (Zeng et al., 2009). In this study, the BCC model is used for measuring the technical efficiency of DMUs, which implies that increases in inputs would leads to changes in outputs in a variable rate, corresponding to the reducing principle of circular economy (Sağlam, 2017). To obtain the best BCC-efficient DMU:

$$\min[\theta - \varepsilon(\hat{e}^T s^- + e^T s^+)] = V_D$$

$$s.t. \sum_{j=1}^{n} \lambda_j x_j + s^- = \theta . x_{j0}$$

$$\sum_{j=1}^{n} \lambda_j y_j - s^+ = y_{j0}$$

$\lambda_j \geq 0, j = 1,2, \dots, n; s^+ \geq 0,\ s^- \geq 0$ Eq. (1)

Suppose the optimal solution of the linear programming (1) is θ*, λ*, s^{-}*, s^{+}*, then:

(a) if θ*=1 and s^{-}*=s^{+}*=0, then MU is DEA effective;

(b) if θ*=1, but s^{-}* or s^{+}* ≠ 0, then DMU is weakly DEA effective;

(c) if θ*<1, then DMU is DEA ineffective.

5.2. SBM Model

The BCC model is able to discover the effectiveness of DMUs (Zeng et al., 2009). However, it is not able to rank the DMUs efficiencies. This study deal with 48 DMUs with the input and output matrices X=(x_ij)∈R^mxn and Y=(y_ij)∈R^sxn, respectively. The dataset is assumed positive, X>0 and Y>0. The production possibility set P is defined as:

$$P = \{(x, y) | x \geq X\lambda, y \leq Y\lambda, \lambda \geq 0\} \qquad Eq. (2)$$

Where λ is a non-negative vector in $\mathbb{R}^n$. Considering an expression for describing a certain DMU (x_o, y_o) as:

$$x_o = X\lambda + s^- \qquad Eq. (3)$$

$$y_o = Y\lambda - s^+ \qquad Eq. (4)$$

With $\lambda \geq 0, s^- \geq 0$ and $s^+ \geq 0$. The vectors $s^- \in \mathbb{R}^m$ and $s^+ \in \mathbb{R}^s$ indicate the input excess and output shortfall of this expression, respectively called slacks. Using s^- and s^+, index ρ can define as follow:

$$\rho = \frac{1 - (\frac{1}{m}) \sum_{i=1}^{m} s_i^- / x_{io}}{1 + \left(\frac{1}{s}\right) \sum_{r=1}^{s} s_r^+ / y_{ro}} \qquad Eq. (5)$$

To evaluate the efficiency of (x_o, y_o), the fractional program can be formulate in λ, s^- and s^+. SBM minimize Eq. (5) subjected to Eq. (3) and (4). A DMU (x_o, y_o) is SMB-efficient if ρ* = 1 (Tone, 2011). The first assessment stands to measure their relative efficiency with BCC model. Should DMUs are DEA ineffective, the rank order can be obtained with their relative efficiency. If, on the other hand, DMUs are DEA effective, the SBM will be utilised to evaluate their efficiency. The rest of DMUs can then be ranked in accordance to the SBM efficiency value. Consequently, the ineffective unit of the DMUs can be improved with the SBM evaluation result.

6. Findings

6.1. Input-output indicators

The foundation of circular economy evaluation in the coal plant reflects the “3R” standard which are reduce, reuse and recycle (Zeng & Zhang, 2011). The circular economy effectiveness, along with the emission reduction can be evaluated through the consumption intensity, resource productivity, material flow intensity, water discharge rate, and etc. In the efficiency assessment, more output is desired as opposed to emissions (Zeng et al., 2009). The emissions, it is the unavoidable output resulted from the burning of fossil fuels (production factors). From a circular economy viewpoint, emissions, should be minimised under the evaluation. Hence, to run-through the DEA model, the emissions shall be considered as an input DMU’s, rather than output, in the analysis (Zeng et al., 2009).

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In China for instance, 12 indicators were used in evaluating circular economy efficiency for coal-fired plant which include among others the water consumption, wastewater emissions, utilization of recycle water, etc. (Zeng & Zhang, 2011). However, due to data limitation in this study, only 6 indicators across the inputs, production, consumption and final discharge of emissions have been investigated. The input and output indicators used are as follows and the descriptive statistics of the data is shown in Table 01:

Input indicators:

x1: Coal consumption per output unit
x2: Energy consumption per output unit
x3: Sulphur dioxide emissions per output unit
x4: CO_2 emissions per output unit

Output indicators:

y1: Ratio of Resource Output
y2: Total output value per power generation unit

Table 01. Descriptive statistics of 43 datasets in year - 2016

	Coal consumption	**Energy consumption**	**Sulphur dioxide**	**Carbon dioxide**	**Resource output**	**Total output value**
Max	270.70	381.56	30.63	0.025	40.10	624.48
Min	40.90	0.164	0.031	0.001	30.70	80.19
Average	211.13	41.86	0.908	0.014	35.77	458.41
SD	46.91	51.06	4.336	0.004	2.281	110.17

6.2. Data isotonicity test of input-output indicators

There are 4 coal power plants operated in Peninsular Malaysia. However, due to data limitation, the study only able to collect data from supercritical coal plant (4 units × 700 MW) located in Peninsular Malaysia. A 12 month data for the year 2016 of the 4 units plant are used in the study which consist of 48 DMUs in the model. In the study, a total of 4 input and 2 output are used as indicators for circular economy measurement. The DEA model entails that the DMUs shall be homogenous with comparability and meet the isotonicity, which implies that the output must not decrease as the input increases (Ruiz & Sirvent, 2016). This can be confirmed using correlation analysis of the 48 DMUs indicators as shown in Table 02. The result revealed that the input and output indicators are all positively correlated. This indicates that the input and output of the coal plant meet the isotonicity requirement and it reflects the relationship required for implementing the circular economy.

Table 02. Correlation coefficients of input-output indicators

	x_1	x_2	x_3	x_4
y_1	0.162	0.026	0.179	0.416
y_2	0.929	0.137	0.003	0.229

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6.3. Assessment Result

The survey data of the 48 unit of the plant are listed in Table 03, with which the efficiencies of the 48 DMUs are calculated by BCC model using DEA software.

Table 03. Input Output Data of the Coal-fired Power Plant

NO	DMU	Input indicators				Output indicators	
		x_1	x_2	x_3	x_4	y_1	y_2
1	P11	209.70	33.15	0.031	0.001	34.20	418.89
2	P12	235.50	36.42	0.290	0.001	33.50	465.06
3	P13	258.40	39.16	0.280	0.013	30.70	479.50
4	P14	229.90	38.68	0.233	0.014	35.00	440.77
5	P15	218.30	35.59	0.343	0.014	34.60	472.13
6	P16	231.20	39.00	0.438	0.015	32.70	472.13
7	P17	119.60	20.45	0.543	0.014	31.80	244.48
8	P18	235.00	38.36	0.236	0.014	36.10	495.52
9	P19	232.50	381.56	0.323	0.014	35.60	481.07
10	P110	238.30	39.20	0.222	0.014	35.70	494.98
11	P111	214.20	31.39	0.263	0.014	32.50	407.29
12	P112	255.30	39.64	0.267	0.014	33.60	500.17
13	P21	154.00	27.26	0.281	0.015	37.50	347.01
14	P22	227.50	34.64	0.336	0.015	34.50	467.18
15	P23	244.20	39.32	0.357	0.015	34.40	497.59
16	P24	234.00	37.67	0.353	0.014	34.60	479.21
17	P25	40.90	6.693	0.171	0.015	32.00	80.19
18	P26	212.40	37.81	0.201	0.013	37.60	486.19
19	P27	206.60	35.89	0.383	0.013	34.70	440.86
20	P28	192.10	30.80	0.249	0.013	34.60	396.74
21	P29	222.70	36.66	0.270	0.014	36.50	482.19
22	P210	229.20	37.57	0.213	0.014	36.40	494.70
23	P211	237.20	38.38	0.204	0.014	33.00	466.55
24	P212	222.20	36.53	0.265	0.014	34.30	453.15
25	P31	212.40	48.89	0.344	0.014	37.10	469.35
26	P32	217.80	37.49	0.245	0.015	34.80	450.72
27	P33	230.60	37.25	0.213	0.015	36.20	491.21
28	P34	196.50	32.41	0.199	0.015	36.10	418.61
29	P35	179.40	30.74	0.221	0.014	34.40	364.15
30	P36	196.30	36.51	30.63	0.013	38.60	458.55
31	P37	125.40	24.81	0.326	0.013	39.40	293.96
32	P38	226.40	41.13	0.204	0.014	36.90	498.56
33	P39	209.70	39.86	0.238	0.013	38.30	479.61
34	P310	239.20	40.95	0.220	0.014	34.40	491.23
35	P311	229.20	39.71	0.202	0.014	34.30	469.52
36	P312	132.10	22.35	0.228	0.014	34.60	274.96
37	P41	228.10	26.58	0.413	0.014	38.20	545.70
38	P42	49.90	8.867	0.420	0.014	34.40	105.79
39	P43	251.50	30.72	0.328	0.014	39.10	621.25
40	P44	226.10	75.16	0.315	0.016	40.00	570.18
41	P45	206.80	27.91	0.326	0.025	38.30	517.12
42	P46	235.90	29.17	0.217	0.025	40.10	590.56

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NO	DMU	Input indicators				Output indicators	
		x_1	x_2	x_3	x_4	y_1	y_2
43	P47	233.00	34.38	0.244	0.023	40.10	608.48
44	P48	250.70	33.30	0.245	0.015	38.60	608.01
45	P49	219.86	0.164	0.296	0.017	37.98	531.65
46	P410	201.90	76.14	0.317	0.014	36.90	469.40
47	P411	263.80	30.15	0.337	0.016	35.40	587.12
48	P412	270.70	32.83	0.097	0.014	36.70	624.48

The results in Table 04 depicts that the circular economy efficiencies of 11 units plant are equivalent to 1, which implies DEA-effective while another 37 units plant are relatively inefficient such as P13 – P24, P26 – P36, P38-P41, P45, P48, P410 and P411, and > θ*P48 > θ*P39 > θ*P26 > θ*P21, > θ*P41 > θ*P312 > θ*P38 > θ*P45 > θ*P411 > θ*P210 > θ*P34 > θ*33 > θ*P29 > θ*P410 > θ*P18 > θ*P31 > θ*P17 > θ*P110 > θ*P36 > θ*P35 > θ*P28 > θ*P15 > θ*P27 > θ*P310 > θ*P112 > θ*P23 > θ*P22 > θ*P311 > θ*P24 > θ*P211 > θ*P32 > θ*P212 > θ*P14 > θ*P13 > θ*P111 > θ*P16 > θ*P19.

Next, the effective DMUs are further assessed by Slack-based model (SBM), to acquire efficiency for the rest of the plants. The data is evaluated and the results are listed in Table 04. The result reveals that all the SBM efficiency of the rest 11 units plant are equal to 1, and θ'*P11 > θ'*P12 > θ'*P25 > θ'*P37 > θ'*P42 > θ'*P43 > θ'*P44 > θ'*P46 > θ'*P47 > θ'*P49 > θ'*P412. Hence, the rank order of the 48 units plants for circular economy efficiency are P11 > P12 > P25 > P37 > P42 > P43 > P44 > P46 > P47 > P49 > P412 > P48 > P39 > P26 > P21 > P41 > P312 > P38 > P45 > P411 > P210 > P34 > P33 > P29 > P410 > P18 > P31 > P17 > P110, > P36 > P35 > P28 > P15 > P27 > P310 > P112 > P23 > P22 > P311 > P24 > P211 > P32 > P212 > P14 > P13 > P111 > P16 > P19. It is evident from the result that P11 can be regarded as the benchmark of common best practices in the plant management plan and served as baseline for performance and technical efficiency improvement of other unit of the coal plant.

Table 04. Evaluation Results of 48 units of coal-fired plant by BCC model and SBM model

No	DMU	Input indicators				Output indicators		θ*	θ'*	Rank
		s_1	s_2	s_3	s_4	s_5	s_6			
1	P11	0	0	0	0	0	0	1	1	1
2	P12	0	0	0	0	0	0	1	1	1
3	P13	30.72	6.099	0.229	0.009	4.237	0	0.796	0.561	45
4	P14	18.74	12.24	0.146	0.010	0	0	0.826	0.565	44
5	P15	0	12.66	0.224	0.007	0.992	0	0.899	0.621	33
6	P16	5.702	5.934	0.390	0.011	2.148	0	0.850	0.551	47
7	P17	9.568	12.49	0.353	0	2.111	0	0.907	0.665	28
8	P18	11.92	18.51	0.088	0.004	0	0	0.893	0.694	26
9	P19	9.162	349.06	0.211	0.010	0	0	0.866	0.429	48
10	P110	11.58	13.99	0.111	0.006	0	0	0.880	0.659	29
11	P111	11.23	0	0.221	0.012	1.687	0	0.820	0.553	46
12	P112	21.48	6.613	0.210	0.008	1.589	0	0.830	0.594	36
13	P21	0	6.236	0.035	0.004	0	0	0.946	0.851	15
14	P22	3.471	1.562	0.289	0.011	0.288	0	0.855	0.581	38
15	P23	11.15	6.289	0.300	0.010	0.757	0	0.843	0.581	37
16	P24	6.401	4.606	0.303	0.009	0.334	0	0.860	0.579	40

No	DMU	Input indicators				Output indicators		θ*	θ'*	Rank
		s_1	s_2	s_3	s_4	s_5	s_6			
17	P25	0	0	0	0	0	0	1	1	1
18	P26	1.736	13.38	0	0	0	0	0.973	0.910	14
19	P27	0	13.77	0.266	0.007	0.573	0	0.904	0.599	34
20	P28	0	4.821	0.162	0.009	0	0	0.886	0.631	32
21	P29	8.673	22.87	0.078	0.003	0	0	0.909	0.706	24
22	P210	9.355	21.92	0.037	0.003	0	0	0.915	0.744	21
23	P211	13.36	5.301	0.157	0.010	1.780	0	0.847	0.574	41
24	P212	2.334	3.433	0.222	0.011	0.317	0	0.867	0.565	43
25	P31	7.548	36.27	0.118	0.002	0	0	0.916	0.684	27
26	P32	0.708	7.282	0.183	0.011	0	0	0.874	0.572	42
27	P33	10.27	19.46	0.052	0.005	0	0	0.897	0.708	23
28	P34	1.675	8.306	0.048	0.008	0	0	0.908	0.739	22
29	P35	0	2.935	0.139	0.010	0	0	0.881	0.641	31
30	P36	4.017	14.14	30.33	0	0	0	0.971	0.651	30
31	P37	0	0	0	0	0	0	1	1	1
32	P38	4.292	9.787	0.088	0.002	0	0	0.933	0.795	18
33	P39	5.780	12.26	0	0	0	0	0.963	0.916	13
34	P310	8.036	7.904	0.166	0.009	0.680	0	0.871	0.597	35
35	P311	4.476	6.637	0.155	0.010	0.516	0	0.877	0.581	39
36	P312	10.19	13.74	0.023	0	0	0	0.916	0.802	17
37	P41	1.567	10.85	0.123	0	0	0	0.974	0.822	16
38	P42	0	0	0	0	0	0	1	1	1
39	P43	0	0	0	0	0	0	1	1	1
40	P44	0	0	0	0	0	0	1	1	1
41	P45	0	12.43	0.064	0.005	0	0	0.972	0.786	19
42	P46	0	0	0	0	0	0	1	1	1
43	P47	0	0	0	0	0	0	1	1	1
44	P48	0	0.007	0	0	0	0	1	0.999	12
45	P49	0	0	0	0	0	0	1	1	1
46	P410	0	45.08	0.165	0.002	0	0	0.958	0.694	25
47	P411	6.130	0	0.233	0.003	1.047	0	0.906	0.769	20
48	P412	0	0	0	0	0	0	1	1	1

6.4. Improvement of DEA Inefficient Unit Plant

The aim of the evaluation is for improving the inefficient DMUs. From the SBM results indicated in Table 04, the projected value of ineffective DMUs of P13– P24, P26 – P36, P38-P41, P45, P48, P410 and P411 can be calculated with model in Eq. (5) and the result is shown in Table 05. Hence, the efficiency of 37 units' of the plant can be improved according to the projected value. The efficiency performance could be achieved, among others, by upgrading or modifying plant design, increasing heat rate, use better coal type and grade, etc. (Malek et al., 2013).

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Table 05. Projected value of DEA inefficient unit of Coal-fired plant

NO	DMU	Input				Output	
		x_1	x_2	x_3	x_4	y_1	y_2
1	P13	227.69	33.06	0.051	0.004	34.94	479.50
2	P14	211.16	26.44	0.087	0.004	35.00	440.77
3	P15	218.30	22.94	0.119	0.007	35.59	472.13
4	P16	225.50	33.07	0.048	0.004	34.85	472.13
5	P17	110.03	7.96	0.189	0.014	33.91	244.47
6	P18	223.08	19.86	0.148	0.009	36.10	495.52
7	P19	223.34	32.50	0.112	0.005	35.60	481.07
8	P110	226.72	25.22	0.110	0.008	35.70	494.98
9	P111	202.97	31.39	0.042	0.001	34.19	407.28
10	P112	233.82	33.03	0.057	0.006	35.19	500.17
11	P21	154.00	21.02	0.246	0.011	37.50	347.01
12	P22	224.03	33.08	0.047	0.004	34.79	467.18
13	P23	233.05	33.03	0.056	0.006	35.16	497.59
14	P24	227.60	33.06	0.050	0.004	34.93	479.21
15	P26	210.66	24.44	0.201	0.013	37.60	486.19
16	P27	206.60	22.11	0.117	0.006	35.27	440.86
17	P28	192.10	25.98	0.087	0.004	34.60	396.74
18	P29	214.03	13.79	0.191	0.010	36.50	482.18
19	P210	219.84	15.64	0.177	0.010	36.40	494.70
20	P211	223.84	33.08	0.046	0.004	34.78	466.55
21	P212	219.87	33.10	0.042	0.003	34.62	453.15
22	P31	204.85	12.62	0.225	0.012	37.10	469.34
23	P32	217.09	30.21	0.062	0.003	34.80	450.72
24	P33	220.33	17.79	0.161	0.010	36.20	491.21
25	P34	194.82	24.11	0.150	0.007	36.10	418.61
26	P35	179.40	27.81	0.082	0.004	34.40	364.15
27	P36	192.28	22.37	0.297	0.013	38.60	458.55
28	P38	222.11	31.34	0.116	0.012	36.90	498.56
29	P39	203.92	27.60	0.238	0.013	38.30	479.61
30	P310	231.16	33.04	0.054	0.005	35.08	491.23
31	P311	224.72	33.07	0.047	0.004	34.82	469.52
32	P312	121.91	8.60	0.205	0.014	34.60	274.96
33	P41	226.53	15.73	0.290	0.014	38.20	545.70
34	P45	206.80	15.48	0.262	0.019	38.30	517.12
35	P48	250.70	33.29	0.245	0.015	38.60	608.01
36	P410	201.90	31.07	0.152	0.012	36.90	469.40
37	P411	257.67	30.15	0.104	0.012	36.45	587.12

7. Conclusion

As a conclusion, there has been widespread recognition that coal usage will continue to increase for power generation in Malaysia. At the same time, it has become increasingly urgent to reduce CO_2 emissions for meeting the emissions reduction target. As the biggest emitter of power generation, coal fired plants shoulder an arduous task. The study finds that the concept of circular economy with 6 input and output indicators based on BCC and SBM model can be employed for assessing, ranking and improving the relative efficiency of coal-fired plants. Builds on Malaysia commitment for CO_2 emissions intensity

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reduction by 2030, the evaluation result provides the benchmark and baseline for the efficiency improvement of coal-fired plants. As the government is in the midst of finalising the emissions standard for heat and power generation, the result provides valuable input to power plant to implement energy efficiency measures in the plant unit which ranked low positions. However, the current model used in the study is a relative assessment which is only based on unit level with limited indicators in the coal-fired plant. In future, when data become available, reliable circular economy indicators can be used to include more complete circular economy indicators of coal plant in Malaysia. With this, the relative assessment and absolute evaluation of the coal-fired plant can be fully assessed that will shed light on the possible improvement of coal-fired plant in Malaysia. By measuring, improving and benchmarking, the results can be used as guidelines to examine policies with appropriate strategies to improve the plant efficiency of the country towards energy sustainability.

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