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Investigating the Effectiveness of Coal-Fired Power Plant Operations: Management, Technical and Air Pollution Aspects

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Abstract

Coal-fired energy has been a major part of Malaysia's power supply, causing environmental pollution and slowing sustainable growth. To address these issues, we evaluated a coal-fired power plant's efficiency using a questionnaire completed by industry experts. This study seeks to find factors affecting coal-fired power generation efficiency and create a statistical model. The questionnaire covered five areas: best management practices, technology efficiency, cost efficiency, fuel efficiency, air pollution control, and the best available technique. Principal Component Analysis (PCA) was used to simplify large data sets. The results showed that 15 principal components were valid, with a KMO value of 0.836 (greater than 0.50) and a Bartlett Test value below 0.05. The results show a strong correlation between the best available technique and various indicators: best management practice ($r=0.614$, $p<0.01$), technology efficiency ($r=0.719$, $p<0.01$), cost efficiency ($r=0.529$, $p<0.05$), fuel efficiency ($r=0.662$, $p<0.01$), and air pollution control efficiency ($r=-0.752$, $p<0.01$). The model indicates that verifying the standard operating procedure (SOP) is crucial for improving power generation efficiency and reducing human error ($R^2=0.914$). This study pinpoints issues reducing power plant efficiency, particularly regarding emissions, and shows that the regression model is strong ($R^2 = 0.916–0.647$). It will assist policymakers and researchers in creating sustainable environmental management plans.

Keywords:

Coal;
Bag Filter;
Efficiency;
Power Plant;
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1- Introduction

Air pollution control (APC) is used to monitor the performance during the emission process to abate the excessive release of air contaminants into the atmosphere [1]. Performance monitoring of APC is important as a preventive measure that requires it to function under proper conditions. Failure to determine the performance of APC can cause the deterioration of air quality in Malaysia [1-3]. The inefficient operation of APC can violate emission standards and workplace air quality standards. Uncontrolled air pollutants such as sulfur oxide (SOx), particulate matter (PM), and nitrogen oxides (NO_2) are common in industrial areas and can pose risks to public health, especially to cardiovascular organs, which contribute to respiratory infections, lung diseases, and the heart [1, 4, 5]. The effectiveness of APC,

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specifically towards energy efficiency for coal-fired power plants, is important, as preventive maintenance procedures can be adopted in industry to determine the operation of APC and the smoothness of the APC itself [6]. It is important to avoid unnecessary plant shutdowns and preventive maintenance by conducting surveys in many aspects to implement corrective actions before APC performance worsens [7]. Considering the prevalent negative impacts on human health, it is crucial to assess the effectiveness of the APC in implementing appropriate measures and ultimately enhancing public health and air quality in specific areas. This evaluation can be performed by individuals involved directly or indirectly in the field [8, 9].

Studies examining the effects of coal-fired power generation on air pollution in Malaysia are scarce. The findings of this study can assist in determining the specific factors that diminish the effectiveness of power plants, particularly their emissions. Additionally, this study will assist policymakers and the scientific research community in developing sustainable environmental management strategies for impacted factors. The prevalence of coal-fired power generation in Malaysia over an extended period has significantly contributed to the electricity supply [10]. However, this has led to environmental degradation and resource depletion, consequently limiting the sustainable growth of the power industry [2]. To resolve these problems, we combined the concept of power plants in the technical and management fields to assess the efficiency of coal-fired power plants through a questionnaire filled out by experts in this field [11]. This questionnaire contained five categories, each containing a list of indicators, including best management practice (A), technology efficiency (B), cost efficiency (C), fuel efficiency (D), air pollution control efficiency (E), and the best available technique (F). These categories are important to determine the efficiency of coal-fired power generation because of previous studies conducted in China and India, which stated that the current status in Southeast Asian coal-fired power generation would potentially affect the region's ability to contribute to global warming up to 1.5 or 2.0 degrees Celsius [11-13]. Therefore, by determining the critical contribution categories for the efficacy of coal-fired power plants, this study can provide solutions or improvements to coal-fired power generation and mitigation measures for climate change.

Currently, South Asian countries rely on conventional energy sources, which are scarce and non-renewable [4, 6, 7]. Within the national energy mix framework, energy is derived from two primary sources: renewable and conventional sources [14]. The use of conventional energy sources is expected to decrease in the future and have detrimental environmental effects [11, 12]. In contrast, sustainable energy is derived from renewable sources (such as biomass, water, solar, and wind) that are consistently accessible and do not harm the environment [5, 15]. An important challenge in meeting national energy demands is excessive dependence on fossil fuel sources. Previous studies have highlighted that the primary energy supply for power generation is predominantly derived from fossil fuels, including coal, natural gas, and petroleum [16]. If all individual portions of the energy source are added together, the total equals 90% [6]. This has emerged as a challenge and threat to satisfying national energy needs [6, 9]. The escalating production capacity of energy sources has prompted substantial efforts to reduce pollution, particularly in coal-fired power plants [17]. The assessment of fuel efficiency, cost efficiency, the best available technique, technology efficiency, and maintenance of power generation are urgently needed to reduce global warming issues [7, 9, 18].

The purpose of the survey is to generate a customer holding study or obtain feedback on the surveys or questionnaires. The effectiveness of the survey depends on its validity. Principal component analysis (PCA) is a valuable component of the validation process [19]. Utilizing PCA most efficiently involves seeking assistance from a proficient specialist. However, it is nonetheless essential to comprehend the underlying principles and advantages of PCA, even if the study delegates the actual computations to an expert and software [20, 21]. Principal Component Analysis (PCA) is a method used to detect the fundamental components present in your survey questions [22]. Factor loadings, or component loadings, provide information that offers valuable insights into the specific aspects of questions that are evaluated [23, 24]. This study was conducted to assess the efficacy of coal-fired power plants. Factor loadings span a range from -1.0 to 1.0, and the identification of primary components often entails identifying values that are at least 0.6 [25]. The number of factor themes from developed questions aligns with and determines the number of factors that the total survey is assessing [26]. Validating a survey involves verifying that it accurately measures the specific aspects of the analysis, a task that can be facilitated by employing PCA [25, 27]. The factors contributing to coal-fired power plant efficiency can be classified using PCA. PCA is used to decrease the number of variables in the datasets, making it easier to understand while limiting the loss of information [28]. It identifies the key aspects that impact the effectiveness of coal-fired power plant generation [29, 30]. These analyses are important for determining the potential sources that can disturb the efficiency of coal-fired power generation [27]. The quantification of factors contributing to the efficiency of coal-power generation has been reported less frequently, especially in Malaysia, than in other Asian countries such as India, China, and Japan [29]. Hence, it is advantageous to develop questionnaires that cover the main efficacy factors using qualitative and quantitative methods. In real-world situations, various factors can influence the efficiency of a coal-fired power plant and show how important it is to determine the interrelationship between the factors. With the year-by-year growth of industrialization in Malaysia, mitigation measures need to be implemented in coal-fired generation to increase coal-fired power plant generation efficiency, indirectly improving the emissions caused by power plants [1, 19, 31].

Many factors can influence the efficiency of a power plant, either in terms of technical or mechanical aspects [32-34]. Hence, this study used indicators to attempt the best management (A), technology efficiency (B), cost efficiency (C), fuel efficiency (D), APC efficiency (E), and the best available technique (F), which has been proven to be the dominant factor influencing the competence of coal-fired power plants in questionnaire forms to obtain feedback from respondents. Regression techniques have long been utilized as forecasting tools in several domains, particularly in the domain of air pollution forecasting [35, 36]. The key advantages of regression are its straightforward computation and ease of implementation [37]. There is much research that examines the importance of considering the correlation between air pollution forecasting and the use of multi-linear regression (MLR) in Malaysia [35, 38]. The primary foundation of this model is the correlation between the dependent variable and multiple independent variables, such as meteorological elements and gaseous contaminants, through straightforward calculations and simple execution. Prior research conducted in Malaysia has established a multiple linear regression (MLR) model for forecasting PM_{10} concentration [39, 40]. This study conducted a distributed questionnaire to specialists in Peninsular Malaysia, specifically focusing on various indicators related to site management (A), technology efficiency (B), cost efficiency (C), fuel efficiency (D), APC efficiency (E), and the best available technique (F) and their sub-indicators. The study aimed to determine the dominant factor influencing the competence of coal-fired power plants by obtaining feedback from respondents through questionnaire forms. In addition, it takes into account the diverse perspectives of responders from several linked fields in the APC, coming from varied professional backgrounds. However, it is necessary to take into account the development of models that contribute to the success of coal-fired power plant operations, particularly in terms of management, technical elements, and air pollution.

2- Material and Methods

2-1- Questionnaire Development and Data Acquisition

This study employed a case study approach, one of the many practices used for data collection, to build and validate theories [41, 42]. According to Nimlyat et al. [43], a case study is an empirical investigation that examines an ongoing phenomenon within a real-life context, mainly when there is ambiguity regarding the distinction between the phenomenon and its context [44]. A case study helps to comprehensively understand a typical case and provides valuable insights into a particular place [45]. Findings from a case study can be used to build theories, especially in exploratory research, because they reflect factual activities at that time [34, 35]. The case study approach adopted in this study offers the ability to explore and use it as a basis for evidence.

The Delphi technique is employed to achieve consensus on a complicated research problem in which no precise information is available [46]. The Delphi application includes instrument design, expert panel selection, panel size, questionnaire administration, and data analysis. According to Mansor et al. [47], the Delphi approach is a group of communication methods and a mechanism for achieving a conclusion on a particular topic [48]. Based on the rationale that multiple perspectives are more valuable than a single one and that inputs from experts who use logical reasoning are superior to simply guessing, this technique involves a group of identified experts engaging in thorough examinations and discussions to investigate policy issues, set goals, and forecast future situations and outcomes [49, 50]. The Delphi technique aims to evaluate the potential or desirable outcomes. The key characteristics of the Delphi approach include the utilization of multiple rounds of questionnaires, the provision of feedback on responses, the ability of participants to revise their answers, and the assurance of anonymity in responses [13, 51, 52]. The Delphi technique was employed in this study for the selection and ranking of variables based on the following justifications:

- Uniqueness in the reliability of different human opinions, which effectively engages a multidisciplinary range of experts spread over significant geographical distances, establishes the content validity of indicators [53-55].
- The Delphi technique straddles both quantitative and qualitative realms, making it an appropriate method for assessing the energy efficiency and APC of coal-fired power plants to develop an energy framework.
- The Delphi method in this study provides valuable solutions for problems inherent in the conventional group opinion based on interaction [56].
- The Delphi method is a widely employed and well-acclaimed approach for collecting data and efficiently achieving consensus [57]. Thus, it is essential to establish an assessment of energy efficiency APC for coal-fired power plants in this study, considering the fundamental assumptions that result in agreement among several expert participants [58].
- This technique is a widely known qualitative method to obtain quantitative results and is widely used in various studies [59].

As Norouzian-Maleki et al. (2015) [30] stated, the initial set of items can be extracted from the literature and assessed in the first round of the Delphi procedure, which is shown in Table 1. The study employed a preset list approach in which the initial items were derived from a review of relevant previous studies and discussions. These items were used to create a questionnaire for the Delphi survey [5, 8, 12]. The initial round of the Delphi questionnaire was designed using a list of factors derived from the previously examined research, encompassing several dimensions [15]. The submitted elements were evaluated by experts to determine their scientific validity, prioritization, and justification for assessing the energy efficiency and air pollution control of coal-fired power plants in Peninsular Malaysia [31, 35]. Table 1 presents the variables obtained from past studies, which were reviewed based on their dimensions.

Table 1. Compilation of Variable for Assessment of Energy Efficiency, Air Pollution, and Expert Opinion on Coal-Fired Power Plant in Peninsular Malaysia

Variables
Best Management Practice
Competency
Leadership
Training
Maintenance
Strategic Planning
Technology
Boiler
Manufacturer
Firing Method
Wall Design
Bottom Ash/ Fly Ash
Air Pollution Control
Fuel
Coal
Coal Pulverization
Air Pollution Control
Type of APC
Manufacturer
Maintenance
Emission Limit
Compliance
Cost-Benefit
Others

According to Voss et al. (2021) [8], the initial phase involves ascertaining whether the study intends to assess the multitude of opinions on a subject or guide a group to reach a consensus. This distinction is crucial for the execution of Delphi. Typically, it is preferable to have three or more rounds when conducting a study to reach a consensus. It is preferable to have the same panel, and it is crucial to have high response rates when assessing the influence of group feedback on panelists. A two-round Delphi [22, 60] is most appropriate when there is clear literature to guide the development of the survey instrument and when the primary objective is to gauge the consensus of opinion on a particular topic. When exploring consensus, rounds may continue until consensus is reached. Nevertheless, this method may rapidly undermine panelists' participation rates and enthusiasm. Typically, three rounds are sufficient and can be completed in four months [23, 24].

Researchers have no universal agreement regarding the optimum number of experts in a Delphi study [24]. The sample size of the Delphi panel varies [25], and the minimum appropriate size includes seven or eight experts [26]. Previous studies suggested panel sizes between 10 and 25 members [27] for homogeneous panel groups (e.g., professions of the same discipline). A larger sample may likely be required for heterogeneous panel groups (people with expertise on a topic but from different social or professional groups), and several hundred people might participate. Sometimes, variability in the number of participants from 8 to 34 is observable [22, 23]. However, studies recommend a range of 10 to 60 as the appropriate size for the heterogeneous group. This is to avoid the increased complexity and difficulty in collecting data, reaching a consensus, conducting analysis, and verifying results often associated with a larger sample size [25]. Moreover, the quantity of participants in a study is contingent upon the extent of the research and the resources at hand [28]. The following sample displays the number of respondents for the initial phase of this study, which includes those working for companies engaged in the maintenance of coal-fired power plants, as well as the Department of Environment Malaysia (DoE).

***63 Samples*: (**5 Academia, 4 Government Servants, 40 Technical Experts/Engineers, 13 Admin / Management, 1 Manufacturer).

The nomination of the panel of expert participants is the most important step in conducting a Delphi study [29]. The research population is a panel of experts in a Delphi study [30]. A subject expert is a group of 'specialists' in their field or someone with knowledge or work experience about a specific subject. Identifying and selecting a panel of experts who can meaningfully contribute to the Delphi process is the most challenging and critical stage of the methodology in the application. The selection of panelists in Delphi procedures is essential because the study's validity depends on the selection process. Thus, the panelists' knowledge must be relevant to the posed questions [31, 34, 35]. Experts should possess technical or scientific expertise, be curious about a wide range of topics, be innovative in connecting dots between many fields of knowledge, and be able to look at issues from several angles. The individuals selected for the expert panel are those experts in the subject matter. Best practice suggests that decisions concerning panel size, characteristics, and composition must ensure that the expertise signifies that the panels are compatible with the study topic and concern. The Delphi process is unique in that it implements multiple rounds of surveys with controlled feedback provided between certain rounds [19]. Ideally, Delphi studies with unlimited time and dedicated expert participants should continue for as many rounds as possible to achieve the target consensus.

Before conducting the Delphi study, the questionnaire was subjected to a pilot test to check for uncertainties that might affect the proposed meaning [34] and to establish the content validity of the survey instrument. A sample size of 10–20% for the actual study was a reasonable number of participants to consider enrolling in a pilot [35, 36]. The participants were asked to respond to each round of the Delphi questionnaire to determine the reliability of the questions. The experts commented on the clarity of the questionnaire, the relevance of the indicator items and domains to the research, and repetition.

In research, it is important to establish reliability to reduce the measurement errors. The instrument's reliability was tested to measure the consistency of the questionnaire sections over and between. Cronbach's alpha reliability coefficient was used [37]. Cronbach's alpha values closer to 1 indicated the reliability of the scale [38]. This study fulfilled the pilot test requirements and proceeded to the next stage.

A formal invitation letter consisting of a brief outline of the study, objectives, expected number of rounds, anticipated time commitment, and feedback notification [39] was sent via email to all selected Delphi respondents. Email is most appropriate for the Delphi method because it permits greater ease for respondents and reduces time and data-gathering costs [40]. Upon accepting the request to participate after several weeks, the participants were involved in three rounds of the Delphi questionnaire administration process.

- ***Round 1 Survey***

The development of this round typically involved conducting a thorough literature analysis, consulting with pertinent individuals, and considering the Delphi study's objectives. Allocating 30 minutes to complete the questionnaire was deemed reasonable, and doing a pilot test was crucial to ascertain the timings, as well as the readability and relevance of the items. Online surveys offer a viable alternative to posting questionnaires and are typically attractive to participants. "SurveyMonkey" provided a straightforward method for creating online questionnaires. Following up with those who did not reply to the questionnaire after it was issued is advisable. This is because a high response rate can enhance the study's credibility. It is ideal to maintain a response rate of 70%. [41]. Consistent communication, adaptability with headlines, and the practice of sending personalized "thank you" notes are believed to enhance response rates.

- ***Round 2 Survey***

The Round 2 survey was developed using the data gathered from round 1. A method regularly employed for conducting surveys is a quantitative approach using Likert (1932)-type agreement scales or ranking scales, designed in a "tick-box" style format. The development of the Round 2 survey can be challenging. Additional piloting may be required to eliminate unclear, redundant, or incorrect things. Descriptive data analyses of the panel's responses begin with the return of the round 2 survey.

- ***Round 3 Survey***

Round 3 questionnaires were constructed after descriptive data analyses of the panel's responses from round 2. The objective of round 3 is to prompt panelists to re-evaluate their scores in light of the group's feedback and determine if they wish to modify any of their comments. Upon receipt of the completed round 3, it is necessary to determine whether any modifications have been made, in which case new data evaluations are required. Calculations of means, standard deviations, medians, and interquartile ranges were performed frequently.

Consensus measurement is a valuable component of data analysis and interpretation in Delphi research [42]; however, achieving 100% agreement on all issues is difficult because expert opinions can differ [29, 39, 43]. Several variances are used to measure consensus, yet there is a lack of guidance on methodological issues concerning the definition and measure of consensus [17, 44]. The lack of detailed guidelines is the most significant criticism of this technique [43]. However, it is a good practice for the investigator to decide the criteria for consensus and clearly outline them before starting the survey [28, 45].

Four sets of predefined criteria were used in this study. These predefined criteria for consensus included a median score of 5 or 4 [46], an interquartile range (IQR) ≤ 1 (Shuib, 2011), a coefficient of variation (CV) ≤ 0.5 [48, 49], and a percentage score ≥ 75% participants score of item ≥ 4 on 5-point Likert scale [50, 51]. These four criteria cut-offs were considered jointly to determine the robustness of the consensus [52]. There was no agreement on any item that did not fit one of the specified standards [53]. Items that failed to reach a consensus were included in a subsequent survey round or otherwise excluded [54].

In addition, more than relying just on the measurement of consensus is needed for Delphi investigations despite it being the main factor [54]. Liu et al. [42] proposed that it is essential to calculate tests for the amount of agreement and stability of experts' ranks between Delphi rounds to fully utilize the data and corroborate the conclusion of the survey rounds [45]. Following implementing the Delphi technique, the study continued to assess the appropriateness of the questionnaire using Cronbach's alpha. After careful evaluation, a final version of the questionnaire was created and disseminated to possible respondents [45, 51, 56, 57]. The participants in this study were chosen based on their competence rather than for statistical sampling objectives [32]. Experts were selected based on their academic qualifications, extensive work experience, in-depth knowledge, and professional skills, particularly in coal-fired power plants, air pollution control, academia, technical experts, environmental engineering, and air quality management in Malaysia. The experts' names and contact addresses were sourced from the staff database and evaluated as potential survey candidates according to these criteria. Qualified individuals who satisfied these requirements were contacted and invited to participate in the Delphi survey, which focused on coal-fired power plants [38, 39]. The study utilized a predetermined list method, in which a thorough investigation of past studies and debates generated initial items. As mentioned earlier, the inquiries were employed to create a survey for the commencement of the Delphi study. A total of 18 participants, representing a variety of backgrounds, provided valid questionnaires.

2-2- Data Analysis

2-2-1- Multivariate Statistical Analysis

A multivariate statistical analysis was performed. The study applied several techniques to determine the factors influencing APC, the relationship between variables, and the statistical models of dependent and independent variables. The multivariate statistical analyses used in this study included principal component analysis (PCA), correlation, and multiple linear regression (MLR) analysis.

2-2-2- Principal Component Analysis (PCA)

This study used PCA to determine the factors influencing APC by quantifying the percentage of sub-indicators based on six indicators, as shown in Figure 1. PCA can be expressed using Equation 1:

$$PC_i = l_{1i} X_i + l_{2i} X_2 + \ldots + l_{ni} X_n \quad (1)$$

where PC_i is the i^{th} principal component, and X_i is the loading of the observed variable X_i.

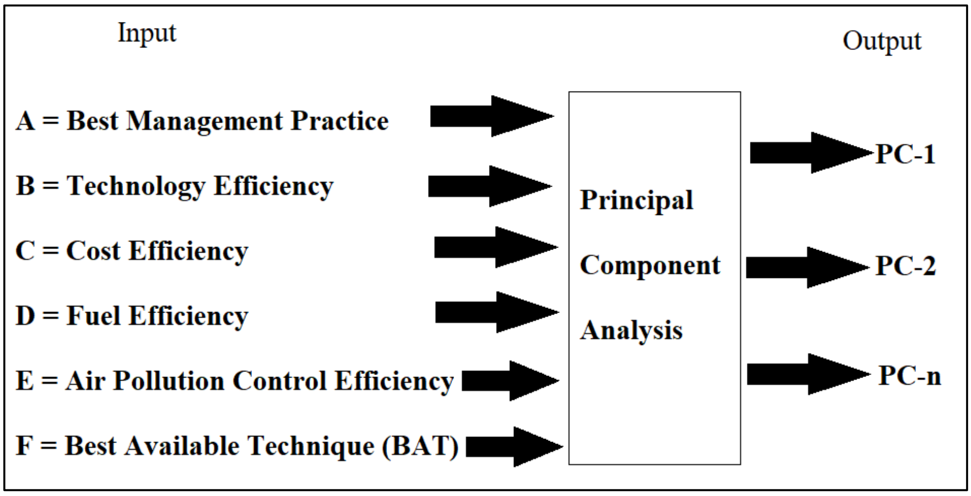

Figure 1. Architecture of PCA

Initially, PCA requires the samples to fulfill two conditions, adequacy and significant value, before further analysis. The Kaiser–Meyer–Olkin (KMO) and Bartlett's test were conducted to determine whether the data set could proceed with PCA in terms of adequacy of data and the significance of the data to run PCA [28, 60, 61]. The KMO value of sampling adequacy must be > 0.50 for the arrangement of the factors. Bartlett's test's value must be < 0.05, as much as the level of noteworthiness. Both conditions must be met; otherwise, PCA cannot be conducted on the dataset [25, 29]. Next, the extracted values in the commonality tables were examined. It is important to determine whether the only variables contributing more than 50% of the variance in the dataset were considered for further analysis. Suppose the data set cannot fulfill 50% variances. In that case, the data must be removed, and the process of re-testing the KMO and Bartlett's test was conducted again until all variables had more than 50% variance contribution [26]. The eigenvalues play an important role in each linear component after rotation and extraction [27]. The function of the eigenvalue is to determine the relation of each factor distinction, which is cleared up by particular linear components, and to demonstrate and explain their eigenvalues in terms of variance percentage in SPSS.

2-2-3- Correlation Analysis

Correlation analysis determined the relationship between the two variables, x and y. Regarding correlation, there was no difference between the dependent and independent variables [62]. The correlation can be positive or negative. For instance, when two variables move in the same direction, one variable increases, followed by another variable; then, the variables are positively correlated (r = 1) [4, 31]. However, when the two variables are inversely proportional, the variable is considered negatively correlated (r = -1) [63, 64]. The correlation equation is shown in Equation 2:

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}} \tag{2}$$

r is the correlation coefficient; $x_i$is the value of x variable in a sample; $\bar{x}$ is mean of the value x variables; y_i is values of y variable in a sample; $\bar{y}$ is the mean of the value of y variables.

2-2-4- Multiple Linear Regression (MLR)

MLR was used to explain the relationship between a dependent variable and several independent predictors. However, establishing a causal relationship was not necessary. This relationship was expressed using a mathematical equation. MLR model is defined based on Equation 3.

$$y = b_0 + \sum_{i=1}^{n} b_i X_i + \varepsilon_i \tag{3}$$

where *i* is from 1 to n, b_i coefficients of regression, X_i are the independent parameters and ε_i is the stochastic error related to the regression.

The multicollinearity of the data assumption was verified by examining the variable inflation factor (VIF) value accompanied by the regression output. If the VIF value is less than 10, the construction of the regression model should proceed smoothly because there is no significant correlation among the independent variables [65, 66]. The VIF equation is expressed as Equation 4.

$$VIF_i = \frac{1}{1 - R_i^2} \tag{4}$$

where VIF_i is the variance inflation factor associated with the i^{th} predictor and R_i^2 is the multiple coefficients of determination in a regression of i^{th} predictor on all other predictors.

The correlation coefficient (R^2) or coefficient of determination (R^2) is an indicator that determines whether the prediction equation fits the data [67]. Additionally, it offers ample data to support the overall model's ability to predict the dependent variables [68]. The equation is shown in Equation 5:

$$R^2 = \left(\frac{\sum_{i=1}^{n} (P_i - \bar{P})(O_i - \bar{O})}{n.S_{pred}.S_{obs}} \right)^2 \tag{5}$$

where n = total measurements at a particular site, P_i = predicted value, O_i=observed values, $\bar{P}$ = mean of predicted value, $\bar{O}$ = mean of observed value, S_{pred} = standard deviation of predicted values and S_{obs} = standard deviation of observes values.

3- Result and Discussion

PCA requires the KMO measure of sampling adequacy and Bartlett's test of sphericity as preliminary tests before the analysis. KMO must be greater than 0.50 for the set of variables, and the probability with Bartlett's Test of Sphericity must be <0.05. The results retrieved from the commonality table were further verified. It is crucial to consider only the parameter that accounts for more than 50% of the variance in the dataset for further analysis. Any parameter that does not meet this criterion is removed [28, 29]. The KMO and Bartlett's tests are repeated until all input parameters have variance contributions of up to 50% in the dataset.

Table 2 presents the eigenvalues linked to each linear component before and after extraction. The eigenvalues of each factor represent the amount of variation explained by the linear component and are expressed as a percentage of the total variance explained. PCA identifies and extracts all elements that have eigenvalues greater than 1. The percentage variability was 99.18% based on the analysis of 15 factors. The rotation improves the factor structure, resulting in an equal distribution of relative importance among the three elements. Prior to rotation, factor 1 (34.58%) had a significantly higher amount of remaining variance.

Table 2. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	37.691	34.579	34.579	37.691	34.579	34.579	19.732	18.103	18.103
2	14.588	13.383	47.962	14.588	13.383	47.962	16.442	15.084	33.187
3	9.701	8.900	56.862	9.701	8.900	56.862	13.412	12.305	45.492
4	7.825	7.179	64.041	7.825	7.179	64.041	12.362	11.341	56.833
5	6.391	5.863	69.904	6.391	5.863	69.904	6.268	5.750	62.583
6	5.744	5.270	75.173	5.744	5.270	75.173	6.245	5.729	68.313
7	4.761	4.367	79.541	4.761	4.367	79.541	5.796	5.318	73.630
8	4.234	3.885	83.426	4.234	3.885	83.426	5.794	5.316	78.946
9	3.827	3.511	86.936	3.827	3.511	86.936	5.205	4.776	83.722
10	3.386	3.106	90.043	3.386	3.106	90.043	4.757	4.364	88.085
11	3.323	3.048	93.091	3.323	3.048	93.091	3.400	3.119	91.205
12	2.191	2.010	95.101	2.191	2.010	95.101	3.205	2.940	94.145
13	1.687	1.548	96.649	1.687	1.548	96.649	2.386	2.189	96.334
14	1.429	1.687	97.960	1.429	1.311	97.960	1.640	1.505	97.839
15	1.328	1.218	99.178	1.328	1.218	99.178	1.460	1.339	99.178

Extraction Method: Principal Component Analysis

The matrix that has been rotated using the varimax method with Kaiser Normalization is displayed in Table 3. This matrix shows the allocation of each variable to each factor. Values below 0.2 (20%) have been excluded from the output [3, 60]. The impact of a variable on PC might be either positive or negative, depending on the sign of the related coefficient. A loading factor of more than 0.5 was considered strong, ranging from 0.4-0.49 was considered moderate, and less than 0.3 was considered weak [58, 59].

Table 3. Rotated Component Matrix

	Component														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A1	0.702	-0.281	-0.019	-0.131	-0.082	-0.368	-0.150	-0.139	-0.304	0.123	0.052	0.063	0.173	0.165	0.053
A2	0.700	-0.119	-0.251	0.051	0.011	-0.107	-0.326	-0.085	0.479	-0.103	0.102	0.055	-0.015	0.163	0.051
A3	0.596	-0.555	-0.387	-0.004	-0.104	-0.199	0.074	0.145	-0.003	-0.131	0.108	0.235	0.124	0.054	-0.022
A4	0.670	-0.289	-0.022	-0.032	-0.062	-0.389	-0.125	0.218	-0.254	-0.280	0.057	0.153	0.216	0.090	-0.045
A5	0.788	-0.329	-0.089	0.018	-0.168	-0.108	-0.004	0.245	-0.212	-0.163	0.269	-0.010	0.117	0.002	-0.014
A6	0.660	-0.068	0.461	-0.131	-0.210	-0.268	0.221	-0.083	0.150	-0.031	-0.029	0.246	0.245	-0.007	0.023
A7	0.832	-0.024	0.056	0.116	-0.198	0.049	0.038	0.006	0.022	0.133	-0.249	-0.071	-0.048	-0.317	0.145
A8	0.722	-0.281	-0.163	0.144	-0.003	-0.211	0.107	0.153	0.292	0.131	-0.029	-0.285	-0.206	-0.143	0.008
A9	0.730	-0.267	0.231	-0.067	0.017	-0.090	0.230	0.026	0.377	0.119	0.081	-0.009	-0.052	0.085	-0.087
A10	0.626	-0.380	0.255	-0.024	0.342	0.008	0.071	0.322	0.189	0.214	0.203	0.145	-0.039	-0.124	-0.007
A11	0.683	-0.457	-0.079	0.067	-0.159	-0.206	0.045	0.391	-0.184	-0.038	-0.032	0.013	-0.016	-0.037	0.201
A12	0.781	0.072	-0.209	-0.019	-0.298	-0.274	0.024	0.308	-0.078	0.074	0.019	-0.106	0.102	0.006	0.194
A13	0.587	-0.462	-0.329	0.076	-0.171	0.167	-0.270	0.331	0.255	0.047	-0.040	-0.045	-0.016	-0.020	0.109

A14	0.429	-0.344	0.354	0.578	0.047	-0.065	-0.283	0.077	-0.111	-0.110	-0.265	-0.060	0.204	-0.056	-0.042
A15	0.647	-0.071	0.378	0.133	-0.307	-0.356	-0.249	-0.277	-0.117	-0.005	-0.080	0.122	0.094	0.094	-0.026
A16	0.516	-0.074	0.650	-0.012	-0.339	-0.248	-0.016	-0.190	-0.053	-0.011	0.029	0.283	-0.022	-0.001	-0.080
A17	0.738	-0.117	-0.241	-0.128	0.133	0.079	-0.150	-0.417	0.033	-0.204	0.080	0.139	-0.208	0.039	-0.076
A18	0.399	0.498	-0.048	0.388	0.254	0.023	-0.280	0.224	0.397	-0.180	-0.083	-0.031	0.001	0.102	0.128
A19	0.449	-0.036	-0.038	0.289	0.539	-0.175	-0.376	0.136	0.191	-0.129	-0.132	0.000	-0.112	0.192	0.062
A20	0.747	-0.113	-0.069	0.023	-0.168	-0.313	-0.316	-0.207	-0.017	-0.127	0.161	-0.065	-0.154	0.279	-0.068
A21	0.764	-0.379	-0.098	-0.012	-0.193	-0.163	0.028	0.192	-0.208	-0.144	0.242	-0.002	-0.029	0.084	0.165
A22	0.786	-0.231	-0.140	0.159	-0.172	0.027	-0.235	0.225	0.102	-0.107	0.078	-0.218	-0.153	-0.144	-0.167
A23	0.879	-0.256	-0.183	0.091	0.021	0.083	-0.086	0.235	0.114	0.022	0.021	0.016	-0.044	-0.011	-0.177
A24	0.734	-0.392	-0.263	-0.109	-0.059	0.067	-0.250	0.189	0.063	-0.101	0.099	-0.131	0.018	-0.214	-0.169
B1	0.374	-0.050	0.687	0.172	0.268	-0.178	-0.235	-0.055	0.208	0.214	-0.065	0.237	0.000	-0.185	-0.095
B2	0.581	-0.334	0.392	-0.133	-0.296	-0.433	-0.142	-0.033	0.198	-0.073	0.050	-0.089	-0.007	0.007	-0.096
B3	0.824	-0.316	-0.099	0.128	-0.100	-0.094	0.075	0.276	-0.057	0.004	0.027	-0.053	-0.284	0.054	-0.044
B4	0.180	0.366	0.086	-0.512	-0.460	0.183	-0.061	0.278	0.106	0.239	0.350	0.081	0.076	0.077	-0.124
B5	0.592	0.526	-0.287	-0.145	-0.382	-0.143	-0.019	-0.023	-0.168	0.256	0.015	0.002	-0.068	-0.029	-0.043
B6	0.665	0.438	0.265	0.289	-0.035	-0.053	-0.196	-0.152	-0.016	-0.308	0.179	0.040	-0.086	-0.065	-0.048
B7	0.621	0.441	0.204	0.258	0.028	0.399	-0.102	-0.252	-0.056	-0.064	0.244	-0.009	0.041	0.070	-0.041
B8	0.809	-0.210	-0.120	0.318	-0.279	-0.146	-0.022	0.028	0.000	0.174	0.048	0.134	-0.068	-0.106	0.109
B9	0.364	0.626	0.250	0.295	0.000	-0.323	0.165	0.060	-0.284	-0.030	0.020	-0.260	-0.100	0.146	0.092
B10	0.482	0.560	0.331	0.384	0.006	0.009	-0.129	-0.246	0.063	-0.173	0.085	-0.193	-0.048	-0.165	-0.033
B11	0.639	0.246	0.283	0.499	0.009	0.081	0.264	0.253	-0.181	0.094	-0.055	0.069	-0.016	0.062	-0.093
B12	0.704	-0.433	0.235	-0.167	-0.221	0.111	-0.148	-0.001	-0.015	0.312	-0.038	0.037	0.132	0.108	-0.100
B13	0.539	-0.473	-0.077	0.219	-0.481	0.191	-0.066	-0.262	-0.157	-0.050	-0.001	0.023	-0.032	-0.223	-0.100
B14	0.325	-0.293	-0.120	0.522	0.114	0.228	-0.422	-0.156	0.257	0.192	0.118	0.223	0.186	-0.220	0.062
B15	0.551	0.144	0.279	-0.508	-0.221	0.288	-0.214	0.193	-0.117	0.263	0.154	-0.104	0.016	-0.069	0.006
B16	0.708	-0.424	0.015	-0.117	-0.031	0.366	0.140	-0.052	-0.283	-0.209	0.067	0.008	0.061	-0.003	0.118
B17	0.608	-0.465	0.281	-0.179	-0.016	0.386	0.001	0.211	0.080	-0.079	-0.163	-0.034	0.171	-0.029	0.196
B18	0.689	-0.494	0.041	0.024	-0.021	0.121	0.211	0.072	-0.257	0.102	-0.252	0.095	0.047	0.099	0.227
B19	0.284	0.760	-0.074	-0.129	-0.131	0.257	0.157	0.083	0.004	-0.079	0.386	0.191	0.055	-0.095	0.041
B20	0.547	0.111	0.103	-0.478	-0.418	0.304	-0.268	0.085	0.219	0.157	-0.015	-0.090	0.142	-0.011	0.033
B21	0.487	-0.358	0.263	0.544	-0.144	0.240	-0.256	0.104	-0.095	-0.182	0.210	0.135	0.075	0.011	-0.013
B22	0.801	0.179	0.096	-0.046	-0.246	0.348	0.013	0.020	0.175	0.024	-0.211	-0.018	0.127	0.193	-0.052
B23	0.657	0.207	0.211	-0.229	-0.305	0.452	-0.020	-0.097	-0.111	-0.028	-0.243	-0.186	-0.025	0.026	-0.079
B24	0.484	0.470	0.298	0.042	-0.039	0.412	-0.359	-0.042	0.067	0.271	0.231	0.006	-0.070	-0.118	0.031
B25	0.552	0.400	0.332	0.040	0.028	0.355	-0.499	0.036	-0.071	-0.107	0.045	-0.051	-0.076	-0.080	0.044
C1	0.649	-0.020	0.219	-0.205	0.026	0.434	0.268	-0.254	0.220	-0.104	-0.171	-0.230	-0.062	0.011	-0.097
C2	0.100	0.055	0.407	0.344	0.624	-0.092	0.133	0.251	-0.032	0.071	0.408	-0.191	-0.043	-0.104	0.042
C3	-0.037	-0.008	0.778	0.260	0.277	0.054	0.118	-0.186	-0.176	0.335	0.208	-0.070	0.036	-0.002	0.064
C4	0.626	0.187	-0.456	-0.088	0.011	-0.200	0.299	0.178	0.139	0.038	-0.129	-0.101	0.161	-0.273	-0.218
C5	0.700	0.080	-0.312	-0.089	-0.078	0.091	0.527	-0.103	0.071	0.021	0.105	0.222	0.098	0.068	-0.106
C6	0.407	0.144	-0.647	0.221	0.142	-0.005	0.169	0.072	0.446	0.167	-0.034	0.186	0.091	0.036	-0.141
C7	0.151	0.239	-0.557	0.369	-0.113	0.022	-0.236	-0.474	0.191	0.260	0.232	-0.002	0.067	0.119	0.039
C8	0.305	-0.442	-0.440	0.484	-0.290	-0.026	0.036	-0.105	0.091	0.093	-0.316	0.191	-0.159	-0.065	-0.061
C9	0.406	0.069	-0.401	0.022	-0.149	-0.412	0.026	-0.037	-0.161	0.542	-0.139	-0.276	-0.216	0.090	-0.054
C10	0.691	0.194	-0.463	-0.188	0.066	-0.010	0.089	-0.165	-0.185	0.278	0.248	-0.100	0.074	0.021	-0.021
C11	0.584	-0.297	-0.279	0.251	0.102	0.054	0.281	-0.136	-0.258	-0.062	0.352	0.004	0.009	-0.192	-0.284
C12	0.414	0.269	-0.439	0.287	-0.025	-0.088	-0.262	-0.188	0.093	-0.374	-0.124	-0.371	0.228	-0.029	0.098
C13	0.105	0.210	0.107	0.452	0.647	0.169	0.254	0.277	0.059	0.006	0.249	-0.092	0.082	0.189	-0.153
C14	0.344	0.336	-0.274	0.441	0.242	0.346	0.098	-0.052	-0.088	0.295	0.003	-0.231	0.391	-0.071	0.061

C15	0.567	-0.401	0.211	0.332	0.114	0.039	0.479	-0.135	0.151	-0.189	0.130	-0.017	0.073	0.013	-0.130
C16	0.612	-0.530	-0.272	0.090	0.095	0.017	0.326	0.090	-0.158	-0.059	-0.199	-0.249	-0.065	-0.043	-0.057
C17	0.558	-0.393	-0.063	0.257	-0.103	-0.140	0.217	-0.492	-0.042	0.113	0.293	-0.011	-0.158	0.031	0.093
C18	0.119	-0.487	0.179	0.291	-0.360	0.491	0.249	-0.147	-0.020	0.038	0.293	-0.017	-0.229	-0.019	0.176
C19	0.570	0.030	0.437	-0.286	-0.080	0.312	0.386	0.190	0.060	-0.132	0.034	0.108	-0.100	0.201	0.167
C20	0.552	0.274	-0.256	0.124	0.093	-0.029	0.271	0.288	0.410	-0.089	-0.071	-0.378	0.198	-0.018	0.105
C21	0.516	0.150	-0.292	0.580	0.123	0.066	0.260	-0.056	-0.148	0.074	-0.137	0.307	0.086	0.050	0.220
C22	-0.132	0.161	0.007	0.711	-0.354	0.314	0.335	-0.103	-0.037	0.131	0.061	-0.206	-0.126	0.148	-0.045
C23	-0.071	0.049	0.621	0.200	-0.130	0.404	0.367	0.126	0.257	0.324	-0.124	-0.004	0.027	0.203	-0.088
D1	0.285	-0.257	-0.370	-0.115	0.590	0.342	-0.047	0.175	-0.143	0.223	-0.230	0.166	-0.205	0.058	0.040
D2	0.703	-0.132	-0.307	-0.362	0.397	0.214	-0.147	0.014	-0.094	-0.071	0.116	-0.051	-0.002	0.079	0.045
D3	0.510	-0.085	-0.397	0.001	0.547	0.148	-0.126	-0.347	-0.092	0.127	-0.066	0.225	0.055	0.030	0.178
D4	0.780	-0.156	-0.321	-0.365	0.188	0.186	-0.021	-0.037	-0.030	-0.111	0.099	0.009	0.038	0.184	-0.003
D5	0.734	-0.174	-0.343	-0.425	0.216	0.233	-0.088	-0.023	-0.035	-0.105	-0.016	-0.048	0.024	0.092	0.019
D6	0.832	-0.059	-0.017	-0.350	0.125	0.259	-0.146	-0.168	-0.025	0.053	-0.113	-0.082	-0.005	0.147	-0.058
D7	0.696	-0.041	-0.092	-0.297	0.187	0.456	-0.032	-0.225	0.021	-0.143	-0.261	-0.009	-0.102	-0.074	-0.047
D8	0.548	0.684	-0.175	-0.055	0.143	-0.017	-0.186	-0.088	-0.167	0.101	-0.162	0.115	-0.020	0.021	-0.211
D9	0.797	0.026	-0.172	0.228	0.427	0.018	-0.131	0.010	-0.228	0.127	0.021	-0.041	-0.080	0.065	-0.017
D10	0.709	0.037	-0.110	-0.032	0.320	0.393	0.092	-0.349	-0.092	-0.191	0.014	0.150	-0.097	-0.038	-0.085
D11	0.524	0.625	-0.332	-0.034	0.281	0.085	0.104	-0.016	-0.308	0.106	-0.089	0.063	0.006	-0.012	-0.015
D12	0.499	0.593	-0.405	-0.042	-0.157	-0.166	0.155	0.000	-0.324	-0.156	0.058	-0.148	0.040	-0.020	-0.007
E1	0.493	-0.131	0.311	-0.150	0.424	-0.144	0.335	0.185	-0.063	-0.110	-0.402	0.215	-0.016	-0.069	-0.136
E2	0.312	0.711	0.211	-0.282	0.290	-0.228	-0.169	-0.147	0.080	-0.141	-0.028	-0.058	0.169	-0.028	-0.002
E3	0.538	0.600	0.261	-0.080	0.168	-0.174	-0.007	0.089	-0.063	-0.369	0.098	0.085	-0.194	0.039	-0.041
E4	0.491	0.725	0.127	-0.207	0.001	-0.123	0.217	0.054	0.014	-0.269	-0.004	-0.032	-0.094	0.115	-0.052
E5	0.383	0.447	0.247	0.187	-0.090	0.247	-0.330	0.352	-0.199	0.222	-0.326	0.105	0.114	0.143	0.013
E6	0.693	0.077	0.418	-0.128	0.014	-0.007	0.234	-0.143	-0.098	-0.370	-0.253	-0.019	-0.090	-0.075	0.062
E7	0.392	0.515	0.075	0.240	-0.385	-0.072	0.107	-0.273	-0.005	-0.077	-0.470	0.031	0.153	-0.002	-0.136
E8	0.812	-0.021	0.158	0.115	-0.130	0.119	0.116	0.053	0.407	-0.241	-0.121	-0.010	-0.014	0.113	-0.049
E9	0.432	0.486	0.216	0.167	-0.116	-0.013	-0.201	0.497	-0.361	0.103	-0.014	0.049	-0.159	0.095	-0.151
E10	0.608	0.090	0.414	0.333	0.370	-0.372	-0.014	0.050	-0.066	0.217	-0.002	-0.031	-0.003	0.016	-0.098
E11	0.163	0.609	0.051	0.459	-0.098	0.203	-0.120	0.397	-0.008	-0.231	-0.061	0.243	-0.049	-0.168	0.090
E12	0.591	-0.434	0.419	-0.056	0.119	-0.063	-0.022	-0.154	-0.323	0.180	-0.227	-0.087	0.075	-0.101	-0.172
F1	0.734	-0.024	0.100	-0.206	0.253	-0.198	-0.137	-0.038	0.112	0.320	-0.220	0.025	-0.302	-0.034	0.158
F2	0.419	0.720	-0.203	-0.092	-0.023	-0.188	0.115	-0.137	0.109	0.139	-0.268	0.128	-0.130	-0.140	0.145
F3	0.580	0.705	-0.209	-0.054	-0.003	-0.148	0.137	-0.094	0.095	0.089	-0.101	0.165	0.029	-0.094	-0.045
F4	0.790	-0.061	-0.038	-0.406	0.280	-0.117	-0.051	-0.006	0.134	-0.041	0.264	0.073	-0.095	-0.065	-0.015
F5	0.579	0.563	-0.216	-0.013	-0.068	-0.231	0.306	0.066	0.110	-0.138	0.148	0.202	0.155	-0.076	0.142
F6	0.532	0.611	-0.291	0.097	-0.282	0.094	0.099	0.036	-0.328	0.046	0.108	0.003	0.010	-0.063	0.159
F7	0.367	0.680	-0.106	0.128	-0.444	0.028	0.067	0.051	0.303	0.109	-0.005	0.083	-0.174	0.170	-0.007
F8	0.678	0.087	0.448	0.014	0.050	-0.196	0.015	-0.300	0.011	-0.122	-0.121	-0.172	-0.145	-0.091	0.329
F9	0.619	-0.066	0.175	0.029	-0.002	-0.420	0.222	-0.219	0.465	0.214	0.109	0.008	0.002	0.090	0.133
F10	0.274	0.635	0.106	-0.514	0.103	-0.148	0.044	0.202	0.074	0.153	0.239	0.114	-0.113	-0.243	0.031
F11	0.813	-0.109	0.071	-0.207	0.238	-0.314	-0.145	-0.057	-0.073	0.178	-0.103	-0.131	0.148	0.080	-0.075
F12	0.630	-0.114	0.289	-0.559	0.095	0.034	0.324	-0.089	0.058	0.068	0.004	-0.061	0.067	-0.200	0.116
F13	0.542	0.031	0.555	-0.213	0.255	-0.166	0.011	-0.236	-0.004	0.184	0.201	-0.204	0.275	0.047	0.072

In general, PC-1 consists of manufacturer guidelines owing to the three dominant factors. Verifying the standard operating procedure (SOP) is important for plant accuracy and sustainability in real operations before implementation (A5). The technology that controls emissions must be based on government regulations (A11), listed on the spider web in Appendix I. The last contributor to PC-1 was the maintenance and operation manual. The Original Equipment

Manufacturer (OEM), Technical Handbook, and central technical library must be properly set up (A21) to improve the efficiency of the power plant and indirectly reduce its emissions from the power plant.

PC-2 comprises different sub-indicators, including fuel consumption and the best available technique; however, it is related to boiler operation. Fuel consumption has a substantial contribution, especially for heat, which is useful and can be utilized to generate more thermal systems (D12). The boiler burnout efficiency increases when the fuel is obtained at a maximum value from coal sources with a minimum carbon value in ash after burning, thus decreasing the efficiency of steam generation (D11). There is an air separation unit among the five main units set up in a CFB combustor that considers the fuel combustion characteristics, simplified power island, steam generation cycle, and CO_2 purification and compression unit [69, 70]. The boiler's efficiency can be improved by installing an electrostatic precipitator (ESP) to collect dust in the flue gas the boiler produces (E4). The accumulated dust was eliminated by a rapping hammer (dry ESP), scraping brush (dry ESP), or flushing water (wet ESP), which proved that dry ESP is more efficient than the wet method [71, 72]. PC-2 also showed the contribution of the best available technique during boiler operation to the usage of CFBC and BFBC fluidized bed combustion (F2), pressurized fluidized bed combustion (F3), cyclone-fired system boilers (F5), and installation of co-generation technology for existing plants (F6). Pressurized fluidized bed combustion (PFBC) is a highly promising technology that enables the clean burning of coal [60, 57, 73]. PFBC, when compared to atmospheric fluidized bed combustion, exhibits improved combustion efficiency, reduced emission of SO_2/NOx, and a more compact combustor size [63].

PC-3 was used for the plant tuning and control. Table 4 shows that all sub-indicators contribute towards PC-3. However, the major contribution was that a well-performing pulverized mill required optimum airflows and good fuel fineness (D2), which is located at fuel processing, followed by the fuel energy content, which stated that coal ash content is regarded as important to plant operation efficiency (D5) and that volatile matter was important to the efficiency of coal-fired power plants (D6). In addition, the remaining fuel energy content variables that influenced plant control were fixed [74]. Carbon is thought to be crucial for plant operational efficiency [75]. (D7), and coal pulverization downtime can significantly reduce overall availability and reliability (D10). The effect of the combustion atmosphere (air or oxy-fuel combustion), combustion temperature, inlet O_2 concentration, fuel type, and biomass blending mass ratio on the combustor temperature distribution, carbon conversion, CO_2 enrichment, and combustion residues was systematically investigated, which is important in plant control to avoid unnecessary events [63, 75].

Table 4. **Equations of Principal Component**

	PC Equation
PC1=	0.92(A5) +0.93(A11) +0.915(A21)
PC2=	0.806(D11) +0.884(D12) +0.805(E4) +0.851(F2) +0.909(F3) +0.886(F5) +0.867(F6)
PC3=	0.812(D2) +0.816(D5) +0.805(D6) +0.896(D7) +0.847(D10)
PC4=	0.807(A6) +0.803(A15) +0.868(A16)
PC5=	0.864(E5)
PC6=	0.896(B4) +0.812(B15)
PC7=	0.967(C2) +0.868(C13)
PC8=	0.825(C18) +0.86(C22)
PC9=	0.857(C7)
PC10=	0.706 (C20)
PC11=	0.842(C9)
PC12=	0.664(C12)
PC13=	0.571(C14)
PC14=	0.375(A7) +0.349(F1) +0.335(F8)
PC15=	0.35(C4) +0.355(C11)

Different sub-indicators were formed in PC-4, which consisted of plant guidelines, and the contribution was concentrated on indicators of best management practices. To increase energy efficiency, the government and company should plan a clear and specific law regarding the released emissions by constantly monitoring, recording, and reporting the air pollutant concentration level to keep it below the standard (A15) because the government conducted enforcement in the legislative term [76, 77]. In order to attain sustainable combustion, it is necessary to properly dispose of garbage in a legally authorised hazardous waste facility (A16). A competent person needs to monitor and implement suitable APCs or strategies to maintain or reduce emissions [78]. Besides these two factors, awarding excellent personnel competency by providing a bonus or incentive for their efficiency improvement must be implemented to encourage them to be more productive (A6). Previous studies [64, 79] indicate that worker performance improves when workers are rewarded with an appreciation of their achievement. This is because the award is part of the 'professionalization' of the occupation [65, 80].

PC-5 explicitly identified electrostatic precipitators (ESP) as a significant air pollution control (APC) system. This study demonstrated that ESP (Electrostatic Precipitators) is a more economical option compared to fabric filters. However, it could be more efficient in terms of capturing particulates and controlling emissions, as confirmed by prior research conducted [66, 67]. The total mercury (Hg) removal efficiency ranged from 7.3% to 72.9% [81, 82]. In comparison, the lead (Pb) removal efficiency ranged from 35.7% to 49.3% at a coal-fired power plant equipped with an electrostatic precipitator (ESP) and wet flue gas desulfurization (WFGD) system [83]. PC-6 pertains to the design parameters that have a substantial influence on the efficiency of coal-fired power plants [67, 84]. The initial aspect pertains to the superiority of keeping the conventional system over installing new sophisticated computerized control of boilers in terms of cost efficiency, as indicated by the best available technique in indicator technology efficiency (B4) [81, 82]. Another crucial consideration is the system architecture, specifically the implementation of the tangential firing mechanism, which has been proven to be more efficient compared to the horizontal position [85]. The numbers 68 and 83 are enclosed in square brackets [85, 86]. The study revealed disparities in the flow patterns between the left and right sides of the upper furnace. Additionally, the gas velocity fluctuation in the horizontal flue gas pass was found to be substantial in the original tangentially fired system [84]. However, by adjusting the opposing tangential angle of the primary air jets in a new tangential firing system, the diameter of the tangential circle in the furnace, the residual swirl at the furnace exit, and the deviation in flue gas velocity in the horizontal flue gas pass were all reduced [85, 86]. The most effective angle for the opposing tangential air jets is 10° and 15° in relation to the original primary air jets [87, 88]. Furthermore, it is necessary to ensure that the ratio between the opposing tangential momentum flux moment and the tangential momentum flux moment remains at a minimum of 0.92 to minimize the variation in flue gas velocity in the horizontal flue gas pass [69, 89].

PC-7 consists of both advanced technology and essential raw resources, which are clear evidence of its cost-effectiveness. It includes technological aspects, such as the cutting-edge technology utilized in coal-fired power plants for the purpose of enhancing energy efficiency (C13). Advanced technology involves elements like the procurement of raw materials, including high-cost coal, and the importation of such goods (C2), despite a study indicating that there was no significant correlation between coal quality and technological efficiency [70]. Regrettably, a review conducted between the years 1981 and 1990 demonstrated that the act of importing superior-grade raw materials, along with the adoption of cutting-edge technology, has the potential to enhance the efficiency of the system by as much as 93%. PC-8 refers to the combined expenses of labour and electricity production, which led to higher costs for worker training and improved energy efficiency (C18). In order to decrease the expense of power production, it is vital to employ a turbine for the specific objective of generating electricity (C22). An effective strategy for reducing the expense of energy in coal-fired power plants involves investigating the feasibility of installing offshore wind turbines in the precise areas where tidal stream arrays are being developed [71, 72]. Furthermore, the correlation between on-the-job training and employee benefits in terms of both monetary and non-monetary advantages indicates that on-the-job training enhances employee working conditions [57, 90, 91].

PC-9 was the maintenance cost, which consisted of the cost of maintaining the power plant and was higher than the installation cost (C7), primarily if early maintenance was not conducted. PC-10 was chosen as an investment for plant management, and plan management was committed to investing in a more comfortable working environment to increase the productivity of workers (C20). A proper strategy will improve the working quality at a low cost without decreasing the efficiency of coal-fired power plants. PC-11 showed that an increase in monitoring power plants by conducting external audits increases the energy efficiency of a coal-fired power plant. Frequent monitoring provides early precautions [72, 92-94]. PC-12 was the management cost, which showed that increasing cost management of coal would increase energy efficiency (C12), while PC-13 specifically stated that transportation cost would increase because the bearing carriage inward is considered higher than the price of coal (C14). Cost efficiency is important in avoiding the deficit or losses of coal-fired power plants.

PC-14 stated that training and optimization are important factors for the efficiency of coal-fired power plants. Employees who have personnel competency and receive suitable training can multitask because of their experiences during the training (A7). Furthermore, the best available techniques can be implemented, such as applying pulverized combustion (F1) and optimizing boiler technology for existing plants. The best available technique can prevent unwanted accidents in the plant. PC-15 is related to green technology and involves cost efficiency. Implementing green technology (C4) is costly, but it can increase the efficiency of the power plant. Using high-quality raw materials can increase the energy efficiency of power plants (C11) and reduce emissions [95]. This is in accordance with the Sustainable Development Goal (SDG)-13, which calls for reducing greenhouse gas emissions and boosting renewable energy sources to mitigate the effects of climate change [96-98].

The Pearson correlation coefficient between the two factors was calculated using the Statistical Packages for Social Sciences (SPSS®) version 25 software. An analysis was performed to assess the positive and negative correlation between the variables in order to determine the efficiency of the coal-fired power plant. Five key indicators were considered in order to assess the efficiency of the coal-fired power plant. These indicators are Indicators of Best Management Practice (A), Indicators of Technology Efficiency (B), Indicators of Cost Efficiency (C), Indicators of Fuel Efficiency (D), Indicators of Air Pollution Control Efficiency (E), and Indicators of Best Available Technique (BAT) (F). Table 5 displays the association among indicators. The correlation is considered strong when it falls within the range of 0.5 to 1, whereas a poor correlation is defined as falling between 0 and 0.49 [2]. The results indicate a strong and statistically significant correlation between the Indicators of Best Available Technique (BAT) (F) and other indicators, such as the Indicators of Best Management Practice (A) ($r=0.614$, $p<0.01$), Indicators of Technology Efficiency (B) ($r=0.719$, $p<0.01$), Indicators of Cost Efficiency (C) ($r=0.529$, $p<0.05$), Indicators of Fuel Efficiency (D) ($r=0.662$, $p<0.01$), and Indicators of Air Pollution Control Efficiency ($r=-0.752$, $p<0.01$).

Table 5. Pearson Correlation

	A	B	C	D	E	F
A	1	0.820**	0.620**	0.591*	0.549*	0.614**
B		1	0.616**	0.608**	0.745**	0.719**
C			1	0.584*	0.413	0.529*
D				1	0.510*	0.662**
E					1	0.752**
F						1

*A= Indicators of Best Management Practice; B= Indicators of Technology Efficiency; C= Indicators of Cost Efficiency; D= Indicators of Fuel Efficiency; E= Indicators of Air Pollution Control Efficiency; F= Indicators of Best Available Technique (BAT).

In order to achieve maximum energy efficiency, it is important to take into account many indicators like technological efficiency, best management practices, cost efficiency, fuel efficiency, and air pollution control efficiency [65, 89]. It demonstrates the necessity of having a capable individual in every field. The competent individual primarily identifies the factors contributing to incidents and recommends the implementation of mitigation measures to maximize the energy efficiency of the coal-fired power plant [45, 78]. This link also demonstrated that every component of the power plant played a crucial role in attaining efficiency. It is necessary to possess expertise in each indicator in order to identify the problem that may be causing the plant's failure [34, 39]. They possess expertise in the specific field of industrial processes and have access to resources that allow them to identify the reasons behind abnormal situations. Early mitigation enables them to make informed decisions to minimize the occurrence of unwanted events [79, 86]. Domain knowledge refers to a comprehensive understanding of a specific topic [90, 99]. Domain expertise is crucial in addressing the efficiency issues of a power plant, as it requires a problem-solver with specialized knowledge rather than relying solely on manual labor [82, 100, 101].

3-1- Development of a Statistical Model for Coal-Fired Power Generations

A two-dimensional radar chart is a graphical representation of multivariate data that displays three or more quantitative variables on axes originating from a common point. The relative positions and angles of the axes are typically not very informative. However, the variables (axes) can be categorized based on their relative positions, which can reveal various trade-offs, correlations, and other comparative measures. This can be achieved using different heuristics, such as algorithms that plot data to maximize the total area [99]. Each variable is associated with an axis, and all the axes are interconnected at the center of the picture. A Spider web graph was utilized to identify the dependent variables of the model in this investigation, whereas the indicators employed in this study, comprising all the questions inside the questionnaires, were included in Appendix I. The findings revealed the metrics of the entire questionnaire.

All the models represented each indicator in determining the efficiency of the coal-fired power plant (Table 6). The dependent variable was chosen based on the ranking given by the respondents to the sub-indicators. The dominant or frequent "strongly agree" in each sub-indicator is nominated as a dependent variable for the model for that particular indicator. The dominant sub-indicator proved that it had the most frequent effect on the indicator. The MLR model of best management practices was obtained with R^2 (0.838) and A4 as the dependent variable. A4 is the standard operating procedure that must be followed to achieve the best management practices. The coefficients for the developed model are given by equation (6). The equation states that two factors influence the best management practice (A): SOP safety briefing and regular training can increase the efficiency of power generation and minimize human error (A1), and verification of the SOP is important to determine the accuracy and sustainability in real operation before its implementation (A5).

Table 6. Model Summary

Model	R	R^2	Adjusted R^2	Regression Equation	
A4	0.915	0.838	0.814	$A4 = 1.413 + 0.464A5 + 0.265A1$	(6)
B3	0.841	0.707	0.687	$B3 = 0.809 + 0.813B8$	(7)
C11	0.804	0.647	0.597	$C11 = 0.556C17 + 0.487C18 - 0.007$	(8)
D7	0.956	0.914	0.894	$D7 = 0.745 + 0.517D6 + 0.566D10 - 0.262D9$	(9)
E6	0.821	0.675	0.628	$E6 = 0.513 + 0.492E1 + 0.472E8$	(10)
F12	0.810	0.656	0.607	$F12 = 0.903 + 0.504F4 + 0.329F13$	(11)

The model for technology efficiency (B) was dominated by installing a supercritical steam cycle system that can increase power generation efficiency (B3) in equation 7. The model obtained for B3 is R^2 (0.707). This model showed that accurate installation of the supercritical steam cycle system (B3) was one of the best available techniques that can directly increase the efficiency of the operating system, especially in ultra-supercritical boiler technology compared to the supercritical boiler and subcritical boiler (B8). Previous studies [74, 82, 100] conducted an analysis of the flow and heat transfer properties of the water wall tube in an ultra-supercritical boiler to improve boiler design. The study found that the heat flux and pressure have a more significant impact on the frictional pressure drop than the mass flux in both subcritical and supercritical pressure regions [101]. Compared to the other two conditions, the optimized tube performed well under ultra-supercritical conditions. Improvements in thermal efficiency can reduce pollutant emissions and result in high efficiency [63]. Equation (4.17) indicates that the ultra-supercritical boiler technology is more efficient than the supercritical and subcritical boilers (B8), which can increase the power generation efficiency by 0.813.

The model for the cost efficiency (C) indicator is obtained with R^2 (0.647) in equation 8. It was monopolized by the high quality of raw materials, which can increase energy efficiency. One of the dominant factors is the high quality of raw materials, such as coal (C11), which is chosen as a dependent variable for cost efficiency. The other factor that highly contributed to this model was the increased cost of training workers (C18), and more expertise was needed rather than the number of laborers (C17). When calculating project expenses, only the expenditures that are additional or incremental due to the project should be considered when assessing the financial impact of the investment on the organization [43]. To clarify, consider just the expenses that occur directly because of the project and would not be present if the project was not undertaken [22]. The primary expenses typically consist of direct costs, including engineering fees, equipment acquisitions, supplies, fees for installation contractors, off-site training costs for employees, production losses due to project installation disruptions and system troubleshooting, and continuous maintenance of new equipment [15, 45]. Irrelevant costs are those that remain unchanged as a result of an investment choice. For instance, any overhead costs that can be assigned to a project but would still exist even without the project should be excluded from a financial analysis as they do not represent additional expenditures [22]. Some examples of these expenditures include allocating internal staff time for identifying and evaluating the project and project design, obtaining management permission, and securing financing from internal or external sources. The internal workforce responsible for carrying out these duties will be there regardless of whether or not the investment is made [35]. While not accounted for in the financial analysis, these non-incremental overheads, often transaction costs, still need to improve efficiency [78, 101]. If efficiency supporters can reduce these obstacles by simplifying the comprehension and execution of efficiency, greater efficiency will be achieved [102, 103]. Equation (8) showed that increasing 0.556 units and 0.487 units of high coal quality indirectly will increase the energy efficiency of the coal-fired power plant (C11) by increasing the expertise for the coal-fired power plant (C16) rather than the number of labor (C17), respectively. This is important for determining the mitigation measures needed to improve the efficiency and control of the power plant's emissions. Expertise needs to determine the problems that can cause plant failure [102]. This is because they have domain knowledge about the industrial process and have sources to determine the cause of the abnormal situation to make the appropriate decision that can mitigate unwanted events [57, 74].

The MLR model for the fuel efficiency (D) indicator was fixed carbon (D7), with the highest R^2 value of 0.914. Three dominant factors that influence fuel efficiency which is fuel energy content needs volatile matter for plant operation efficiency (D6) because highly volatile material in coal can cause rapid combustion and increase the efficiency of fuel consumption (D9), and coal pulverization downtime can be a significant factor in reducing overall plant availability and reliability (D10) [79, 103, 104]. Equation 9 showed that increasing 0.517, 0.566, and 0.262 of fixed carbon in fuel energy content can increase one part of fuel energy content, especially volatile matter for plant operation efficiency (D6), high volatile material, which can cause rapid combustion and directly increases the efficiency of fuel consumption (D9) and also coal pulverization downtime which can be a significant factor in reducing overall plant availability and reliability (D10). It is crucial to comprehend the impact of an air pollution control device system (APCD) on the emission of volatile organic compounds (VOCs) to effectively reduce VOC emissions and achieve ultra-low emissions in coal-fired power plants [63, 105]. This equation states that increased volatile matter and highly volatile material can reduce fuel efficiency. This statement has been supported by controlling VOC and implementing strict regulations for the emission of VOC in coal-fired plants [75, 78]. VOCs have an "irritant-teratogenic-carcinogenic" effect that can cause significant harm to human health, plant growth, animals, and ecology [58]. The model obtained for the air pollution control efficiency had an R^2 value of 0.675. Based on equation (10), flue gas desulfurization (FSD) is highly efficient in removing sulphur dioxide (SO_2) from flue gas produced by boilers, furnaces, and other sources (E6) and can be used as one of the best reduction methods in coal-fired power plants. It increases the removal of nitrogen oxides from flue gas emitted from the plant using selective catalytic reduction (SCR) (E8) [105, 106]. It increases the APC technology system, causing the bag filter to be more efficient than the electrostatic precipitator (ESP) in terms of emission reduction [9, 107]. A previous study used selective catalytic reduction (SCR) systems and flue gas desulfurization (FGD) systems installed in coal-fired power plants to decrease emissions of conventional pollutants such as NO_x, PM, and SO_2 (Dai et al. [101]). Such APCDs can also cause the transformation or removal of PAHs from flue gases [75, 76].

The last model is related to the indicator of the best available technique for the coal-fired power plant. The model obtained R^2 with 0.656, with the contribution of dependent and independent variables being 65.6%. Online monitoring is important for monitoring the emissions of PM, NOx, sulfur, and CO concentrations (F12). The efficiency of the best available technique will increase using tangential firing system boilers, and stack sampling must be performed regularly in addition to online monitoring (F13). It is crucial to attain a high-efficiency coal-fired power plant by employing the most advanced approach currently accessible [60, 70]. Process monitoring has gotten more intricate due to the complexity of industrial processes, which is attributed to the use of process models and expert knowledge [99, 101]. Due to advancements in sensors and control systems, a large amount of data and valuable information are now being generated in industrial operations [21]. The use of data-driven process monitoring has been more prominent and has been extensively utilized in the past few decades [79, 80].

4- Conclusion

This study was able to identify the factors that contribute to the efficiency of coal-fired power plants. It is useful for decision-makers, especially companies, to improve the energy efficiency of coal-fired power plants. The results indicate a robust and statistically significant correlation between the best available technique and other indicators, including best management practice ($r=0.614$, $p<0.01$), technology efficiency ($r=0.719$, $p<0.01$), cost efficiency ($r=0.529$, $p<0.05$), fuel efficiency ($r=0.662$, $p<0.01$), and air pollution control efficiency ($r=-0.752$, $p<0.01$). The model output indicated the significance of evaluating the standard operating procedure (SOP) in order to enhance power-generating efficiency and reduce human error ($R^2 = 0.914$). The findings of this study will aid in pinpointing the precise factors that contribute to the reduced effectiveness of power plants, particularly in relation to their emissions. Additionally, the study demonstrated a robust regression model with a significant correlation coefficient ($R^2 = 0.916$-0.647). The analysis revealed the need to validate guidelines and standard operating procedures to design effective mitigation measures. This study developed a framework for improving energy efficiency in coal-fired power plants, which supports community development and sustainable growth. Data showed that the technical and management aspects require improvement, particularly in implementing SOPs and guidelines. The framework adds to scientific knowledge by exploring factors that affect coal-fired power plant efficiency and sustainability, aiming to enhance workforce quality and plant conditions. This study introduces a new method for measuring efficiency and suggests future research should use various indicators to better understand and assess energy efficiency.

5- Declarations

5-1- Author Contributions

Conceptualization, Z.T.A.R. and M.Y.I.; methodology, Z.T.A.R.; software, Z.T.A.R.; validation, Z.T.A.R., M.Y.I., and A.M.A.; formal analysis, Z.T.A.R.; investigation, Z.T.A.R.; resources, Z.T.A.R., M.I., and S.A.; data curation, Z.T.A.R. and A.A.M.; writing—original draft preparation, Z.T.A.R.; writing—review and editing, Z.T.A.R., M.Y.I., A.M.A., and A.A.M.; visualization, Z.T.A.R.; supervision, M.Y.I. and M.I.; project administration, M.Y.I. and S.A.; funding acquisition, M.Y.I. and S.A. All authors have read and agreed to the published version of the manuscript.

5-2- Data Availability Statement

Data sharing is not applicable to this article.

5-3- Funding and Acknowledgments

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5-4- Institutional Review Board Statement

Not applicable.

5-5- Informed Consent Statement

Not applicable.

5-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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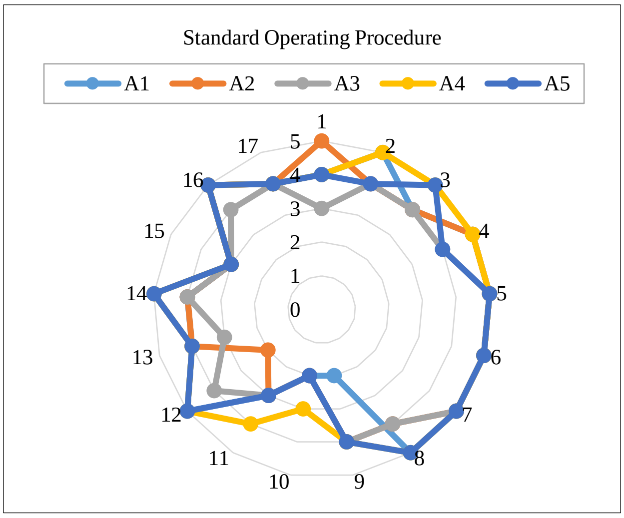
Appendix I

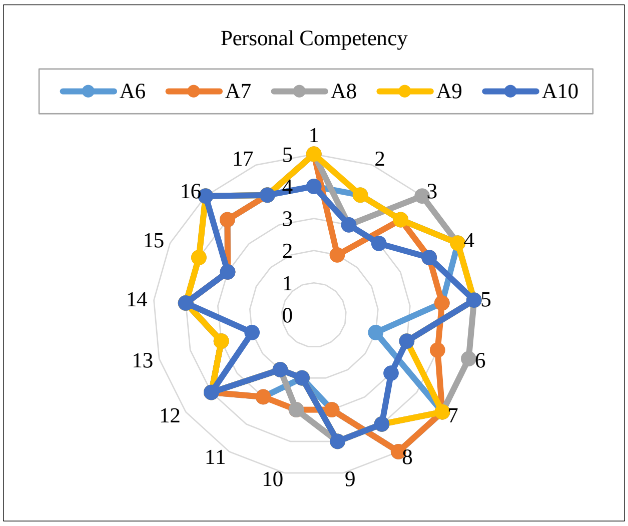
A. Indicator of Best Management Practice

Standard Operating Procedure



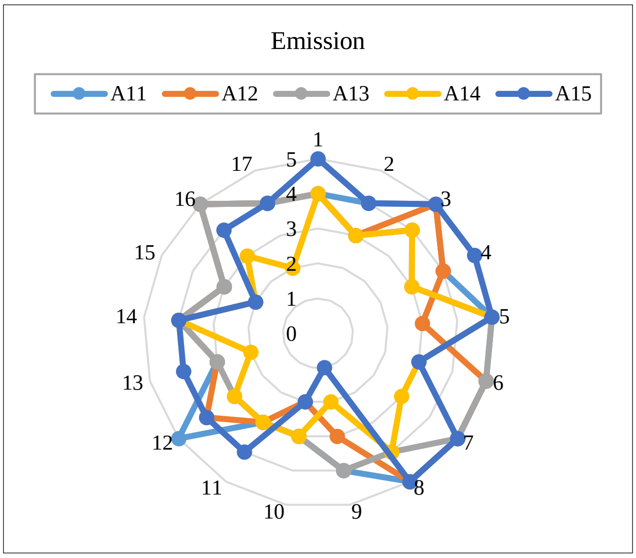
A1	Standard Operating Procedure safety briefing and regular training increases the efficiency of power generation and minimizes human error
A2	An appointed team to review and make the standard operating procedure (SOP) is an obligation
A3	Review of standard operating procedure (SOP) for power generation is done at least once a year to increase energy efficiency
A4	Make sure that everyone follows the standard operating procedure that was made
A5	The standard operating procedure is verified to check its accuracy and suitability in real operation before it is implementation

Personnel Competency

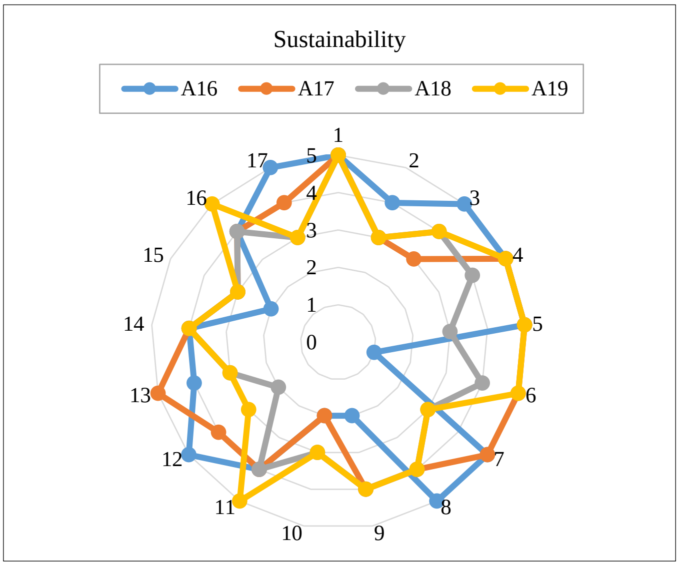


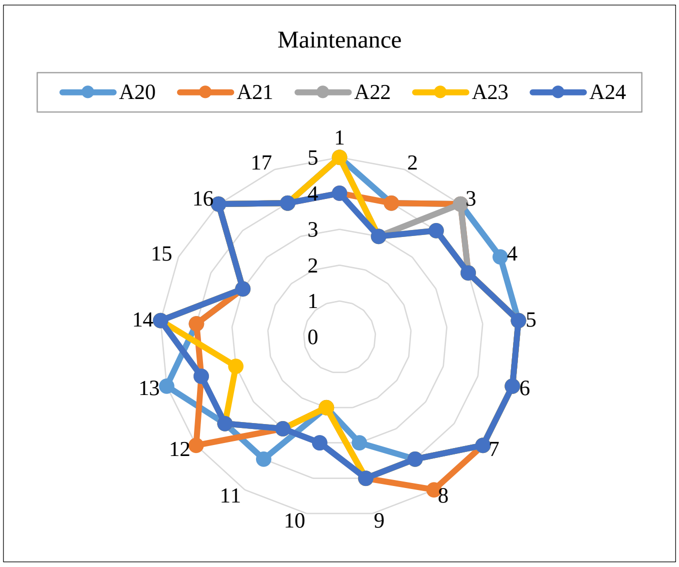
A6	Excellence performing shift was awarded performance bonuses or incentive for their efficiency improvement
A7	Employees receive training to perform multiple tasks
A8	Top management is committed to giving training program for employee
A9	Management provides training and development process, including career path planning, for all employees
A10	The in-house energy audit is conducted regularly by Power Plant Energy Unit

Emission

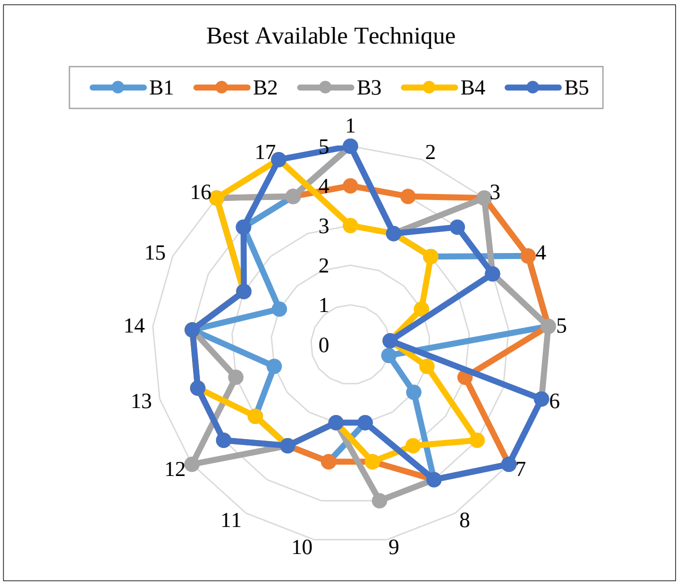


A11	We make sure that the technology that we use control emission based on government regulations
A12	There is a particular procedure that we made if the rate of emission that we release exceeds the government regulation for example increase the technology of controlling emission
A13	Annual review of standard operating procedure conducted for emission control
A14	Internal audit on emission rate conducted 2 to 4 times a year
A15	To increase energy efficiency, the government should plan a clear and specific law regarding emission release by constantly monitoring, record and report the air pollutants concentration level to keep it below standard

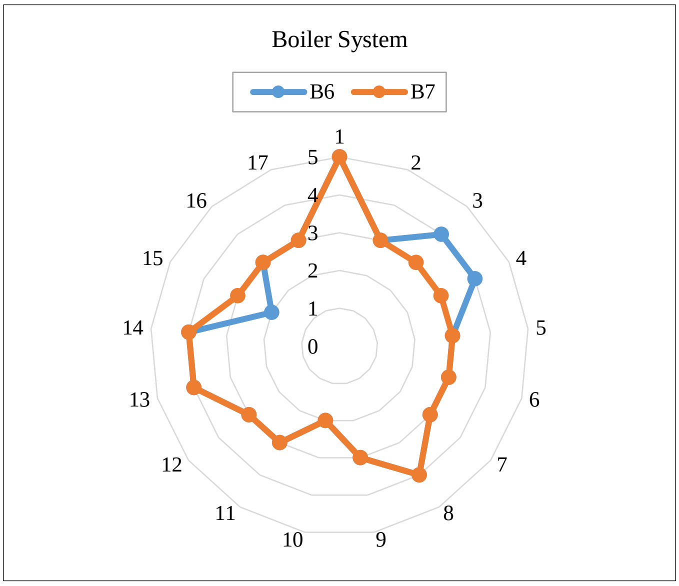
	Sustainability	
	A16	Combustion waste should be disposed of at the legal hazardous waste facility
	A17	Preventing spontaneous combustion if using coal stockpile management by checking the condition of the stock, the wind direction, moisture, and other things like foreign materials.
	A18	Semi-dry systems or dry ash systems, co-fired materials, air emission control methods, and degree of ash weathering were methods used to conserve water
	A19	Coal source and quality, combustion process determine the disposal of ash technique and technology

	Maintenance	
	A20	Maintenance record is documented for regular SOP efficiency improvement
	A21	Operation and maintenance manual which from Original Equipment Manufacturer (OEM), Technical Handbook, and central technical library are set up in our plant
	A22	Pro-Active maintenance which is the prediction of profit impact, estimation of returns on reliability enhancement, and comparison of investment cost with risk reduction returns are in implement in our plant.
	A23	Establishment of the programmed maintenance management system which includes modules like plant performance module, human resource module, work permit module
	A24	Pro-Active maintenance which is the prediction of profit impact, estimation of returns on reliability enhancement, and comparison of investment cost with risk reduction returns are in implement in our plant

B. Indicators of Technology Efficiency

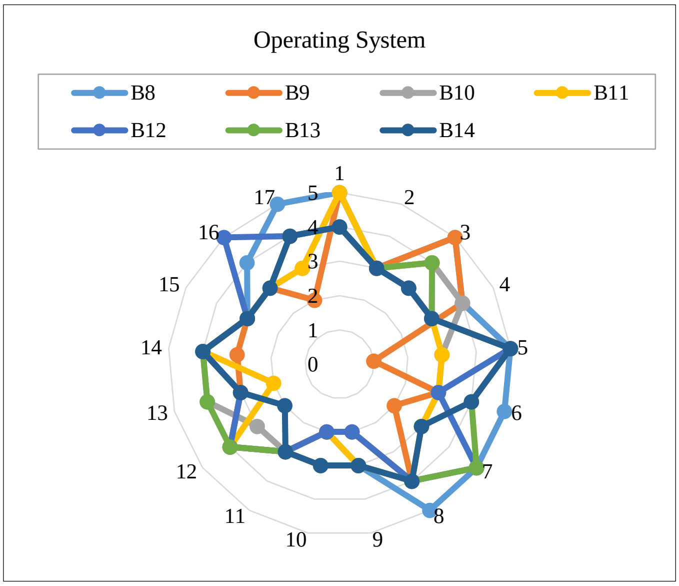
	Best Available Technique (BAT)	
	B1	Installing new advanced technology is more affordable than optimizing each part of the system in power generation
	B2	Optimization of feed water-preheat system increases the efficiency of steam generation
	B3	Installation of supercritical steam cycle system will increase the efficiency of power generation
	B4	Maintaining a conventional system is more efficient in terms of cost compared to installing new advanced computerized control of boiler
	B5	Installation of the advanced computerized boiler system is efficient in improving combustion yet too costly and unaffordable

Boiler Types



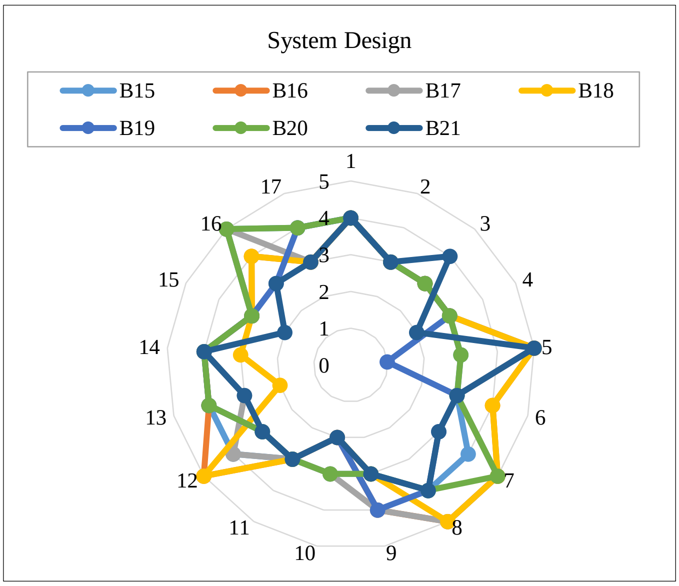
B6	Bubbling Fluidized Bed Combustion (BFBC) boiler technology is more suitable in burning inhomogeneous fuel source compared to Circulation Fluidized Bed Combustion (CFBC)
B7	CFBC boiler technology is more practical and efficient in terms of cost and fuel sustainability

Operating system



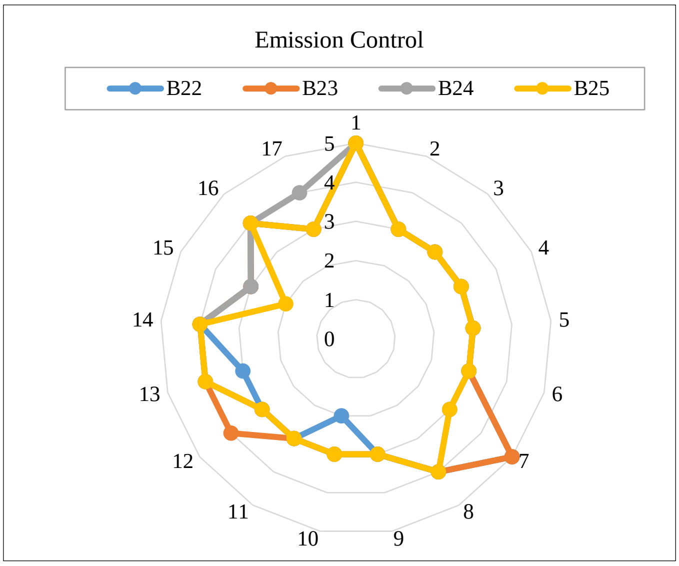
B8	The tangential firing method is more efficient compared to the opposition horizontal position.
B9	The tube of wall design also contributes to the efficiency of the heat transfer. Rifled and smooth are commonly used in wall design
B10	Furnace wall design is playing major rules to generate a homogenous steam
B11	A spiral-type water wall is the more efficient compared to a vertical type of water wall and others.
B12	Material such as ferritic steel, austenitic steel, and nickel alloys contribute to energy efficiency
B13	Tangential firing produces ultra- low NOx emissions.
B14	The use of additives will reduce the emission of pollutants thus increases the efficiency of power generation.

System Design



B15	The tangential firing method is more efficient compared to the opposition horizontal position.
B16	The tube of wall design also contributes to the efficiency of the heat transfer. Rifled and smooth are commonly used in wall design
B17	Furnace wall design is playing major rules to generate a homogenous steam
B18	The spiral type of water wall is the more efficient compared to the vertical type of water wall and others.
B19	Material such as ferritic steel, austenitic steel, and nickel alloys contribute to energy efficiency
B20	Tangential firing produces ultra- low NOx emissions
B21	The use of additives will reduce the emission of pollutants thus increases the efficiency of power generation

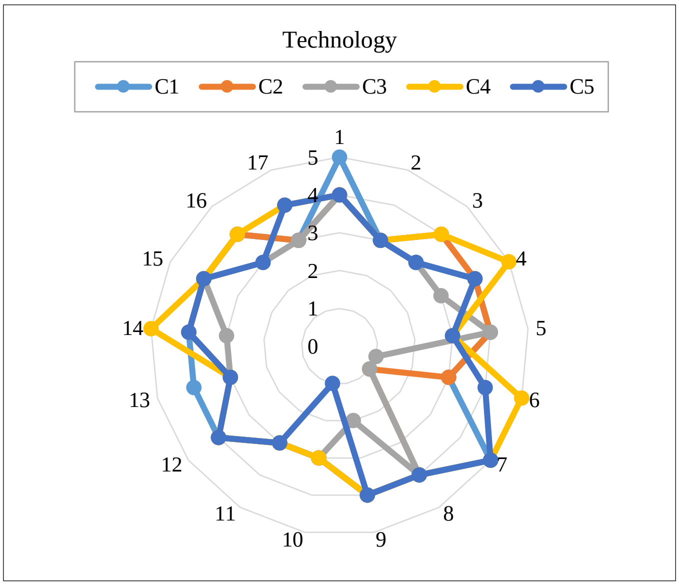
Emission Control



B22	Selective non-catalytic reduction (SNCR) systems add to CFB boilers, lower the NO_X emissions
B23	Advanced tangential firing systems and effective over-fire air arrangements for Tower-type boilers will lower the NOx emissions
B24	Installation of the catalytic converter is better than soot trap to reduce pollutant emission in internal combustion
B25	Catalyst design can lower pressure drop across the reactor and reduce induced fan auxiliary power requirements

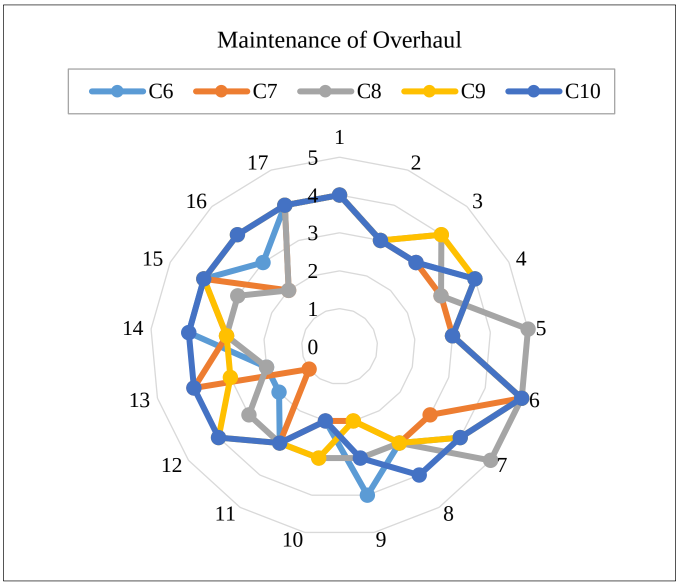
C. Indicators of Cost Efficiency

Technology



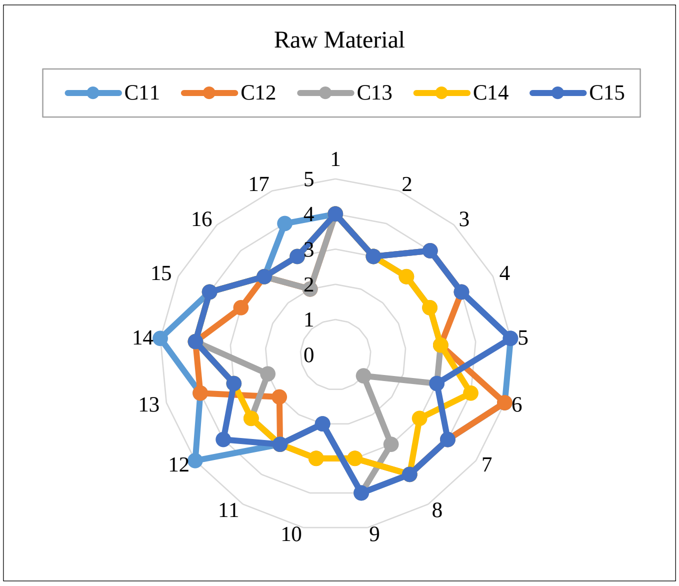
C1	Technologies for coal power plant are easy to access
C2	The latest technology of coal power plant is within purchasing power
C3	The cost to install the latest technology for the power plant is affordable
C4	Using green technology for the power plant will cost more
C5	Replacement of new technology through part by part due to price, expertise, and operation of coal power plant

Maintenance and Overhaul



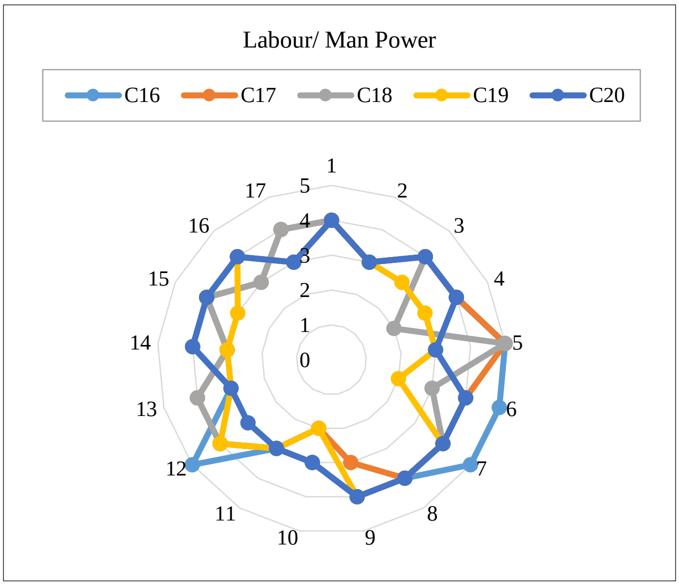
C6	An increase in the cost of maintenance of power plant will increase energy efficiency
C7	The cost of maintaining the power plant is higher than the installation cost
C8	An increase in monitoring power plant (external audit) will increase energy efficiency
C9	Energy efficiency will increase if the cost of electricity for coal power plant decrease
C10	Improve (increase in the cost) maintenance for the cooling system will increase energy efficiency

Raw Material



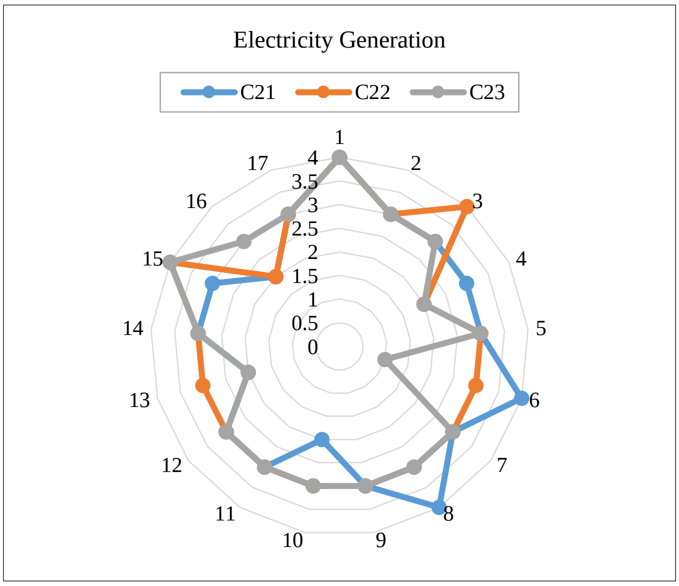
C11	The high quality of coal will increase energy efficiency
C12	An increase in the cost of management of coal will increase energy efficiency
C13	Importing the most expensive coal will increase energy efficiency
C14	Carriage inward is considered more than the price of coal
C15	The consumption of coal can be reduced by using the latest technology of power plant

Labour/Manpower



C16	Expertise for the power plant is needed to increase energy efficiency
C17	More expertise is needed to increase energy efficiency rather than the number of labours
C18	An increase in the cost of training workers will increase energy efficiency
C19	Managements are willing to increase bonus for workers to increase personnel productivity
C20	The Plant Management is committed to investing in a more comfortable working environment to increased productivity for workers

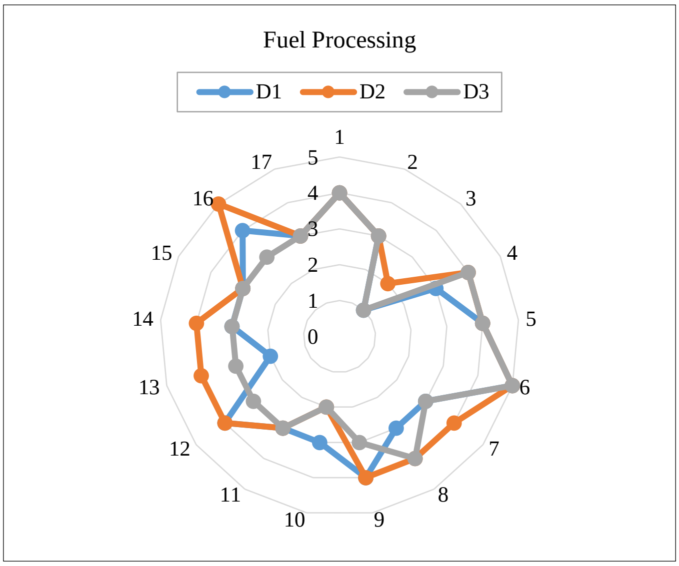
Electricity generation



C21	Increasing the efficiency of 700 MW turbine are more costly rather than increasing the number of turbines.
C22	To decrease cost, willing to use a turbine that can generate less electricity.
C23	Willing to use a turbine that is less efficient in terms of energy to reduce cost.

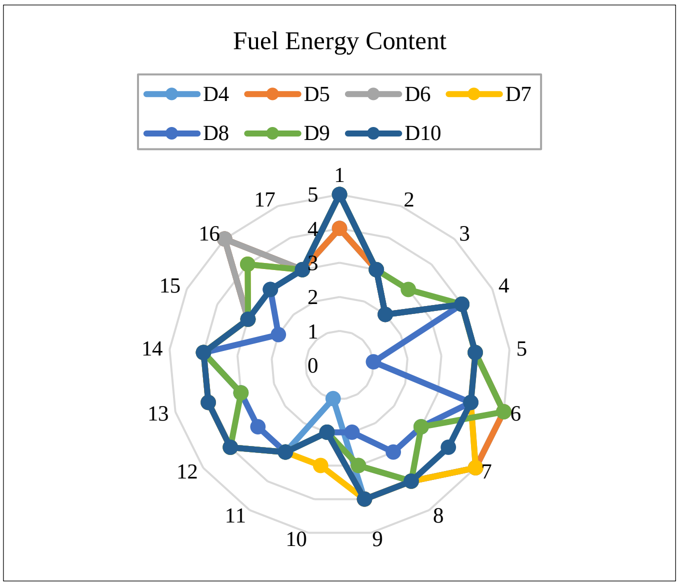
D. Indicators of Fuel Efficiency

Fuel Processing



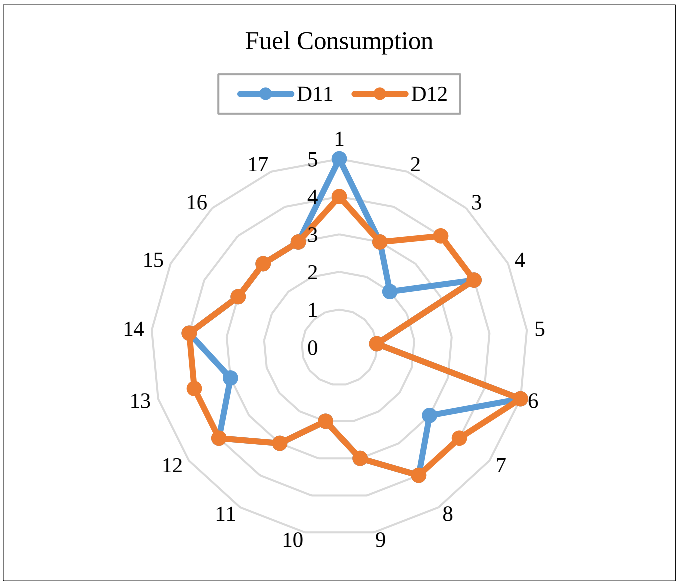
D1	Bituminous coal is more influential to energy efficiency compared to sub-bituminous and blended coal.
D2	A well-performing pulverize mill required optimum airflows and good fuel fineness.
D3	Vertical roller mill (VRM) is more efficient compared to Ball tube mill and ATRITA.

Fuel Energy Content



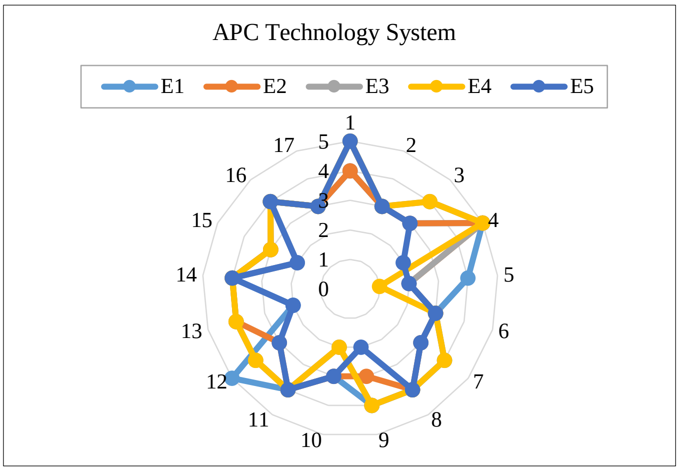
D4	Coal moisture content is regarded as important to plant operation efficiency.
D5	Coal ash content is regarded as important to plant operation efficiency.
D6	Volatile Matter is regarded as important to plant operation efficiency.
D7	Fixed Carbon is regarded as important to plant operation efficiency.
D8	NO_X emission will increase using coal blending.
D9	High volatile material in coal increases rapid combustion and efficiency of fuel consumption.
D10	Coal pulverization downtime can be a major factor in reducing overall plant availability and reliability

Fuel Consumption

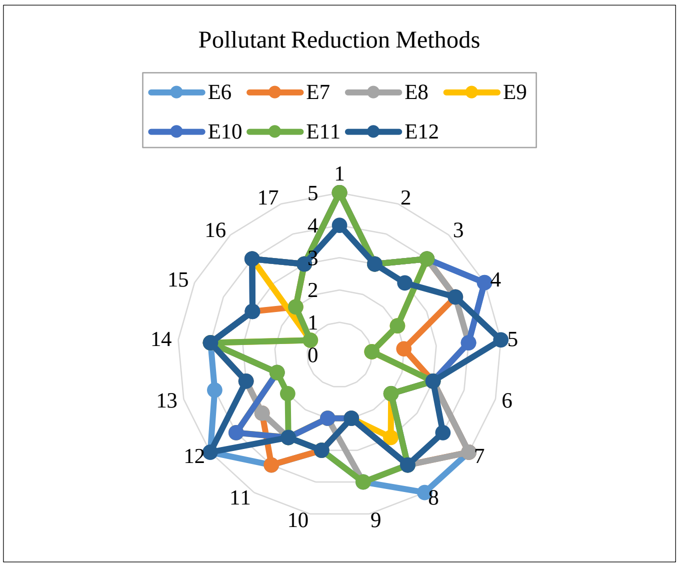


D11	Boiler burnout efficiency increases when fuel obtained at maximum value from coal source with minimum carbon value in ash after burning thus decreasing efficiency of steam generation
D12	Waste heat is useful and can be utilized in generating more thermal steam

E. Indicators of Air Pollution Control Efficiency

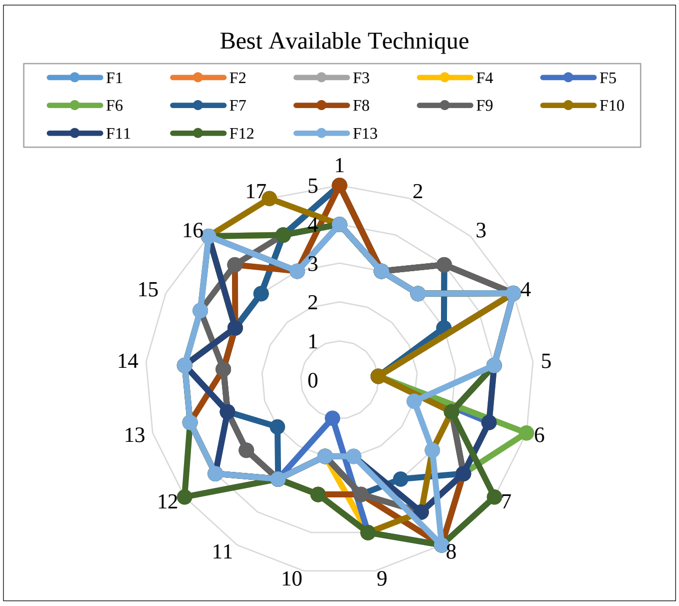


	APC Technology System
E1	Bag house filter is more efficient compared to Electrostatic Precipitator (ESP) in terms of emission reduction.
E2	ESP is more cost-effective and highly available compared to bag house filters.
E3	ESP is effective for low sulphur coal and low SOx emission.
E4	Electrostatic precipitators (ESP) collect dust in the flue gas produced by the boiler. The accumulated dust is removed by rapping hammer (dry ESP), scraping brush (dry ESP), or flushing water (wet ESP). Dry ESP is more efficient compared to the wet ESP method.
E5	Electrostatic precipitators are more cost-effective compared to fabric filters yet not highly effective in terms of particulate capture and emission control.



	Pollutant Reduction Methods
E6	The flue gas desulfurization (FGD) highly efficient in removing sulphur dioxides (SO_2) from flue gas produced by boilers, furnaces, and other sources
E7	Spray dryer scrubbers are used for applications with less demanding SO2 requirements. A lime- or sodium-based scrubbing liquor is atomized into the flue gas to absorb the acid gases, which is more cost-effective
E8	Selective Catalytic Reduction (SCR) System removes nitrogen oxides (NOx) from flue gas emitted by power plant boilers and other combustion sources, and the catalyst is the key component of this system.
E9	Reducing combustion temperature will reduce the emission of PM and increases fuel efficiency
E10	Reducing combustion temperature will reduce the emission of NO_X and increases fuel efficiency
E11	Reducing combustion temperature will reduce SO_X emission and increases fuel efficiency
E12	Production of thermal NO_X from high combustion temperature resulting in high NO_X emission

F. Indicators of Best Available Technique (BAT)



	Best Available Technique (BAT)
F1	Application of pulverized combustion
F2	Use of CFBC and BFBC fluidized bed combustion
F3	Use of pressurized fluidized bed combustion
F4	Use of tangential firing system boilers
F5	Use of cyclone fired system boilers
F6	Installation Cogeneration technology for new plants
F7	Installation of Cogeneration technology for existing plants
F8	Optimization of boiler technology for existing conventional plants
F9	Installation of new technology for conventional plants
F10	Optimization of ESP to higher performance to reduce heavy metals emission from flue gas is more effective compared to the installation of new high-performance bag filters
F11	The use of a wet scrubber or spray dryer for reduction of HCl is more effective compared to additives such as limestone injection
F12	Online monitoring is important in monitoring emission of PM, $NO_{X,}$ Sulphur, CO concentration
F13	Stack sampling (direct measurement) must be performed regularly other than online monitoring.