Development of Green Maintenance Strategy of Coal-Fired Power Plants in the Philippines

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Abstract

Coal-Fired Power Plants (CFPPs) in the country constitute the largest share of electricity for its demand is relatively high but its drastic effect on the environment is quite observed. In other industries, Green production is a practice to achieve a sustainable perspective that in effect with the increase in the efficiency of production and reduce the use of resources such as fuel, water, spares, etc. The power industry like CFPPs has a big contribution to reducing environmental problems.

This study aims to identify the applicability of Green Maintenance of CFPPs in the Philippines. This study used interviews and surveys to gather data and information. A series of statistical tools, such as Descriptive Statistics and ANOVA were used to study and interpret the data. The study was able to assess the current maintenance strategies, practices, and maintenance-related performance of CFPPs, to determine the significant operating and maintenance parameters affecting the environmental performance and to formulate a Green Maintenance Strategy. It is concluded that the principles of green systems for maintenance can be applied in CFPPs in the Philippines.

To be able to improve this study, it was recommended to conduct more analysis in the improvement of the Green Maintenance Strategy.

Keywords

green maintenance strategy, sustainability, CFPPs, green production

1. Introduction

Energy is defined as an "engine of development" because of its important role in economic and social development, including a higher standard of living, advanced health outcomes, and an increased life age (Greenpeace 2016). The use of energy in human society has been the measure of advancement in the adaptation and control to the society and environment. Electricity is the most-consumed energy source in the world and is one of the indicators of economic activity and growth (Lekshmi S.,2010).

In the Philippines, the generation of electricity is by using different sources such as coal, natural gas, oil-based and renewable energy known as green energy such as geothermal, hydrothermal, wind, solar energy, and biomass. Based on the Department of Energy (DOE), coal has the largest supplier to the Philippines's present electricity generation at 39 percent because it is known to be the cheapest and reliable source of energy. According to the Philippine Bureau of Energy Development (BED, 1981) coal is widely available in the country with an estimated potential at 1.7 billion MT. But at some point, coal is one of the major causes of climate and environmental changes, and some of it in the air, soil, and water pollution that undermines human health and the environment. Also, coal is

being the biggest contributor to global GHG emissions that trigger climate-change disasters (Lootens, J.Bomasang, B.Mann, Charles E., 1982).

As of 2018, the Department of Energy (DOE) listed 39 coal-fired power plants in the country. These units are spread throughout the country, although most of them are in Luzon and Visayas.

With the increased investment of coal-fired power plants, some environmental advocates and other individuals understand the agreement of the Paris Agreement by the Philippine Senate as an argument to change the coal to renewable energy (K. Javier, 2016). Thus, the country is promoting clean and green energy through renewable energy development as an alternative but the country is not yet ready with the technology needed to make it a sustainable source (Mayuga, 2017). Concerning RE projects, the Philippines has not enough experience in the development and operations of it and the country will rely on foreign expertise. Besides, the cost of the RE project is much higher than the other countries that consume RE (Energeewende Team, 2016).

Based on the study, "clean coal" is the solution of the future, the key to CFPPs in the country. The government agency specified that the energy and environmental situation have changed markedly in 35 years since the first CFPP adopted by the government and since then, the government is working to find the solution to balance the demand in energy, its impact on the environment and economic competitiveness (D. Lucas, 2016).

Accordingly, the DENR started to evaluate the plant efficiency of CFPPs in compliance with the environmental standard. This led to identifying equipment with high priority related to environmental performance improvement and in studying technology development in reducing the environmental impacts of CFPPs to achieve environmental sustainability. CFPPs will remain the main source—even with the issue in the environment sustainability—for it would help the country in meeting the required energy on its cost. (E. Lucas, 2016).

Nowadays, plant productivity determines the plant efficiency, also environmental aspects affect the overall performance of the plant. Based on the study (OM Enofe, 2010), the function of maintenance is one of the most important activities in the process of which can increase the efficiency of the production, decrease emergency shutdown or lost time, enhance the quality of product or services and therefore maintain and increase plant financial aspect which is one of the substantial reasons of investors. The study describes the applicability of maintenance to the productivity of the plant by increasing the life and performance of the equipment towards an increase in productivity as well as profitability. To attain the overall performance of the plant with regards to plant efficiency and environmental aspects the green maintenance strategy is developed.

According to the Fitch Group BMI Research, CFPPs will be the main driver of economic growth in the next decade. To support the increasing demand for power, the Government support to build a slew of new power plant. Due to the high number of CFPPs operating in the Philippines, some issues relating to the environment were determined such as air, land, and water pollution.

From the sustainability requirements' point of view, green maintenance would make a lot of sense as a primary concern for achieving eco-friendly and environmentally–safe operations of operating plants of CFPPs. Sustainability is known as the development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (E. MacArthur, 2014). It is also described as a Triple Bottom line framework such as social, environmental, and financial aspects (Oxford University Press, 1987).

The significance of this study is to be a part of the achievement of the country's power sector sustainability objectives covering the social, economic, and environmental needs of progressive development. This concept helps the power industry to increase productivity and energy efficiency, low risk, prevent waste, and transform products or services or processes by producing environmentally friendly electricity.

The study is beneficial to CFPPs in institutionalizing good maintenance practices as in good manufacturing practices for factories. The results of the study will serve as a strategic platform for CFPPS to formulate sustainability programs focusing on the operations and maintenance of capital-intensive power-generating assets toward better environmental performance, higher operating efficiency, and lower waste generation.

1.1. Objectives

Given the increasing number of CFPPs in the country, technology including green maintenance must be developed that meets the requirement and compliance without challenging the future in meeting their needs (E. Cruz, 2017). It is in this light that this study aims to define the platform to incorporate green maintenance as a solution and mitigate if not prevent, the environmental impacts of CFPPS operations. This study would like to find a solution to the research question, “What holistic approach can be adapted by Philippine CFPPs in formulating green maintenance towards environmental sustainability?”

Consequently, objectives of the study are as follows: (1) To assess the current maintenance strategies, maintenance practices, and maintenance-related performance of CFPPs in the Philippines; (2) To determine the significant operating and maintenance parameters affecting the environmental performance of CFPPs; and (3) To

formulate a Green Maintenance Strategy framework and recommend a Green Maintenance Program for Philippine CFPPs.

2. Literature Review

The following literature presents the existing maintenance practices and strategy application in a different industry. This section also presents the theoretical framework from other literature. Information sources such as news, books, journals, internet sources, publications (and so on), of relevant topics and keywords that form the source for the study.

Prasad et. Al. (2016) developed correlation analysis between lean and green practices application in the foundry industry for improving productivity and eliminating waste which incorporated to the sustainability.

Shurrab et al. (2019) developed the models that incorporates green construction factors to its activities to support environmental sustainability. Based on the research, the construction industry's benefits by applying green practices such as sustainable competitive advantage, an improved corporate image and sustainable competitive advantage, increase compliance with customers' expectations within the construction industry.

Quantitative modelling was developed to determine that green strategy and green innovation in electrical and electronic industry are more likely competitive while other factor like information management affects competitiveness partially while there is no influence with the external management (Sellitto & Felipe Fehlberg Hermann 2019)

Laari et al. (2017) identified the connection between competitive strategy and advanced green supply chain management (GSCM) and that advanced GSCM strategies were needed to manage the environmental performance of their supplier.

Maintenance is no longer considered as an aftermarket service but a service function of the product (B.Iung and E Levrat 2014). This is related to "green maintenance" requirements or TPM philosophy which linked to regeneration/restorative health management strategy or integrated energy management approach. For this direction the development of additional models for monitoring and predicting issues to address it in advance.

Dekker (1996) and Sandve and Aven (1999) developed the maintenance optimization as early as 1960s. It is difficult to maintain good performance when using a non-moving technique (Vasili 2011). With this, the researched in the maintenance field, developed models, procedures and continuous improvement technique depending on the current state of the business.

Maintenance strategy developed for two or three decades due to different changes in the increase of assets or equipment, equipment requiring advanced technology such as monitoring tools, proactive maintenance approach, life extension of equipment and competent maintenance personnel (Ndjenja, 2015).

Duffuaa et al (1999) developed the six (6) maintenance strategies that are mainly used in decision making are as following:

1. Run-to-failure (RTF) – run the equipment until its fails and then replace or repair
2. Time-based maintenance (TBM) – perform maintenance (cleaning and replacement) based on the given period.
3. Condition-based maintenance (CBM) – rely on the monitoring tools for maintenance
4. Fault Finding Maintenance
5. Opportunity Maintenance – maintenance can be done during outage or shutdown
6. Design-out Maintenance – re-engineering and upgrade

Table 1 shows the maintenance generations defined by maintenance professionals and from time to time it is improving to a proactive approach. In the first generation of maintenance, reactive maintenance such as failure-based maintenance and corrective action are presented until such time monitoring and risk assessment approach.

Generation	Year	Maintenance
1st Generation	*1940 – 1955*	Failure-Based Maintenance Basic PM CM
2nd Generation	*1955 – 1975*	PM TBM Planning and controlling system

3rd Generation	*1975 – 2000*	CBM RCM CMMS Multi-skilled and team work approach Proactive approach
Latest Generation	*2000 and above*	Risk-based inspection, life assessment and maintenance RCM CBM CMMS

Table 1: Maintenance Generation

Table 2 shows the maintenance type and how it works, cost, application and criticality of the activity. The maintenance type is divided are as follows:

Maintenance Type	How does it Work?
Reactive or breakdown maintenance	• No maintenance activity – no cost on manpower, spares or even consumables • Need more time to shut down and high cost on replacement
Run-to-failure	• No maintenance activity for the equipment is more feasible to replace than to maintain • Equipment with low cost and easy to replace
Preventive Maintenance	• Perform maintenance based on the predetermined frequency and tasks (e.g. from OEM, historical data) • Has maintenance cost to manpower, spares and consumables but it prolongs life of equipment
Predictive Maintenance	• Perform condition monitoring of equipment. This is a proactive approach that uses different tools which detect the condition of equipment and may depend the maintenance action to be applied.
Reliability Centered Maintenance	• This kind of maintenance is much deeper than other. This will define the all possible failure mode of an equipment and may depend the maintenance action to be applied.

Table 2 Maintenance type and its work

Tabikh and Khattab (2011) defined the main purpose of PM scheduling activity is to identify the right time interval and procedure to be applied. This will maximize the equipment efficiency at minimum cost and; essential to lessen equipment failure or plant shutdown and corrective maintenance (Kattan and Hassan 2010).

The implementation of PM has recognized to be as one of the strategies to decease the failure rate of equipment and continuous operation. In most cases, PM is not always done on a given schedule due to some maintenance factors (Ab- Samat et al 2012).

Using FMECA for example could make the analysis more accurate. Recording the failures of the machine is one step forward to enhance the availability of it. Analyze historical data is the second step to improve the maintenance schedule and policy (Tabikh and Khattab (2011).

Hashemian, H. and Bean (2011) stated that power industry should be more active in applying predictive and online maintenance for this strategy will prevent stoppages and the organization should not rely on the repair or replacement for the reason that some failure may occur after certain fixed amount of time.

Jasiulewicz-Kaczmarek (2014) developed RCM objectives to enhance the current maintenance practices in the organization. This technique analyzes the maintenance program/plan to have an effective and efficient operation including the safety. RCM strategy operates the three maintenance methods existing on the manufacturing industry. This maintenance is subdivided into percentage, for reactive or corrective maintenance around 15 – 30 %, for Preventive maintenance around 25 – 45 % and for predictive maintenance around 25 – 45 %.

Some of the maintenance management used in the different industry is based on Kaplan and Norton strategic approach which focuses on the process of maintenance and other internal processes that directly affects the management. This model analyzes the following process such as:

- competency of maintenance personnel/worker,
- Maintenance equipment (technology) used;
- Knowledge of maintenance personnel on the technology
- Organization culture

Venkatesh (2017) developed TPM as an advanced approach on maintaining equipment. This program also includes the employee and its job satisfaction in order to reach zero equipment failure due to rework. TPM composed of eight (8) pillars of TPM (see Figure 1). It also includes the 5S as the basic foundation of TPM which define consist of five elements such as Sort; Set in Order; Shine; Standardize; and Sustain. The main focus of the pillars is the proactive approach of maintenance to improve equipment reliability.

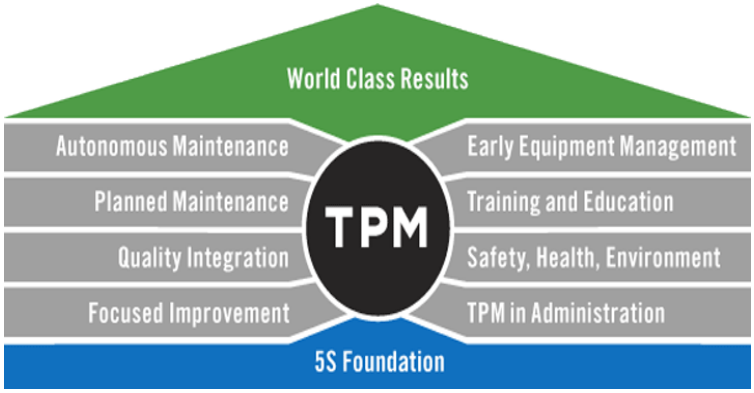

Figure 1: The TPM model

In Figure 2, Total Productive Maintenance defined as (1) minimizing defects, minimizing accidents and minimizing downtime which cover different factors such as quality, safety and production. In order to attain the TPM the following items are needed:

- Maintenance Strategy such as Preventive Maintenance, autonomous maintenance and early equipment maintenance
- Training and education among all employees (workers and higher level of management)

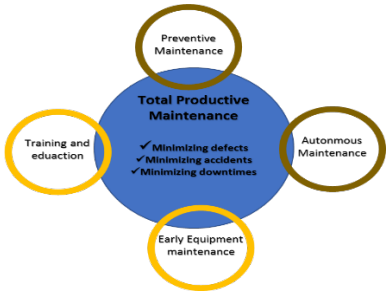

Figure 2: Total Productive Maintenance

Measuring environmental impact is about calculating what is saved instead of what was spent: fuel that wasn't burned, water that wasn't used, and waste that never happened (The Future of Maintenance Management, 2014). Here the six (6) sustainability goal that the management system should meet:

1. Reduced Energy and Water Consumption
2. Reduced Material Consumption and Waste
3. Optimized Equipment Lifecycle
4. Certification Support
5. Community Relations
6. Risk Management

Based on Raouf's framework, to surpass the operations and its environmental cause and effect, Figure 3 shows the 6R's Effect of Poor Maintenance should be analyze during maintenance activities. These are the following:

- Reduce: pollution, consumption of raw materials and energy, production of waste;

- Reuse: products and components;
- Redesign and Remanufacturing: products and components;
- Recover and recycle: replaced components and materials.

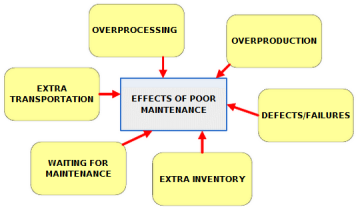

Figure 3: Environmental effect due to poor maintenance

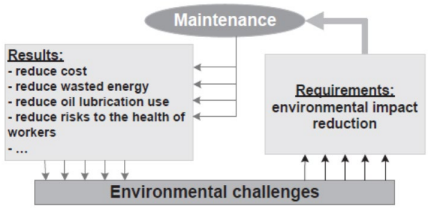

Figure 4: Environmental challenges and maintenance

In figure 4, it illustrates the environmental challenges and maintenance in the lean production. The industry uses different tools and lean process to achieve the requirements are as follow:

- Minimized number of inventory
- Reduced material consumption
- Maximize equipment
- Reduced utilization of factory facilities
- Increased production
- Increased flexibility
- Decreased complexity

For coal-fired power industry, some countries are promoting clean coal technology to improve the existing coal-fired power plants. One of their tools to mitigate the environmental challenges is to upgrade the system and technology of the plants. This improvement contains some modification using advanced software that support plant reliability (Giglio 2009). Using online system like integration of air quality, the emission of CFPP may led to reduction if monitored through online (Giglio 2009).

In other countries, carbon capture and storage (CCS) is used as one of the possible emission mitigation technology for CFPPs CO_2. But at present, no CCS are being implemented in the Philippines (Allam and Bolland 2018). This process has been practices by the gas processing industry particularly in gasification-based power plants and it is done by eliminating the big amount of the nitrogen, approximately 80% of air.

3. Methodology

The methodology of this study was generated in a way that would answer the research gap and objectives of this study. Therefore, this section will show the results of the assessment of current maintenance strategies affecting the environmental aspects and the analysis between the application of Green Maintenance strategy in the productivity and sustainability of CFPPs.

Applying a green maintenance strategy would mean a change in the traditional maintenance of any CFPPs. This would affect the industry's current practices and factors affecting its operation. Figure 5 shows the conceptual framework developed for this research for green maintenance strategy.

The major context coal-fired power plant that affects maintenance and operation would suitable to the so-called 4M's which are manpower, machine, methods, and materials since these 4Ms are the drivers of productivity as a function of effectiveness and efficiency. The green maintenance strategy changes the effective component of the cause-effect relationship between 4M's factors and productivity. This affects productivity in terms of operational efficiency and environmental performance.

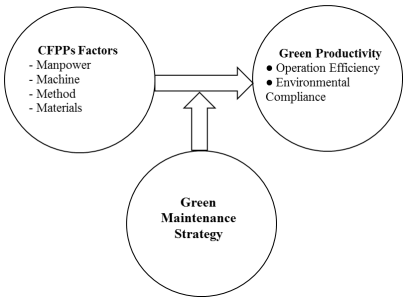

Figure 5. Conceptual Framework of the study

4. Data Collection

The researcher uses methods such as surveys, interviews, case studies, and direct observations. Data collection is conducted through an online survey of relevant respondents from the CFPPs that include questions about the knowledge of sustainable maintenance available at the company and the knowledge and use of green maintenance strategy to the sustainability. Questionnaires are divided into three (2) sections – the demographic profile of the respondents, the current maintenance practices and strategies they are implementing in their respective workplaces. On the first part, the respondent's profile is gathered to the analysis of the demographics. The demographic includes the number of employees of the organization, position, number of years in the organization and the department. Second part is the current maintenance strategies and practices applied in the organization and level of awareness of employee in the green productivity of total number of questions of thirty-three (33).

Questionnaires were subdivided into categories where current maintenance and practices and awareness level of respondents were determined. In current maintenance practices and strategies, the categories are MP1, MP2, MP3 and MP4, for the level of understanding on the green productivity and sustainability, the categories are A1, A2, A3, A4, A5, A6 and for the maintenance strategy for sustainability the code.

Interviews correlated to the research were handed out to relevant personnel from the industry to respond through emails and face to face interaction and conversation with the respondents. The data is then collected and thoroughly analyzed as will be presented in the interview results section. The questions are nothing more than the already presented research questions for conciseness. The researcher selects the higher position in the organization as the interviewee in terms of the strategical perception of the coal-fired power plants in the sustainability of the environment. The respondents are the plant manager, maintenance personnel and environmentalist within the organization and DENR representative around the area. For the qualitative data, the company's practices, policies, strategies and activities will determine from structured interview.

To be able to visualize the study, a study on the existing literature related to the subject has been performed. The topics included in the study are the impact of CFPPs in the environment, effects of operation and maintenance in the plant efficiency, maintenance strategies and management and its theories. The cited literature sources were collected from books, via internet, journals and other published documents.

5. Results and Discussion

According to the interview, the maintenance activity as a process affects the environment when producing toxic emission and waste and too much energy consumption, rework activities and usage of chemicals and other environmental means like lubricants, etc.

It was identified that the most common type of maintenance they are using is preventive and condition-based maintenance. Preventive maintenance considers as the most important maintenance in achieving plant availability and the most practice by operation and maintenance and condition-based maintenance that enables specific time predictions on the equipment breakdown. This action is necessary to optimize maintenance costs and offers sufficient time to provide applicable maintenance action before failure. Besides, the industry is using 5S lean tools as the most widely used of all in addressing environmental concerns and this must not come as a surprise.

Productivity factors incorporated into maintenance were identified and confirmed also during the interview. According to the interviewee, the unavailability of equipment is one of the factors that maintenance desired to eliminate. This mainly affects the production and plant efficiency, profitability as it requires maintenance cost. Another identified item is poor spare management that also affects the productivity and cost of the plant. In greening productivity concept defines as both increasing profit and boosting the organization image by reducing spares and consumption of energy.

About the industry's maintenance strategy, the interview identified three (3) strategies that can contribute to environmental sustainability such as RCM, PM and TPM. However, in the current practices, condition-based and preventive maintenance are most used and implemented.

The organizations are the focus on incorporating environmental sustainability for competitive advantage, decision support, and awareness in the impact of CFPPs in the environment. Some of the demands of sustainability include profitability (stakeholder satisfaction and financial results), plant reliability, social acceptance, and good environmental performance.

One of the factors to successfully implement or into action such strategy is the top management support for they can help the necessary resources (facility, capital, IT, human resource, etc.) and then achieve the benefits of the strategy. They can also empower employees to lead to success and culture transformation. The culture should be designed to complement the strategy.

Besides, community relation also affects organization sustainability. Managing external relation provides positive returns to the entity. Trust and long-term benefits of the community and organization build more give and take interaction.

Based on the interview, respondents are aware of the implementation of green productivity concepts in the organization. This will be essential to address environmental issues in every process. Workers in the industry should be provided with pieces of training to be up to date with the current environmental standards and regulations.

Organizations can determine the environmental impact associated with operation and maintenance processes of CFPPs including waste production, energy consumption, air emission, and water discharge, the volume of rejections scrap and reworks activities and level of usage of chemical, therefore, life cycle asset management will be beneficial to the demand sustainability requirements. Advanced information regarding asset management and CFPPs technology should be able to understand to align with the sustainability issues.

The power industry is required to follow the regulations and standards set by the government agency to achieve objectives on the plant reliability for environmental care. This is possible through the following points:

- Management support on the predictive tools and equipment for condition monitoring
- Prevent plant stoppage by undertaking root cause analysis (RCA) techniques and;
- Increasing plant efficiency focusing Overall Equipment Efficiency (OEE)

Based on the questionnaire results, it can be seen that the lean tools used by the organization are 5S with an average of 3.9 with the interpretation of being reviewed for improvement. This is an indication that the basic TPM is implemented.

For the second question, the industry was implementing Green productivity as it shows that the respondents were satisfied. The data also showed in the third question that organizations focused on areas such as competitive advantage, management and organization, awareness, decision support, and lean and green to incorporate environmental sustainability. This is a fact that the industry is now realizing the strategic advantages of environmental strategy wherein the initial incentives with environmental improvements were often connected to regulatory pressures. Decision support has the highest average of 4.86 which means the environmental aspect has a great impact on sustainability and for Management and organization with 4. 72, it is said to be that this aspect is very important in the success of the implementation of the program.

From the results of maintenance wastes about environmental impact, the most significant maintenance waste is the equipment unavailability. These concluded that maintenance activity plays a big role in sustainability by increasing the life of the equipment. It is also determined that the respondent is knowledgeable about the impact of coal-fired power plants on environmental sustainability.

Based on the survey results, preventive maintenance has proven a great impact on environmental sustainability by reducing machine failure rates and ensuring continuous operation (H Ab-Samat, 2012). Based on the literature, PM will maximize the equipment efficiency at minimum cost and; essential to lessen equipment failure or plant shutdown and corrective maintenance (I.Kattan, 2013). Also, one of the maintenance strategies that contribute to environmental sustainability is the Condition-based maintenance which has an average mean of 5.21 out of 6 which it is based on predicting failure before it happens, rather than on the average life stats of an assets (which is the case with preventive maintenance). It is a widely accepted approach to the maintenance strategy because its result can be seen and analyzed which promotes a proactive approach to maintenance.

The respondents were satisfied with the status of their maintenance structure of an organization. This can affect the working environment and interaction of maintenance workers and may affect the work quality. Based on the literature, when applying for an asset management program, it is said to be that the culture should be designed to complement the effectiveness of an asset management program depends on the way people make decisions. And based on the questionnaire results, asset management has a great contribution to sustainability.

The study also defined that performing the audit to assess the compliance with the defined process and procedure or result-based assessment criteria is highly implemented in the industry. Based on the study, one of the sustainable that management should have is the certification support for this increase in the reputation of the organization.

5.1 Numerical Results

According to the survey, below were the tabulated results that shows the perception of the respondents in the practices of the organization.

1. Lean tools used in the organization

This survey identified the lean tools implemented in the organization. The respondents were asked to score or rate the following lean tools based on the implementation in their company. Rating legend: 1 – Not at all (no idea at all), 2 – Starting (Thinking of to implement), 3- Being Implemented, 4 – Being reviewed for improvement/ Being improved, 5 – Institutionalized (as SOP or a regular MUST do the activity)

Lean Tools	Mean	Interpretation
5S	3.90	Being reviewed for improvement
TPM	2.59	Being implemented
Kaizen (continuous improvement)	3.24	Being implemented
Just in Time (JIT)	1.83	Starting (thinking of) to implement
Six Sigma	1.97	Starting (thinking of) to implement

Table 3 Lean tools and its results

Based on the questionnaire results Table 3, it can be seen that the lean tools used by the organization are 5S with an average of 3.9 with the interpretation of being reviewed for improvement. This is an indication that the basic TPM is implemented.

2. Understand the green productivity concepts in the organization

Green Productivity Concepts	Mean	Interpretation
Knowledge / Implementation of Green productivity Concept	4.55	Satisfied

Table 4 Green Productivity Concepts

For the second question Table 4 shows that the industry was implementing Green productivity as it shows that the respondents were satisfied on the current practice of the organization.

3. The organization focus on the areas when incorporating environmental sustainability are Competitive advantage, management and organization, Awareness, Decision Support, and Lean and Green. The respondents were asked to score or rate the following areas based on the level of acceptance (1 – strongly disagree to 6 – strongly agree)

Organizational focus on to incorporate environmental sustainability	Mean	Interpretation
Competitive advantage	4.67	Satisfied
Management and Organization	4.60	Satisfied
Awareness	4.70	Satisfied
Decision Support	4.83	Satisfied
Lean and Green	4.53	Satisfied

Table 5 Organizational focus on to incorporate environmental sustainability

In terms of organizational focus, table 5. shows that the organization was the focus on areas such as competitive advantage, making decision, organization and management (investors), lean and green and awareness to incorporate environmental sustainability. This is a fact that the industry is now realizing the strategic advantages of environmental strategy wherein the initial incentives with environmental improvements were often connected to regulatory pressures. Decision support has the highest average of 4.86 which means the environmental aspect has a great impact on sustainability and for Management and organization with 4. 72, it is said to be that this aspect is very important in the success of the implementation of the program.

4. Use of life cycle approach to the maintenance management system. This will measure the usefulness through rating (1- not at all helpful to 5 Extremely helpful)

Life Cycle approach	Mean	Interpretation
Use of Life Cycle approach to the maintenance management system	5	Satisfied

Table 6 Life Cycle Approach

The table 6 shows that the respondents were satisfied on the life cycle approach of the organization. Based on this, it is an implication that organization are aware on the significant of it in prolonging the life of the plant.

5. Maintenance Waste concerning environmental impact. These are identified as Unplanned/Emergency Maintenance, Poor spare management, Equipment unavailability, technology, excessive/ unnecessary work, poor quality of work, and poor quality of spares, this will be rate or score as 1- insignificant, 2 - minor, 3- moderate, 4- major and 5- severe

Maintenance Waste	Mean	Interpretation
Unplanned / Emergency Maintenance	2.86	Moderate
Poor spare management	2.93	Moderate
Equipment Unavailability	2.97	Moderate
Technology	2.90	Moderate
Excessive/unnecessary work	2.86	Moderate
Poor quality of work	2.38	Minor
Poor quality of spares	2.48	Minor

Table 7 Maintenance Waste

From the results Table 7 shows that the maintenance wastes concerning environmental impact most significant maintenance waste is the equipment unavailability. These concluded that maintenance activity plays a substantial role in sustainability by enhancing the life of the equipment. It is also determined that the respondent is knowledgeable on the impact of the coal-fired power plant on environmental sustainability

6. Understand the impact of CFPPs on environmental sustainability. This will determine the awareness level of respondents through rating (1 – strongly disagree to 6 – strongly agree)

Satisfaction level	Mean	Interpretation
Understand the impact of a coal-fired power plant on environmental sustainability	5.21	Strongly Agree

Table 8 Understanding on the CFPPs impact on environmental sustainability

Table 8 shows that the respondent is knowledgeable on the impact of the coal-fired power plant on environmental sustainability.

7. Maintenance Strategy can contribute to environmental sustainability. These are identified as PM, TPM, CM, CBM, and RCM this will be rate or score as 1 – strongly disagree to 6 – strongly agree

Maintenance Strategy	Mean	Interpretation
Preventive Maintenance	5.38	Strongly Agree
Total Productive Maintenance (TPM)	4.97	Agree
Corrective Maintenance (failure-based maintenance	4.55	Agree
Conditioned Based Maintenance	5.21	Strongly Agree
Reliability Centered Maintenance	5.03	Agree

Table 9 Maintenance Strategy

Based on the survey results Table 9 shows that the PM has an impact on the sustainability by reducing equipment failure. Based on the literature studies, PM will optimize the equipment efficiency at minimum cost and; important to lessen equipment failure or plant shutdown and corrective maintenance. Also, one of the maintenance strategies that contribute to environmental sustainability is the Condition-based maintenance which has an average mean of 5.21 out 6 which it is based on forecasted failure before it occurs. It is a widely accepted approach to the maintenance strategy because its result can be seen and analyzed which promotes a proactive approach to maintenance.

8. Satisfaction with the maintenance structure of the organization. This will determine the satisfaction level of respondents through rating (1 – strongly disagree to 6 – strongly agree)

Satisfaction level	Mean	Interpretation
Satisfaction on the maintenance structure of the organization	4.45	Satisfied

Table 10 Satisfaction on the maintenance structure of the organization

Table 10 shows that the respondents were satisfied with the status of their maintenance structure of an organization. This can affect the working environment and interaction of maintenance workers and may affect the work quality.

9. Asset Management contributes to sustainability. This will determine the significance of asset management to sustainability through rating (1 – strongly disagree to 6 – strongly agree)

Asset Management contributes to sustainability	5.24	Strongly Agree

Table 11 Asset Management contributes to sustainability

Based on the literature, when applying for an asset management program, it is said to be that the culture should be designed to complement the effectiveness of an asset management program depends on the way people make decisions. And based on the Table 11 it agrees on the statement of literature that asset management has a great contribution to sustainability.

10. Maintenance Strategy used in the organization that can contribute to environmental sustainability. These are identified as PM, TPM, CM, CBM, and RCM this will be rate or score as 1 – strongly disagree to 6 – strongly agree

Maintenance Strategy used in the organization	Mean	Interpretation
Preventive Maintenance	5.10	Agree
Total Productive Maintenance (TPM)	4.00	Slightly Agree
Corrective Maintenance (failure-based maintenance	5.34	Strongly Agree
Conditioned Based Maintenance	4.79	Agree
Reliability Centered Maintenance	5.07	Agree

Table 12 Maintenance Strategy used in the organization

The table 12 shows that the maintenance strategy that they are most used in the organization is the Corrective maintenance followed by Preventive Maintenance, Reliability-centered maintenance and Condition-based maintenance. It is described that the organization were not able to unleash the reactive maintenance even they also performing the proactive approach.

11. Performing audit to assess the compliance of the organization to the process and procedures or results-based assessment criteria (e.g. Environmental system, Quality system, etc.) This will be rate as 1 – strongly disagree to 6 – strongly agree

Audit	Mean	Interpretation
Perform an audit to assess the complies with the defined processes and can involve procedural or results-based assessment criteria (e.g. environmental system, quality system, OHS system, etc).	5.38	Strongly Agree

Table 13 Performing audit within organization

Table 13 shows that organization is performing an audit to assess the compliance with the defined process and procedure or result-based assessment criteria is highly implemented in the industry. Based on the study, one of the sustainable that management should have is the certification support for this increase in the reputation of the organization.

5.2 Proposed Improvements

The study proposed to promote sustainability, including steps to reduce CFPPs' operations and maintenance impact on human health and the environment, increase plant efficiency, and reduce waste. Another improvement is to promote health, safety and productivity throughout the organization through quality maintenance and operations of CFPPs in the Philippines, and to ensure a long-term commitment to sustainability by increasing profit and boosting the organization image.

5.3 Validation

Furthermore, to conclude the hypothesis using ANOVA on a significant difference in the current maintenance practices among New CFPP and Old CFPP in the Philippines the below table shows the P values.

Current Maintenance Practices and Strategies	Old Plants			New Plants		
	F value	**F crit**	**P-Value**	**F value**	**F crit**	**P-Value**
MP1	0.77	2.21	**0.63**	1.49	1.70	**0.11**
MP2	5	2.20	0.0003	15.78	1.70	0.00
MP3	12.43	2.11	0.000	5.67	1.65	0.00
MP4	2.57	2.21	0.025	2.36	1.70	0.003

Table 14 Current Maintenance Practices of New and Old Plant

Based on the Table 14, the P-value is greater than 0.05 which means the null hypothesis is accepted for an old and new plant for lean tools implemented in the company. Both old and new CFPPs in the Philippines have P-value resulted in 0.63 and 0.11 respectively, which suggests that there is no significant difference in the perception survey of both plant employees regarding their lean tools. This implies that employees on both plants are aware and are conforming to the maintenance practices and strategies set to their respective company specifically on the lean tools. In this case, lean tools as part of maintenance practices and strategies are very important to obtain sustainability.

For the MP2 of old and new plants, the P-value is 0.003 and 0.000 respectively which means that the null hypothesis is rejected. This implies that the organizational focus for both plants is not a basis of compliance with maintenance practices and strategies.

For MP3 of old and new plants, the P-value is both 0.000 which means that the null hypothesis is rejected. This concludes that the identified maintenance waste is not a basis to evaluate the maintenance practices and strategies of the plants.

For MP4 of old and new plants, the P-value is 0.025 and 0.003 which means that the null hypothesis is rejected. This implies that the current maintenance strategies and practices of the plants are insufficient to achieve sustainability.

Table 15 Maintenance Practices and Strategies for Sustainability

Maintenance Practices and Strategies for Sustainability	Old Plants			New Plants		
	F value	**F crit**	**P-Value**	**F value**	**F crit**	**P-Value**
MS1	0.70	2.21	**0.76**	15.5	1.70	**0.000**

Following the decision rule P-value > 0.05, Table 15 presents that the P-value is 0.756 in the old plant accepted the null hypothesis. This implies that the old plants have the same knowledge of the maintenance practices and strategies to be implemented for sustainability. Based on Table 15, the P-value of new plant is 0.000 which means that the null hypothesis is rejected. Based on the result, the new plants have different ideas on maintenance practices and strategies to be perfumed to a sustainability approach.

Regardless of plants where employees are, it is still not the basis of compliance to maintenance practices and strategies if the company itself has state of the art facility or a longstanding one. But this can be seen in the maturity level of old plants in the analysis on what to practice/implement in the future to have a sustainable performance in terms of maintenance aspects

6. Conclusion

This study was conducted to develop a Green Maintenance framework that can be applied to CFPPs in the Philippines. The objective of the study was: (1) to assess the current maintenance strategies, maintenance practices, and maintenance-related performance of CFPPs in the Philippines; (2) to determine the significant operating and maintenance parameters affecting the environmental performance of CFPPs; and (3) to formulate a Green Maintenance Strategy framework and recommend a Green Maintenance Program for Philippine CFPPs.

To assess the current maintenance practices and strategies of the existing CFPPs in the Philippines, this study used a survey and series of interviews. The survey consisted of current maintenance practices and strategies and target respondents were asked the level of implementation of their current practices. On the other hand, current maintenance strategies asked the level of satisfaction of implementation.

With this, the study identified that the CFPPs current maintenance practices were observed as being reviewed for improvement. Furthermore, the current maintenance strategies were deemed very satisfactory. Also, the researcher

resorted to ANOVA to identify the significant difference between current maintenance practices and strategies between the type of plant, whether old or new. Based on the analysis of data, there is a significant difference in current maintenance practices and strategies between old and new plants. This difference can be related to the standard procedures each plant was following. Technology also contributes to this difference as this may vary to the age and efficiency of the plant.

The substantial operating and maintenance parameters affecting the environmental performance of CFPPs were listed from related literature as and have been categorized as air and water toxic emissions, consumption of energy, unwanted production, number of re-work and scraps, consumption of chemicals, and other means affecting the environment from operation and maintenance work.

Figure 6: Proposed Green Maintenance Framework

With the data gathered and analyzed, the researcher come up with the framework Figure 6, which objectives are (1) to promote sustainability, including steps to reduce CFPPs' operations and maintenance impact on human health and the environment, increase efficiency, and reduce waste, (2) to promote health, safety and productivity throughout the organization through quality maintenance and operations of CFPPs in the Philippines, and (3) To ensure a long-term commitment to sustainability by increasing profit and boosting the organization image.

References:

Prasad, S., Khanduja, D. and Sharma, S.K.,"An empirical study on applicability of lean and green practices in the foundry industry", *Journal of Manufacturing Technology Management*, Vol. 27 No. 3, pp. 408-426, 2016.

Shurrab, J., Hussain, M. and Khan, M, "Green and sustainable practices in the construction industry: A confirmatory factor analysis approach", *Engineering, Construction and Architectural Management*, Vol. 26 No. 6, pp. 1063-108, 2019.

Miguel Afonso Sellitto & Felipe Fehlberg Hermann, Influence of Green Practices on Organizational Competitiveness: A Study of the Electrical and Electronics Industry, Engineering Management Journal, 31:2, 98-112, 2019.

Sini Laari, Juuso Töyli, Lauri Ojala, "Supply chain perspective on competitive strategies and green supply chain management strategies", Journal of Cleaner Production, Volume 141, Pages 1303-1315, 2017.

Benoit Iung, Eric Levrat, Advanced Maintenance Services for Promoting Sustainability, Procedia CIRP, Volume 22, Pages 15-22, 2014.

Dekker. "Applications of maintenance optimization models: A review and analysis", Reliability Engineering and System Safety, 51(3):229-240, 1996.

Sandve and Aven, "Cost optimal replacement of monotone, repairable systems", European Journal of

Operational Research, 116(2):235–248, 1999.
Greenpeace Philippines, *Coal: A Public Health Crisis. Publication,* 2016.
Lekshmi S. Article. *Importance of electricity*, 2010.
Lootens, D J., Bomasang, R. B.; Mann, C. E.,*Coal in The Philippines Present Status and Future Potential,* 1982.
Mayuga, J.L.,, Duterte's change of heart on climate deal welcomed. Business Mirror, 2016.
Mayuga, J.L., Power struggle: Solar, wind challenge coal as a more affordable energy source, 2017.
Energiewende Team, A struggle between coal and renewable energy in the Philippines , 2016.
Lucas. D. *Coal here to stay, says DOE Chief. Inquirer Business,* 2016
Enofe OM, Maintenance impact on Production Profitability: A case study, 2010.
MacArthur E. Foundation and McKinsey & Company, *Towards the Circular Economy: Accelerating the Scale-up Across Global Supply Chains,* World Economic Forum, Geneva, 2014
Hammer, J., *The Triple Bottom Line and Sustainable Economic Development Theory and Practice,* 2017.
R. Counts and C. Counts*, 4 M's of Production Management, 2011*
Yin, R. K.. Case study research*: Design and methods*, 2003.
Shields, P., & Rangarjan, N. OK: New Forums Press. *A playbook for research methods: Integrating conceptual frameworks and project management*. Stillwater, 2013.
Vasili, Maintenance optimization models: A Review and Analysis. P 1136, 2011)
Ndjenja, L. & Visser J.K., Development of a Maintenance Strategy for Power Generating Plants, 2015.
S.O. Duffuaa, A. Raouf, and J.D. Campbell, Planning and Control of Maintenance Systems: Modeling and Analysis, John Wiley and Sons, New York, 1999.
Giglio, R. S., Clean technology for coal-fired plants. An Article, 2009.
Allam, R., Bolland, O., Capture of CO2, 2018
Tabikh M., and Khattab A., Scheduled maintenance policy for minimum cost- A case study, 2011)
Kattan, I. and Hassan, A., A case study on improving the effectiveness of preventive maintenance. Engineering System Management, 2010.
Ab-Samat, H., Jeikumar L., Basri E., Harun, N., and Kamaruddin, S., Effective Preventive Maintenance Scheduling: A Case Study, 2012.
Jasiulewicz-Kaczmarek, M., Practical aspects of the application of RCM to select optimal maintenance policy of the production line, 2014
Hashemian, H. and Bean, W.,State-of-the-Art Predictive Maintenance Techniques, 2011.
Ventakesh J., An Introduction to Total Productive Maintenance (TPM), 2015

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