CARBON DIOXIDE EMISSION REDUCTION USING COMBINED CLEANER PRODUCTION STRATEGY AND CARBON EMISSION PINCH ANALYSIS IN AN OFFSET PRINTING PLANT

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ABSTRACT: In this study, Cleaner Production (CP) strategy and Carbon Emission Pinch Analysis (CEPA) were used to reduce carbon dioxide (CO_2) emission generated in printing industry. CP audit was conducted in a printing premise to quantify the consumption of materials and energy, waste generated and other aspect such as safety and productivity. The amount of CO_2 emission generated from the operations and activities in the premise was estimated to identify key issues. Subsequently, CP options were identified to overcome the issues. Feasibility studies were conducted for each option identified to evaluate the reduction of CO_2 emission and monetary returns. The study revealed that a total of 0.8 kg CO_2 emission was generated per kg of paper processed, where electricity consumption was the main contributor. A total of eight CP options were identified and evaluated to reduce CO_2 emission generated from the electricity consumption and solid waste generation. Implementations of the suggested CP options are expected to potentially reduce the CO_2 emission to 0.7 tons CO_2/kg of processed paper, which is a reduction of 78%. The CEPA study also demonstrated that a saving of 211,194 kWh/month of electricity and a reduction of CO2 emission of 141.5 tons/month (68%) from the total emission of 209 tons/month could be achieved. There are four CP options can be implemented without any cost incurred, with expected CO2 emission reduction of 96.5 tons/month. Hence, the case study proves that it is possible to reduce CO2 emission in printing premise by implementing CP and CEPA.

KEY WORDS: *CO_2 Emission, Printing Process, Cleaner Production Audit, Cleaner Production Options, Carbon Emission Pinch Analysis*

1. INTRODUCTION

The printing industry in Malaysia is one of the oldest industries and has been growing rapidly in the last 10 years. It has played a major role as the main media for education, communication and dissemination of knowledge and information. Compared to the modern electronic media, it is by far, the cheapest means of bringing home the information to the public in every sector of society and in every nook and corner. According to Malaysia Department of Statistic, printing and publishing industry is grouped by wood products, furniture and paper products with accumulates 12.7% of components of value added of the SME's manufacturing sector. The printing industry is probably also among the top five largest industries in the manufacturing sector in Malaysia, with new licenses being issued every year. There are about 1,000 printing premises in Malaysia, which involved in general printing [1]. The Malaysian printers over the years have acquired vast experience and technical capability. Being aware of this potential of growth, the Malaysian Government is actively promoting the export of this service. Owing to its long existence, this is an industry where the competition has always been great, especially for the general-purpose printers who have to face stiff pricing competition. However, this does not deter inflow of foreign funds into the country to set up new printing factories in Malaysia. In recent years, the Malaysian paper industry has progressively increased its production capacity by two-fold, recording 90% self-sufficiency in the supply of paper and paper products and providing employment opportunities to 4,000 persons to date. In 2021, the investments recorded for printing and publishing, paper products and pulp and paper, was RM 403.4 mil [2].

Offset printing technology constitutes about 65% of complete printing industry, but very few in the printing community are aware of the environmental aspects of the premise [3]. Through various production processes for different types of printed products, various types of raw materials, chemicals, water and energy were used. This resulted to the generation of wastes and emissions that can cause significant impact to the environment and human health. Wastewater generated from printing operations, mainly from cleaning activities may contain lubricating oils, waste ink, cleaning solvents, photographic chemicals, acids, alkalis, and plate coatings, as well as metals such as silver, iron, chromium, copper and barium. The printing activities also emit volatile organic compounds from the use of cleaning solvents and inks, as well as alcohols and other wetting agents. Paper remains one of the major waste streams encountered in the lithographic industry. In Malaysia, only 100,000 tons out of 250,000 tons of newsprint a year recovered from the waste stream [1]. Other solid wastes also consisted of environmentally hazardous wastes such as photographic and residual chemicals, metal hydroxide sludge, dyestuffs and solvent residues, cleaning rags containing dyes and solvents, oil spills, expired materials, test production, bad printing or damaged products.

Another aspect of environmental pollution associated with printing premise is energy use, which contributes to greenhouse gas emissions and climate change. Energy consumptions are generally contributed by lighting, heating, cleaning, ventilation and motors used in different manufacturing and handling equipment [4]. A study by [5] indicated that electrical energy consumption and carbon dioxide (CO_2) emission associated with the production of 20,000 pieces of coloured printed box are 339 kWh and 207.5 kg, respectively. Various types of machines were used in printing processes mainly computer to plate machine, printing machine and trimming machine. Energy consumption can be minimized through efficient energy used. A study by Amon-Tran *et al*., (2012) showed that the optimization of an offset printing machine can reduce CO_2 emission from 399 kg to 129 kg, which is a reduction of 50%.

Cleaner Production (CP) is a preventive strategy, aiming to minimize negative impact of production processes, activities and products to the environment. CP combines all sustainability aspects that are required for greening the industry, since it implies zero pollution measures, energy and natural resources conservation, efficient, economical, safe and healthy environment for workers, communities and consumers, and socially rewarding outcomes at all production levels. CP strategy focuses on material saving, water and utility saving, reduction of waste generation and energy saving. It has been demonstrated through various case studies that CP is an effective environmental strategy, which bring out sustainable development for the industries. Previous works have presented case studies on fruit juice processing factory [6] and plastic resin recycling factory [7]. For example, [8] have conducted a study on a printing premise namely Printing Innovation Co. Ltd. to identify sources of air pollution and wastewater generation together with the sources of electricity loss. The study applied CP strategies to minimize air pollution in the production area, developed a wastewater treatment and minimized electricity loss in the production area. Thus, the study proposed to apply an air conditioning system that integrated with an Evaporative Cooling System which reduced electricity consumption of 149,841.8 kWh/year and monetary savings of USD14,210.5/year. The energy saving air conditioners reduces intensive inhalants in the air concentration of the production area to comply with the standard criteria. CP options for water management have reduced wastewater generation by 0.8% or 0.6 m^3/year and a savings of USD119.7/year. Subsequently, the construction of wastewater treatment system has reduced wastewater generation by 4.8 m^3/year and costs savings of USD6,580/year. Furthermore, it provided water recycling of 45 m^3/year. The study demonstrated that CP strategy could be implemented to identify improvement opportunities for printing premise as well as reducing the operational cost. However, study on the CO_2 emission evaluation before and after the implementation of CP options was not conducted.

CEPA is a Pinch Analysis technique that focuses on carbon-constrained sectors, where specific CO_2 emission limits are imposed on the planning of different energy resources. CEPA demonstrates the graphical approach of optimization between energy supply and demand. CEPA also quantifies the environmental impact in terms of emissions of using energy. CEPA is a graphical method for showing how much CO_2 emission are contributed from each part of energy sector and exploring possible pathways for modifying the energy system to meet fixed emissions targets. The CEPA technique evaluates the CO_2 emission reduction options available for a given process or system, making it a useful tool for energy sector planning that simultaneously considers the environmental and economic constraints [9]. CEPA is usually used to maximize the use of renewable energy sources and indirectly to replace conventional fossil fuel sources with high carbon intensity [10].

Hence, the aim of this study is to demonstrate the feasibility of using CP strategy in reducing CO_2 emission in a printing premise. Therefore, to achieve the aim, the objectives of this work are to identify key issues contributed by printing industry and thus identify opportunities in reducing CO_2 emission through implementation of CP options. The identified CP options were then evaluated in term of economic and environmental return. CEPA analysis was conducted based on the CP strategy. This study focuses on CO_2 emission, where material, energy and waste are the main contributors to the generation of CO_2 emission. Inefficient use of materials and energy leads to high amount of waste generation, thus contribute to high generation of CO_2 emission.

2. METHODOLOGY

The selected case studied printing premise is located in an industrial area in Kuala Lumpur, Malaysia, which occupies a land area of 83,000 ft^2. The premise was established in 1988 with 600 permanent workers. The premise processes an average of 3,600 tons of paper annually in various types of printing media, of which mainly comprises books, annual reports, magazines, examination papers, calendars and brochures. It provides a wide spectrum of basic to advance services in General Printing, Variable Data Printing, Security Printing, Digital Imaging and Archiving Solution. It also supplies Manage Print Services & Print Room Services, Information Products and A4 papers. The premise has ISO 9001:2008 certifications. The printing process, which is presented in Figure 1, incorporates four main sections, namely, pre press, printing, post press and auxiliary process. The premise operates in a batch production, where two batches of eight-hour production are done daily.

The production process of print media can be presented as image design and digital printing plate preparation, printing, finishing, packaging and finish product storage and delivery. The printing process starts with designing the digital image according to clients' specifications, followed by preparation of printing plates through the application of computer-to-plate technology. Hence, adjustment of printing colours is done, followed by overall printing operation. Finally, the printed media are cut, folded and glued. Finished products are then stored before delivery to customers. The production processes are operated in a 16°C fully air-conditioned rooms. At the end of each production day, printing rollers are cleaned with solvent-base reagents. Wastewater generated from the roller cleaning activities is collected and stored in 10-litre containers before being collected by the waste contractors. Remaining wastewater is discharged into public drains without any pre-treatment.

This study is conducted with an objective to demonstrate that implementation of CP strategies can assist printing industry to improve their economic and environmental performance, as well as productivity and company image. The study presents a feasibility study on the implementation of CP strategy with focus to reduce CO_2 emission in a printing premise in Malaysia. Hence, the CP methodology implemented in this study adopted step-by-step procedures developed by United Nation Environmental Programme, that comprises of conducting CP audit to quantify resources (materials, energy) consumption, waste generation and other related items such as safety, productivity, etc. estimate CO_2 emission generated from printing processes and activities in the premise, identify main issues in the premise, identify improvement opportunities, and evaluate the returns in term of economic and environment.

A walkthrough audit was conducted with an objective to obtain basic company background such as information of workers, production hours, products details, plant layout showing location of production area, administration building, storage area and process flow chart with detailed information on production processes and other activities related to the production. Visual inspection and observation were conducted to gather information and qualitatively identify issues in the premise. Hence, information obtained was used to identify the basis for determining the focus and depth of audit scopes. CP audit was conducted with an objective to quantitatively quantifying resources consumption, wastes and emission generated related to the production process. This was done through reviews on records and inventories of material and energy purchasing. Interview sessions were also held to inquire information on production processes. Further, material and energy balances were established where input and output streams were carefully measured to quantify materials and energy loss. In addition, one ton of paper processed was considered as the functional unit for this study. Hence, CO_2 emission generated from production operations in the premise is quantified as kg CO_2/ton of paper processed. Information obtained from the audit is used to evaluate premise performances on operational efficiency, as well as identifying sources of issues, thus determining targets for improvements. Materials balance was conducted by comparing the quantity of input materials and output materials, where the quantity of output should be equal to input. For example, total waster used in cleaning the facilities in the premise should be equal to wastewater generated that needs to be discharged into treatment facilities.

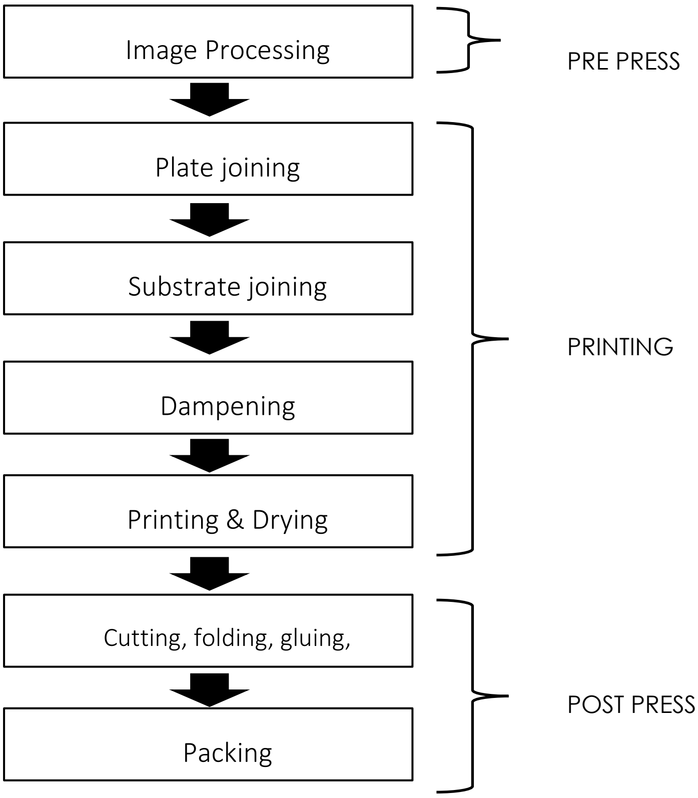

Fig. 1: Process flowchart of printing media processes

The difference in the quantity of wastewater generated and water used, indicate that there is a loss due to leakage or accidentally discharged into public drain without any treatment. Hence, the quantity of loss needs to be identified and improvement opportunities will be identified too. The energy balance was conducted by estimating the electricity consumed by most of electrical printing machines. Power ratings, together with operating hour were identified and kWhr were estimated by multiplying the two parameters (power rating (kW) and time (h)). For example, electricity consumed by the monthly operation of air conditioner is estimated by multiplying power rating (horsepower) and duration of the operation (hour/month). If there are any differences in the electricity bill and estimated values by calculation, the efficiency of each machine will be assessed, where low efficiency of machines consumed more electricity. Based on the analysis of material and energy balance, quantity of input and output streams are obtained sources of material and energy loss as well are identified, thus would be the basis for generation of CP opportunities. The analysis concentrated on water usage in different production process as well as wastewater generated by the production processes. Chemical characterization of wastewater stream was done to identify the loss of raw material and pollution load to the environment [11]. Further, electrical energy consumption for main unit operation in the process and solid waste generated from overall production activities was also presented.

Brainstorming session was conducted to generate as much as possible of CP options using methodologies developed from previous work [12] which can be further evaluated for capability in improving environmental performances especially in reducing CO_2 emission, as well as reduction in total production costs. The possible options are generated in two main categories, which are material substitution and technology changes, thus referring to reduction in electricity consumption and waste generation. However, as CP options are known as the economic-reasonable [13], the options proposed considers only on the low-cost and medium-cost, which potentially be implemented in a short period of time.

Subsequently, the amount CO_2 emission generated in the premise was estimated by evaluating five entities, which are the amount of water and electricity consumed as well as amount of wastewater, solid waste and scheduled waste generated. Thus, the calculation for the estimation of CO_2 emission generated in the premise adopted emission factor-based approach, according to default emission factors listed in the Intergovernmental Panel of Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories and heat value of fuel, using formula in Equation 1 by IPCC. CO_2 emission of an entity can be calculated by multiplying the quantity of entity with the respective emission factor. The respective emission factors are listed in Table 1.

$$\Sigma CO_2 = \Sigma\ (\textit{consumption or generation of entity} \times \textit{emission factor of entity}) \qquad (1)$$

Table 1. Emission factors of input and output streams [14]

Resources and Wastes	Emission factor	Unit
Water	0.8	Kg CO_2/ m^3
Electricity	0.67	Kg CO_2/ kWh
Scheduled waste	3.7	Kg CO_2/ kg
Solid waste	3.7	Kg CO_2/ kg
Waste water	1	Kg CO_2/ kg COD (removed)

The most commonly used graphical tool in CEPA is the energy planning pinch diagram (EPPD), which consists of the demand and source composite curves. The source composite curve is plotted with the total electricity generated from the equipment on the x-axis and cumulative quantity of total CO_2 emissions generated on the y-axis. Each energy source is plotted as a segment so that its electricity output (kWh/month) and carbon emissions (kg CO_2/month) lie along the horizontal and vertical axes of the diagram.

3. RESULTS AND DISCUSSION

3.1 Cleaner Production Strategy

The study showed that a total of 2,886 m^3 of water is used monthly. The quantity of water consumed was obtained by reviewing the water bills. Approximately 38 m^3 of wastewater are generated from the roller cleaning activities. The wastewater generated from this process was stored in a specific labelled container. Thus, the quantity of the wastewater was obtained by weighing the water containers. Furthermore, 2,092 m^3 are generated from overall washing activities, with a chemical oxygen demand (COD) value of 96 mg/liter. City water was purchased at USD0.63/m^3 of water, resulted in USD1,818/month. In addition to water, electricity is used in the production processes with hourly operation consumption is approximately 312,226 kWh/month. Electricity was purchased at USD0.11/kWh, resulted in an annual cost of about USD412,138. Table 2 shows details resources consumption of the studied premise.

Table 2. Resource consumption of overall printing processes

Resources	**Water (m^3)**	**Electricity (MWh)**	**Paper (tons)**	**Ink (kg)**	**Fountain Solution (l)**	**Lubricating Oil (l)**	**Cleaning agents (l)**
Annual consumption	34,632	3,747	3,600	4,908	9,096	16.8	150,216

In addition, solid waste generated from overall production activities was identified to be the waste papers, included trimmed papers and off-specification products and quantified as 6 tons/month, with approximately 72 tons generated annually. The scheduled wastes mainly spent oil, solvents, scrapped ink from rollers and cleaning cloths were estimated to be 3,116 kg/month, were stored and labelled before being collected by waste contractors. The amount of waste was obtained by weighing the containers. Figure 2 presents results on material and energy balance study conducted.

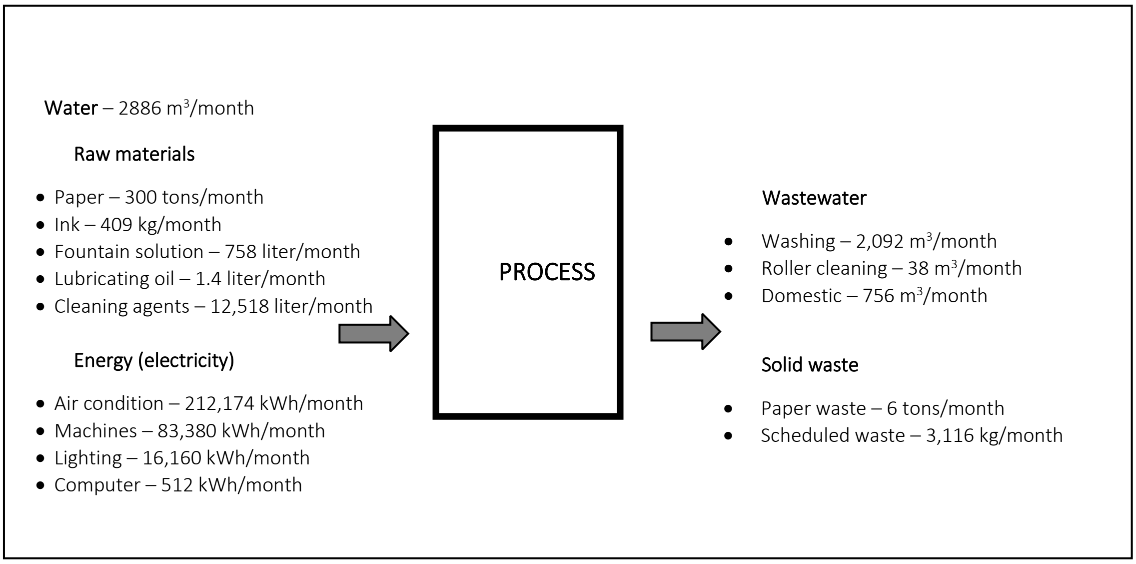

FIG. 2. Analysis of input-output streams

Referring to Table 1 and Table 2, the amount of CO_2 emission can be estimated by applying formula as per Equation 1. For example, water consumed was 34,632 m^3/year, whereas emission factor for water as per listed in Table 1 was 0.8 kg CO_2/m^3. Hence, by multiplying the amount of water and emission factor of water, CO_2 emission generated from water consumption will be 27,705.6 kg/year. The same calculations were then applied to another four entities and total CO_2 emission generated from the premise was obtained by summing the values from the total five entities. Therefore, the breakdown of CO_2 emission sources and respective percentage are summarized in Table 3. From the CO_2 estimation obtained in Table 3, total emission is approximately 245 tons on a monthly basis, resulted in 2,940 tons per annum or can be presented as 0.8 tons CO_2/ton of paper processed. Further, electricity consumption is the major contributor of CO_2 emission, which constituting about 85% of total percentage, with quantitative values of 209 tons CO_2/kWh in a monthly basis or 0.7 ton CO_2/ton of paper processed. Thus, electricity can be considered as the targeted entity as well as focus areas for major improvement potential, in terms of CP opportunities.

Table 3. Ecological profile

Entities	CO_2 emission (ton)	ton CO_2/ton paper processed
2,886 m^3 of water	2.3 [a]	0.007
312,226 kWh of electricity	209 [b]	0.7
6,000 kg of solid waste	22 [c]	0.07
3,000 kg of schedule waste	11 [d]	0.04
2,886 m^3 of waste water	0.3 [e]	0.001
Total	244.6	0.8

a	CO_2 emission (kg)	=	0.8 kg CO_2 /m^3 x 2,886 m^3	= 2,309 kg
b	CO_2 emission (kg)	=	0.67 kg CO_2 /kWh x 312,226 kWh	= 209,191 kg
c	CO_2 emission (kg)	=	3.7 kg CO_2 /kg x 6,000 kg	= 22,200 kg
d	CO_2 emission (kg)	=	3.7 kg CO_2 /kg x 3,000 kg	= 11,100 kg
e	CO_2 emission (kg)	=	1 x 2,886 x 96 x 1, 000 / 1, 000, 000	= 277 kg

As shown in Figure 2, air conditioning system contributes as the major electrical consumer with approximate percentage of 68%, followed by machinery operation. CP options focuses on implementing efficient operation of air conditioners, lighting system and air compressor. Efficient energy use may be achieved through implementation of options that require low monetary investment. Options that do not require monetary investment should be implemented immediately such as turning off lights during the 1-hour rest time can reduce electricity consumption by 2,222 kWh/month or 1.5 tons of CO_2 emission/month, which is equivalent to a cost reduction of USD244/month. Improving lighting zone by installing clear glass window at the operation areas can allow penetration of natural light, thus reduces the needs for commercial lighting by 50%. Hence, the option can reduce electricity consumption by 8,000 kWh/month and CO_2 emission by 5 tons. The premise can potentially save USD880/month by implementing the option. In addition, the premise should install 22 watt-T5 fluorescent lamp, where a unit of T5 consumes only 9,300 kWh of electricity a month, thus reducing 42% of electricity consumption as compared to the existing lighting system. CO_2 emission can be reduced by 4.6 tons and cost reduction of USD755 a month.

As for the ventilation requirements, it is recommended that the premise should ensure suitable temperature setting for air conditioners, where low temperature setting causes high cooling load, thus increase electricity consumption. Based on calculation according to the Formula of Ideal Air Conditioner Temperature, by increasing the inner temperature from 16°C to 26°C, with an outside temperature of 30°C, approximately 71% of energy savings can be achieved. Hence, implementation of this option should be able to achieve monthly electricity savings of USD16,571 as well as reductions of 101 tons of CO_2 emission. Further, installation of energy saving air conditioner could achieve a monthly reduction in electricity consumption by 67,244 kWh, or can be translated into USD7,397. Thus, reduction in CO_2 emission can be achieved by 45 tons/month. Recent studies show that cooling requirement can be determined according to the size of the area covered. Though the cooling capacity of existing air conditioners should be revised accordingly. Based on the observation at the premise, air-conditioning systems are not mandatory in all areas, where certain area only requires good ventilation.

In further, installation of an inverter unit of the motorized equipment could potentially reduce 70% of the energy consumption, or 58,366 kWh/month, resulted in the monthly estimated reduction of CO_2 emission of 39 tons. A case study by screen-printing premise has proven that the installation of smart meters to monitor its electricity usage resulted in USD470 of reduction, with return on investment in eighteen months. In addition to CP options for electricity savings, turning off air compressor during the one-hour rest time can potentially reduce monthly electricity consumption by 29,172 kWh or 20 tons of CO_2 emitted, with the monetary savings of USD3,209. Further, leakages could be a significant source of energy wasted in industrial compressed air system. Hence, maintaining and regular monitoring of compressed air system able to reduce electricity consumption without any cost investment.

Table 4. Summary of economic and environmental feasibility evaluation of recommended cleaner production opportunities

Area	**CP options**	**Estimated monthly savings in USD**	**Estimated monthly CO_2 emission reduction in tons**
Air conditioning	1. Increase temperature from 16°C to 26°C.	16,571	101
	2. Installation of energy saving air conditioner.	7,397	45
Machineries	1. Installation of inverter unit of motorized equipment.	6,420	39
	2. Turn off air compressor during one-hour rest time.	3,209	20
Lightings	1. Turn off lights during one-hour rest time.	244	1.5
	2. Installation of clear glass window at the operation areas.	880	5
	3. Installation of 22 watt-T5 fluorescent lamp.	755	4.6
Solid waste	1. Optimizing the size of papers for printed media.	9,300	13

As for the reduction of solid waste generated in the premise, the CP options focuses on the strategy to reduce the amount of waste trimmed paper generated. It is recommended that the excess paper can be used for printing notepad or calendar. Further, the waste paper generation can be reduced by optimizing the size of papers for the production of certain types of printed media. The strategy can be done through the dissemination of knowledge to the clients on the need of paper optimization. Based on the estimation, material cost can be reduced by USD9,300 a month for a 50% reduction of waste paper. Hence, CO_2 emission is reduced by 50% or approximately 13 tons, which equivalent to 51 trees. Good housekeeping should be implemented to avoid excessive waste. Maintaining sharp cutter for post printing processes can avoid damage to printed products, thus lowering product rejection rate and waste eventually. Clear guidelines and training should be provided to workers in handling materials and machines. In addition, proper loading of papers into the printing machine could reduce paper damage as well as save in production time by reducing faulty machine operation. Table 4 presents on the details of the above-mentioned suggested CP options.

3.2 Carbon Emission Pinch Analysis

In this study, graph between CO_2 emission and electricity was plotted to find its relationship. This investigation was performed based on the CP strategy. Figure 3 shows that there was a saving of 211,194 kWh/month of electricity. The study also demonstrated that there was a reduction of CO_2 emission of 141,500 kg/month (68%) from the total emission of 209,191.4 kg/month as shown in Table 5.

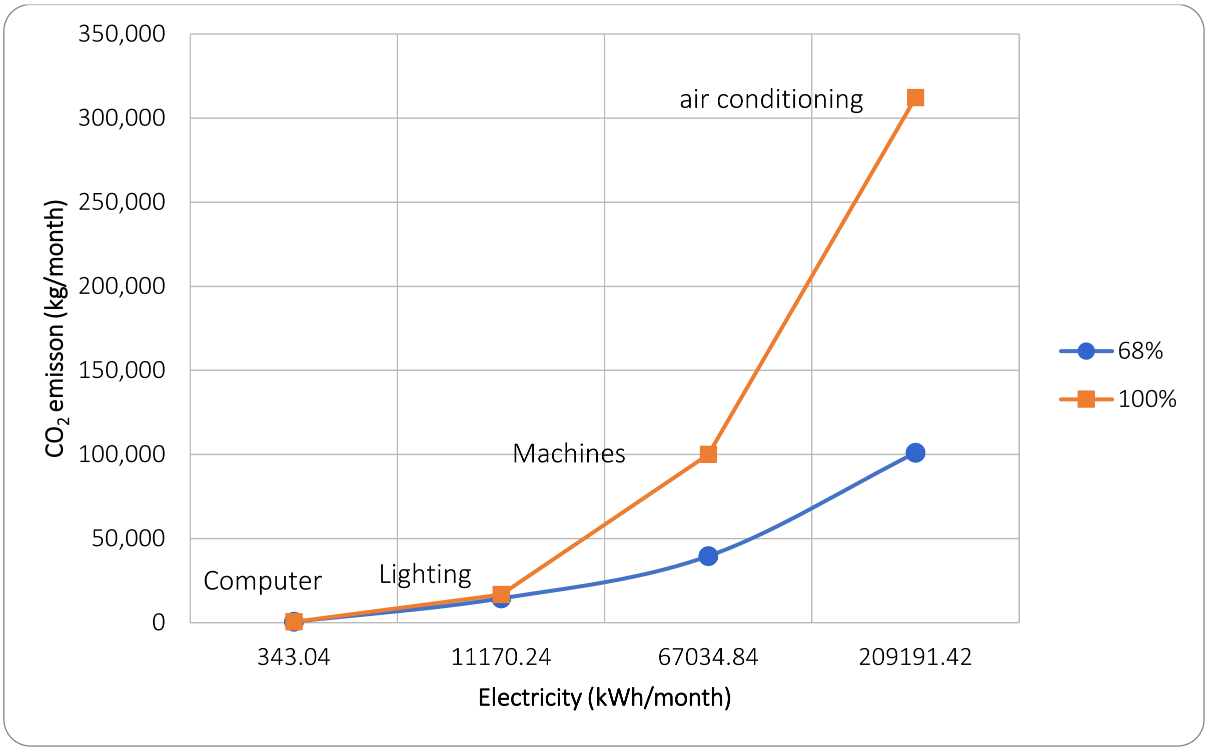

FIG. 3. Plot of electricity and CO_2 emission

Table 5. Summary of CEPA for electricity

	Actual		After reduction 68%	
	Electricity (kWh/month)	CO_2 emission (kg/month)	Electricity (kWh/month)	CO_2 emission (kg/month)
Air condition	212,174	142,156.58	61,428	41,156.58
Machines	83,380	55,864.6	25,171	16,864.6
Lighting	16,160	10,827.2	13,921	9,327.2
Computer	512	343.04	512	343.04
Total	312,226	209,191.42	101,032	67,691.42

4. CONCLUSION

From the study conducted on the premise, it shows that the key issue in the premise is high electricity consumption. The total CO_2 emission of the premise was estimated at 245 tons of CO_2/month, which produced 0.8 kg CO_2/kg of paper processed. It was found that energy consumption, which contributed to the high percentage of CO_2 emissions, consisted of three major sources, which were air conditions, machineries, and lightings. To reduce energy consumption, the main CP options for each of the sources were generated and evaluated with the estimated total electricity savings of USD35,476 and reduction in the generation of CO_2 emission by 216 tons of CO_2 a month. Meanwhile, even though the premise generated 6 tons of paper waste as a result of its printing activities, the amount of wastepaper was only 2% of the total paper used. This value is still below the normal standard of the printing industry and can be used as a benchmark for the premise to further reduce the amount of paper waste generated from the printing process. However, a saving of USD9,300 a month is expected to be achieved by implementing suggested option. Implementation of proposed CP options is expected to reduce 229 tons/month of CO_2 emission, with cost savings of USD44,776.

Based on the findings, it shows that CP concept can be applied in the printing industry to identify the opportunities that can be implemented to reduce the CO_2 emission generated from printing activities and processes. This assessment of CO_2 emission serves as a first step for the industry to establish the procedure and methodology for comprehensive CO_2 emission printing of the printing industry. In addition, similar concept can be introduced to other types of industry, which can contribute to reduce CO_2 emission.

Finally, this concludes that the aim of the study, which is to demonstrate the greening of the offset lithography printing industry through the implementation of CP practices, is achieved. The CP options proposed are feasible in terms of economic and environmental aspects and can be implemented by the industry successfully especially the cost free options. Furthermore, CEPA proves that it can identify the minimum requirement of electricity to be included in printing industry. However, this method only applicable for electricity planning since it did not includes other waste such as water, wastewater and solid waste.

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