Study on the opportunity of carbon footprint reduction through energy measurement by implementing good operating practices in PVC flooring mat manufacturing industry

F Wahab, A M Andrew, N Z N Azizan, S Ragunathan, N A A Seman, W H Tan, M A C Munaaim and S Y Seah.

Abstract. This paper outlines the carbon emission reduction opportunities through energy measurement by implementing good operating practices and good housekeeping in PVC floorcovering mat industry in Perlis, Malaysia. The baseline data was obtained through the energy audit to identify the area to be improved. Cleaner Production (CP) options through good operating practices and good housekeeping were suggested to be implemented in the area of concern. The performance of the suggested CP was analyzed in terms of (1) energy efficiency, (2) carbon emission reduction and (3) cost-saving according to the payback period. The results show that the CP option of utilization of rest time of intensive mixer has contributed to the most energy saving of 8.18%, followed by steam pipe insulation, 2.9%; steam trap maintenance, 0.95% and steam pipe leakage maintenance, 0.15% with the total CO2 emission saved of 185,573 tCO2/year corresponds to the overall energy save of 5.2%. Through the comparison between the estimated values and the measured values based on energy baseline model, it was found that the CO2 intensity had decreased by 21.8%. The finding shows that there exists a significant opportunity to reduce CO2 emissions through energy measurement in PVC flooring mat manufacturing industry by the implementation of good operating practices and good housekeeping.

1. Introduction.
Greenhouse gas emissions and their impact on climate change are of great concern. Malaysia has put its commitment to reduce 45% of carbon emission intensity of Gross Domestic
Products (GDP) by 2030 equivalent to 2005 level [1]. Although the use of pollution control technology may help in reducing the industrial effluent and emission, but the installation of the pollution control was not always affordable in all manufacturing industries especially small medium industries (SMIs) since it requires vast investment and high cost of maintenance. The sustainable option to reduce the emission and waste generation without involving higher investment is through reducing it from its source. Manufacturing sector is the highest consumer on energy and energy sector has contributed the highest amount of greenhouse gas to the environment. Therefore, the effort to reduce carbon emission by increasing the energy efficiency per production and reducing the energy wastage are the sustainable initiatives to reduce carbon emission from its source with least cost and most practicable way.

The main objective of this project is to promote the Cleaner Production (CP) concept among Malaysia’s industries especially for the Small Medium Industries (SMI) by discovering the opportunities for energy reduction through the implementation of CP options. To achieve this, three (3) specific objectives had been established. Firstly, the establishment of baseline data for energy consumption and CO₂ emission for the production process. Secondly, the identification of practicable CP options to be implemented in the selected area of production. Thirdly, the comparison of the CP options performance in term of CO₂ emission reduction and energy savings. A case study was performed in PVC flooring mat manufacturing industry, located in Bukit Keteri, Arau, Perlis, Malaysia. The company was established in 2006 with a paid-up capital of RM 2,000,000 and employed the manufacturing technology from Korea. Previously, the company was owned by Perlis State Economic Development Corporation. The capacity productions are 45000 rolls or 1500 tonnes per month and send to the local market and overseas. Recently, the demand for PVC flooring mat has decreased due to competition with other alternatives of floor finishes. As a result, the company showed higher electricity consumption per unit of production which resulting in lower energy efficiency for each production. Consequently, the relative CO₂ emissions from electricity consumption also increased. The data from this study is as proof to justify the energy performance and the initiative of the company to improve the energy efficiency in their production, as a result the special rate could be obtain from the electricity provider.

2. Methodology

Energy audit was performed in the production process to measure the energy usage at a specific process or area before the CP initiatives being implemented. On top of CP options, only good operating practices and good housekeeping were considered to be implemented as it involves low cost and has more acceptance from the company. The feasibility study was carried out to the suggested initiatives which include calculation, simulation, and economic evaluation.

2.1 Energy measurement

Two (2) types of energy sources that are mainly used in the production process are electrical energy and fuel energy as shown in Table 1. Electrical energy was obtained from electricity provider which is generally used to move the mechanical parts of the machinery. While the fuel energy obtained from three (3) types of oil fuels, they are recycled medium oil, fuel oil 92 and diesel. The oil fuels were used to generate steam from the boiler and to provide heat to the thermal oil heater respectively.
Table 1. Energy sources used in the production of PVC flooring mat.

| Energy source | Equipment                      | Function                                      |
|---------------|--------------------------------|-----------------------------------------------|
| Electricity   | All machinery in the production line | To move the mechanical part of machinery      |
| Oil fuel (Recycle medium fuel) | Boiler                     | To generate steam to supply heat to the equipment |
| Oil fuel (Fuel oil 92)     | Thermal oil heater 1 (TOH 1)  | To supply heat to the equipment               |
| Oil fuel (Diesel)         | Thermal oil heater 2 (TOH 2)  | To supply heat to the equipment               |

The baseline data of energy utilization was obtained through an energy audit that was performed in two (2) stages, preliminary audit and details energy audit. A preliminary audit was performed by analyzing the previous record of electrical energy consumption as well as the monthly fuel consumption of the boiler and thermal oil heater from the year 2015 to 2017. Besides, a walkthrough survey was carried out to obtain overview information on the overall process and energy distribution in the plant. Specific energy consumption (SEC) and baseline graph were constructed according the data obtained from this stage by using equation (1) [2].

\[
SEC = \frac{\sum_{i=1}^{N} I_{i}E_{i}t}{P_{t}} \tag{1}
\]

where, \(J_{i}\) is number of units associated with energy source, \(I_{i}, E_{i}\) is quantity of energy source \(I\) used during period \(t\), \(N\) is number of energy sources and \(P_{t}\) is quantity of production during period \(t\).

In the detailed audit, the measurement of energy input and output was performed gate-to-gate starting from the process of backlayer, top and middle layer, printing and laminating. The calcium carbonate plant process as filler supplier was also included in the audit. The overall process and the audit boundary is shown in Figure 1. Furthermore, a digital current clamp ammeter was used to measure the exact power consumption for the electrical equipment by clamping the main electric wire inside the particular electric box.

The measurement of the electrical energy of each equipment was calculated by using equation (2).

\[
\text{Electrical energy} = \text{power} \times \text{time usage} \tag{2}
\]

Then, the efficiency of the electrical equipment was calculated by using equation (3).

\[
\text{Efficiency} = \frac{\text{Different}}{\text{Input}} \times 100\% \tag{3}
\]

2.2 Carbon Dioxide Emission.

The overall CO\(_2\) emission from the PVC flooring mat production was calculated by multiplying the energy consumption by the associated emission factor (EF) as shown in equation (4) [3].

\[
\text{CO}_2 \text{ emission} = \Sigma \text{EF} \times \text{Energy Consumption} \tag{4}
\]
The emission of carbon dioxide is usually expressed in tonnes. To get the specific emission per production, carbon dioxide emission was presented in term of carbon dioxide intensity and calculated according to equation (5).

\[
\text{CO}_2 \text{ intensity} = \frac{\text{CO}_2 \text{ emission (ton)}}{\text{Production (roll)}}
\]  

(5)

2.3 Performance analysis
Performance analysis was focus on the three (3) elements include energy saving, carbon footprint reduction, and operational cost savings. The data is presented to evaluate the effectiveness and feasibility of each suggested CP practices. The potential saving for each CP practices was calculated using formula (6) and (7) while the pay-back period and CO2 save was calculated by using formula (8) and (9) respectively [2].

\[
\text{Energy save (MJ)} = \frac{\text{Energy usage before CP practices} - \text{Energy usage after CP practices}}{\text{Energy usage before CP practices}}
\]  

(6)

\[
\text{Cost save (RM)} = \text{Energy save} \times \frac{\text{cost}}{\text{kWh or cost}}
\]  

(7)

\[
\text{Pay-back period} = \frac{\text{Investment cost}}{\text{cost save/month}}
\]  

(8)

\[
\text{CO}_2 \text{ save} = \text{Energy save (MJ)} \times \text{emission factor}
\]  

(9)

3. Results and Discussion

3.1 Energy consumption and CO2 emission analysis.
Figure 2 shows the specific electrical energy consumption for the PVC floor mat production in the year 2015 to 2017. It can be seen that electrical energy usage was increased by production. According to electricity consumption data from 2015 to 2017, the amount of electricity consumption was decreased by 20.76% however the production rate was also decreased even more than that at 37.61%. This indicates that the energy usage per roll of products was increased year by year and consequently had increased the intensity of CO2 emission. Fig. 3 shows the comparison between the total CO2 emission over the intensity of CO2 emission per roll production for year 2015 to 2017.

According to the daily record of fuel consumption in the year of 2017, the energy baseline of fuel consumption was established as shown in Fig. 4. From the figure, it is shows that boiler had consumed the most of fuel energy which is using 18099.65 GJ annually with the average of 1665.53L/day, followed by thermal heater 1, 5596.26 GJ (594.94L/day) and thermal oil heater 2, 2226.52 GJ (251.13L/day). The calculation of CO2 emission from the fuel consumption indicated that the boiler operation emit the highest CO2 emission followed by thermal oil heater 1 and thermal oil heater 2 with the total CO2 emission of 1168.9 tonnes, 350.93 tonnes and 139.62 tonnes CO2.

An overall CO2 intensity baseline for 2017 was constructed as shown in Fig. 5. This graph was constructed by the combination of the amount of CO2 emission from electrical usage and fuel usage in manufacturing production in year of 2017. It is based on linear regression model to construct a baseline with an equation of \( y = 0.0149x + 208.97 \) that able to calculate and predict the energy productivity target for future. The positive sign of correlation value, \( R^2=0.687 \), shows that the relationship between the production rate and the amount of CO2 emission produced is strongly link.
Raw material management → Back layer → Mixing → Laminating → Deliver

- Raw material input
- Transportation
- Calcium carbonate plant → crushing → milling

Mixing → Warming → Calendaring → Embossing → Cooling → Winding

Unwinding → Heating → Embossing → Cooling → Inspection → Winding

Electrical energy
Fuel energy

CO₂ emission
Heat loss
Others emission

Boundary of energy audit of the PVC flooring mat manufacturing process.
Figure 2. Energy baseline from 2015 to 2017

Figure 3. CO₂ emission versus CO₂ intensity from 2015 to 2017

Figure 4. Energy baseline based on fuel consumption in 2017
Figure 5. CO₂ intensity baseline in 2017

3.2 Energy significance cost area.
Significance cost area is defined as the area or equipment with high energy consumption. Fig. 6 shows the energy usage by process which includes calcium carbonate plant, factory 1, factory 2, printing line, laminating line, boiler and thermal oil heater in daily basis. Factory 1 is responsible to process the back layer of the flooring sheet while factory 2 is responsible to process top layer and middle layer of the flooring sheet. It shows that boiler has consumed the most energy (83,183 MJ), followed by factory 1 (53,424 MJ), factory 2 (44,103.6 MJ) and thermal oil heater (37,503 MJ). The rest of the process shows insignificance energy usage compared to others. Hence, the process of factory 1 and factory 2 will be concern based on electricity consumption, while boiler and thermal oil heater are concerned based on fuel consumption.

Figure 6. Energy usage by process
As each process is actually involved several small processes by using specific machines, it is more applicable to identify significant cost area in equipment involved so that it is easier to target with suitable CP option implementation. Fig. 7 shows the electrical consumption of equipment that exists in both factory 1 and factory 2 process such as intensive mixer, mixing mill, warming mill and calendaring machines that consumed energy more than 500 kWh per day. The significant cost areas that will be concern to do energy efficiency efforts in this project in electrical consumption are intensive mixer and planetary extruder. While for fuel consumption area, boiler is concerned with steam pipe distribution system since it has the highest energy consumption rate.

3.3 Cleaner Production (CP) Options.

The area of processes that had been improved were boiler operation which focus on the steam pipeline distribution; and electrical machinery. Both area indicated consumed major of fuel and electrical energy. The CP initiatives suggested for steam pipeline distribution were divided into three (3) options, consist of steam pipe insulation, steam trap maintenance, and steam leakage maintenance which categorized as Good Houskeeping initiative. While for the electrical machinery, only one (1) option has been suggested. It is utilization of rest time of intensive mixer which categorized as Good Operating Practices initiative.

3.3.1 Steam pipe insulation. Table 2 shows the data of fuel energy consumption of boiler in 2017. From the table, it is indicated that 15,365L or 3.26% of total fuel consumption have been wasted in year 2017 due to the heat loss of steam in the pipe line distribution. From the view of energy, it is about 589,980 MJ had been wasted that cost the company about RM 14,597. It also contributed to the excess emission of CO2 for about 38.1 ton from wasted fuel.

| Table 2. The data on the efficiency of steam pipe insulation. |
|---------------------------------------------------------------|
| **Consumption** | **Heat loss** | **Heat loss (projection after CP implementation)** | **Saving** |
| Fuel (L) | 471,345 | 15,364.1 | 1,536.7 | 13,827.4 |
| Energy (MJ) | 18,099,648 | 589,980 | 59,000 | 530,980 |
| Cost (RM) | 691,881.1 | 14,597 | 1,459.87 | 13,137.13 |
| CO2 emission (ton) | 1168.93 | 38.1 | 3.81 | 34.3 |
It is projected that 90% of the heat lost will be reduced after the installation of steam pipe insulation which resulting about 2.9% of fuel saved which correspond to 13,827.4L in year 2017. Furthermore, the cost to install rock mineral wool pipe insulation in this factory is about RM 2,312.1 which result in a short pay-back period that only requires 2.11 months. The effectiveness of steam pipe insulation was simulated by using ANSYS academic version software to illustrate the temperature distribution along a 1m length steam pipe with insulation. From this simulation, it shows that only 1ºC of temperature has been dropped from the inlet to the outlet. It means that very less heat loss occurred along the steam pipe as the rock mineral wool pipe insulation will be prevented the heat loss penetrate to the surrounding environment. The pipe insulation has greatly conserved the heat energy inside the pipeline and maintains the temperature of steam fluid.

3.3.2 Steam trap maintenance. The steam trap is a great energy saving element in steam pipe distribution as it can separate condensate water and quickly exhaust it and prevent steam hammer inside the pipe. The steam pipe need to be maintain after 3 to 5 years otherwise 15%-20% of the traps can be malfunctioning, thus allowing live steam to escape into the condensate return system [4]. The steam pipe distribution in the factory including 13 steam traps had no maintenance since 2014 which were more than 3 years. Therefore, it can be assumed that 2 out of 13 steam traps in the factory might be inefficient or malfunction to operate.

| Table 3. The data on the efficiency of steam trap maintenance |
|---------------------------------------------------------------|
|                               | Annually | CP practice | Annually |
| Fuel loss (L)                | 4519.51  | 0           | 4519.51  |
| Energy loss (MJ)             | 173549.18| 0           | 173549.18|
| Cost (RM)                    | 4293.5   | 0           | 4293.5   |
| CO₂ emission (ton)           | 11.2     | 0           | 11.2     |

According to Table 3, it was assumed that 50% of steam leaked throughout the trap orifice. The estimated steam loss was about 4.16 kg/hr which corresponded to fuel loss and the energy loss at 4,519.51 L/year and 173,549.2 MJ/yr respectively. The CO₂ emission correspond to the energy loss was 11.2 tCO₂ per year and contributes to cost wastaged up to RM 4,293.50 per year. From the estimated calculation, it was found that even after maintenance on the steam trap leakage with 100% efficiency,
only 0.95% energy saved on the recovery of the leaking trap. Hence, the amount of energy saved is about 4,519.51 L/year which is same as the amount of energy saved.

3.3.3 Steam pipe leakage maintenance. Steam pipe leakage is a serious energy waste situation as it is completely unnecessary but unfortunately quite common to happen in the factory. Based on the observation, it was found that there were few steam pipe leakage occur at factory 1 during production. There are two area on 20mm steam pipe leakage with 20mm hole diameter and another two area on steam leaks with 3mm hole diameter on 30mm steam pipe. The annual fuel loss, energy loss, cost and corresponding CO2 emission is shown in Table 4. Since the occurrence of steam pipe leakage is very frequent, the monthly loss were evaluated to understand the serious effect of pipe leakage to the wastage on the energy, cost and unnecessary emission of CO2. From the calculation, it was found that the pipe leaks have contributes to 59.1 L fuel loss per month with energy loss of 2,269.5 MJ which cost RM 56.15 that going to emit 0.15 tCO2/month. With 100% efficiency after the maintenance, it is about 0.15% on energy saving for this practices. The cost to do the maintenance work on these four areas including sealed material is around RM 60. With the occurrence of 6 times per year, the total cost would be RM 360 per year. Hence, the pay-back period was found to be 6.41 months.

|                | Monthly | Annually | CP practice | Annually Save |
|----------------|---------|----------|-------------|---------------|
| Fuel loss (L)  | 59.1    | 709.23   | 0           | 709.23        |
| Energy loss (MJ)| 2,269.5 | 27,234.43| 0           | 27,234.43     |
| Cost (RM)      | 56.15   | 673.77   | 0           | 673.77        |
| CO2 emission (ton) | 0.15   | 1.76     | 0           | 1.76          |

3.3.4 Rest time utilization of intensive mixer. Intensive Mixer is the first process of making back layer at factory 1. It is also the highest energy usage of all others machinery which contain 7470 kWh/day. This machine will run for 24 hours with the cycle of 9 minutes processing and 5 minutes gap time for rest. The rest means there is no production on work on the intensive mixer but the machine is still running. Therefore, this 5 minutes gap time has the opportunity to reduce and thus, increase the productivity of production. From the calculation, if the rest gap time is reduced from 5 minutes to 3 minutes, the time wasted is reduced from 8.57 hours to 6 hours per day. 2.57 hours is saved to perform production that can increase productivity which approximately 8.18% of energy saving on electrical consumption. Refer to Table 5, rest time utilization on intensive mixer can help to save 250,371.8 kWh of energy loss that corresponding saving 185,525.5 tCO2/year which would also cost RM 67,350.02 per year. From here, the CO2 saved means the carbon emission saved from the energy waste that has turned into productivity and not the actual carbon footprint saved that could emit to the atmosphere. In other words, the carbon emissions saved has been turned into production which has increased energy productivity and lowers down the value CO2 intensity of the product. This means the energy efficiency is increased with good management of resources. This operating practices only involve the engagement of labor force that should increase their salary about RM360 per person to do extra work. Hence, the pay-back period was found to be 6.7 days for every month. For yearly, it was found to be 2.63 months.
Table 5. The data on the efficiency of rest time utilization of intensive mixer

| Energy loss (kWh) | Daily | Annually | CP practice | Annually Save |
|-------------------|-------|----------|-------------|--------------|
|                   | 2667.41 | 834,899.33 | 584,527.5 | 250,371.8 |
| Cost (RM)         | 717.53  | 22,458.792 | 15,723.79  | 6,735.02   |
| CO₂ emission (ton)| 1976.55 | 61,866.04  | 43,313.49  | 18,552.55  |

3.4 Performance Analysis.

The performance analysis of the suggested CP options were evaluated in term of energy saving, cost saving, carbon dioxide reduction correspond to energy saving and pay-back period of CP options.

3.4.1 Energy saving. Base on record from detail audit, there were 128,355 rolls of PVC mat had been produced in 2017. On top of that, about 3,425 MWh of electrical energy and 18,947 GJ of fuel energy have been used with the specific energy consumption 26.69 kWh/roll and 147.61 MJ/roll respectively. From the performance of four (4) suggested CP options, it was found that the utilization of rest time of intensive mixer had reduced 8% of electrical energy loss which contributes to 55% of energy saving from the total energy saving as shown in Figure 9. Meanwhile for the reduction of fuel energy loss, steam pipe insulation provide the highest reduction followed by steam trap maintenance and steam pipe leakage maintenance which contribute to 32%, 11% and 2% reduction of total energy saving respectively. It can be concluded that electrical energy provide significant impact on energy saving as compared to fuel energy.

![Figure 9. The Energy saving](image)

3.4.2 Cost saving. In comparison between the four (4) initiatives, the initiative of rest time utilization of intensive mixer provides the highest saving in energy cost at about RM 67,509 or 79% of total energy cost saving per year. Then, followed by initiative of steam pipe insulation, steam trap maintenance and
steam pipe leakage maintenance which contribute to 15%, 5% and 1% of total cost saving respectively (Refer Figure 10). Through the implementation of these four (4) initiatives, the estimated of total cost that could be saved is about RM 85,454.42. It can be concluded that good operating practices initiative (rest time utilization of intensive mixer initiative) provide the significant impact on cost reduction than good housekeeping initiative (steam pipe insulation, steam trap maintenance and steam pipe leakage maintenance).

**Figure 10.** Cost saving

![Cost saving](image)

**Figure 11.** Carbon dioxide saving saving (tCO₂)

![Carbon dioxide saving](image)

3.4.3 *Carbon dioxide emission reduction.* The previous sub chapter had highlighted that the great saving in energy and cost were contributed from the initiative related to the optimization of electrical energy
usage. Similar result for the carbon dioxide emission as shown in Figure 11, the rest time utilization of intensive mixer indicates the greatest amount of CO$_2$ reduction that is 185,525.5 tCO$_2$/year correspond to electrical energy saving. This is due to the higher emission factor of TNB grid that is 0.741 tCO$_2$/kWh as compared to medium fuel oil emission factor at only 0.00248 tCO$_2$/L which was used for steam generation.

The total CO$_2$ emission reduction from the fuel saving on the steam pipe distribution is only about 47.26 tCO$_2$ per year. Among CP options suggested on the steam pipe distribution, the highest CO$_2$ reduction was contributed from the steam pipe insulation option that is 34.3 tCO$_2$/per year, followed by steam trap maintenance and steam pipe leakage maintenance which are 11.2 tCO$_2$ and 1.76 tCO$_2$ reduction per year respectively. Although the amount of CO$_2$ reduction from fuel energy saving is relatively lower than electrical energy saving, however the impact is also significance and must be acknowledged since the CO$_2$ emission is released directly from the operation processes of the factory. Unlike the electrical energy, the CO$_2$ emission was emitted indirectly from the factory.

3.4.4 Payback period. Payback period refers to the time required for the investment reaches a break-even point. Refering to Figure 12, steam trap maintenance has performed the shortest pay-back period which only contains 1.09 months, followed by steam pipe insulation, rest time utilization of intensive mixer and steam pipe leakage maintenance with the period of 2.11 months, 2.63 months and 6.41 months respectively. Although the option of utilization of the rest time of intensive mixer provide no initial investment, however the option requires the engagement of labor force to do extra work which increase their salary about RM 360 per person.

![Figure 12. Pay-back period based on suggested CP practices](image)

4. Conclusion
This project was done at PVC flooring mat manufacturing factory located in Bukit Keteri, Arau, Perlis, Malaysia. They were four (4) CP options suggested to the area that required some improvement that include boiler operation which focus on the steam pipeline distribution; and electrical machinery. The CP options were categorized into good housekeeping initiative (three (3) options) which implemented on the steam pipeline distribution; and good operating practices initiatives (one (1) option) which implemented on the intensive mixer. Among of the CP options, the utilization of rest time of intensive mixer indicated the highest energy saving at 8.18% of total electrical energy, followed by steam pipe insulation, 2.9%; steam trap maintenance, 0.95% and steam pipe leakage maintenance, 0.15% which save from the total amount of each energy usage respectively.

In the view of CO$_2$ emission, the saving on the electrical energy from the utilization of rest time of intensive mixer shows the tremendous CO$_2$ emission reduction about 185,525.5 tCO$_2$/year, followed
by the steam pipe insulation option, steam trap maintenance and steam pipe leakage maintenance which reduced 34.3 tCO₂, 11.2 tCO₂ and 1.76 tCO₂ per year respectively. Although the electrical energy saving provides huge impact to the operational cost and the CO₂ emission reduction, however the initiative of good housekeeping through insulation of steam pipe distribution, maintenance of steam trap and maintenance steam pipe leakage also need to be emphasized. The options will assist to the reduction of CO₂ emission from the direct source instead of indirect source which contribute from the use of electricity. In addition, the total saving projected from the implementation of the CP options was RM 85,454.42 per year. Apart from the amount of energy saving and CO₂ reduction, the CO₂ intensity has reduced about 21.8% based on the baseline model which included the consideration of production rate. The finding shows that there exists a significant opportunity to reduce CO₂ emissions through energy measurement in PVC flooring mat manufacturing industry by the implementation of good operating practices and good housekeeping.

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Acknowledgement

The authors would like to acknowledge management and technical team from MASFLOOR Sdn Bhd, who support this research with providing sufficient consultation insight and information needed to made this research possible.