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A Methodology for Identifying Cleaner Production Options to Reduce Carbon Emission in the Manufacturing Industry

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ABSTRACT

While industries are familiar with environmental management systems for continuous improvement of production processes and products, there are various green-concept-oriented methods that can address environmental concerns significantly. This work focused on adaptation of cleaner production strategy for enhancing environmental management systems. Specifically, this work developed self-implementable methodology that systematically leads to identification of cleaner production options to improve environmental performance and efficiency of manufacturing industry. The developed methodology aims at preventing or reducing carbon emission from production processes and activities. The proposed methodology comprises three steps. In step 1, the sources of carbon emission from the manufacturing industry are identified through materials and energy consumption and waste generation. In step 2, the fate of the sources of carbon emission is determined. The sources are to be prevented or reduced. In step 3, cleaner production options are generated. Cleaner production options include modification of key operating parameters in manufacturing processes, such as temperature, pressure and time; implementation of housekeeping practices; modification of production process; substitution of greener materials; adaptation of new technologies; training to workers and 3R (reuse, recover, recycle). The options are generated with investigative questions. A food manufacturing industry was selected as a case study to demonstrate the practicality of using the developed methodology to generate cleaner production options. A total of 15 specific cleaner production options were identified for the studied premise using the methodology proposed demonstrating the practicality of the developed methodology.

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1. Introduction

With rising concerns related to industrial pollution, environmental regulations are becoming more stringent in many countries, while efficient resource usage is gaining more attention. The manufacturing industry is under continuous pressure to improve its environmental performance in terms of production operations and activities, waste minimization and prevention of end-of-pipe treatment. There are various strategies for pollution prevention for a typical production process and activity, which can be implemented individually or combined. It can be challenging for choosing efficient and cost effective strategies as the decision making process involves consideration in economic and environmental aspects (Yilmaz et al., 2015).

In recent years, industries have considered green strategies as the means by which they could maintain environmental practice and competitive advantages (Jia et al., 2013). For industries to achieve sustainable environmental performance, it is necessary to create changes in the production systems through the implementation of cleaner production strategies (or simply CP), targeting sustainable development by eliminating and minimising pollution, together with obtaining economic benefits (Oliveira Neto et al., 2016). Cleaner production options are defined as any improvements or initiatives, which aim to prevent or reduce emissions created by manufacturing operations. Cleaner production strategies include good housekeeping of materials and energy, training of employees, better logistics, improvement in data availability, substitution of raw materials, modification of process and design and waste recycling. The benefits of cleaner production implementation include reduction in consumption of raw materials, water and energy, emissions, generation of wastewater, solid waste and hazardous waste and improvement in safety and health aspects (Glavič & Lukman, 2007). Cleaner production options may require small to large investments, ranging from good housekeeping practices to adaptation of new technologies (Rahim & Raman, 2015). Therefore, it is necessary to understand both the achieved benefits of cleaner productions options and their impacts on manufacturing processes in order to evaluate the performance of cleaner production options. In addition, cleaner production options should also be financially feasible and the cost of implementation must be balanced against the benefits. Therefore, to ensure successful implementation of cleaner production options, It is also necessary to identify as many Cleaner Production options as possible and prioritize the most feasible option.

Many cleaner production strategies have been implemented to create green awareness among industries. The Standards and Industrial Research Institute of Malaysia (SIRIM) has launched the national eco-labelling program according to environmental criteria, such as Environmentally Degradable, Non-toxic Packaging Materials, Hazardous Metal-Free Electrical and Electronic Equipment, Biodegradable Cleaning Agents and Recycled Paper. A study by Rashid (2009) showed that with the

exposure of environmental awareness, Malaysian consumers reacted positively to eco-label. There is also much effort in greening research activities. For example, DeSimone (2002) eliminated the use of organic solvents and other volatile organic compounds from paints and coatings, which resulted in dry, solvent-free powder coating and solid ultraviolet curable coating. Garrigues et al. (2010) developed cleaner production strategies to reduce the toxicity of waste streams in chemical industries, through implementation of organic solvent recovery and recycling, degradation of toxic waste in water streams and passivation of pollutants from aqueous streams. Besides, various methodologies and tools have been developed in initiating the implementation of cleaner production strategies. For example, Olson (2008) developed a methodology and tool set to formulate cleaner production strategy that can be integrated with other areas of strategy formulation in an enterprise, such as business, technology application and infrastructure. Rahim & Abdul Raman (2017) developed several options in a recycled plastic plant to reduce CO₂ emission. Recently, researchers also suggested combining novel technique and technologies as options for CP (de Hoyos-Martínez et al., 2019). The developed methodology helps business leaders to capture new values and benefits from cleaner production options. The above review describes various examples of cleaner production strategies implemented by industries and methodologies of formulating the strategy. Although much research has proposed different types of cleaner production options over the last two decades, the approach is process specific (Duan et al., 2011; Kumar & Raja, 2013; Zhang et al., 2015) or industry specific (G. Y. Abbasi & Abbasi, 2004; T. Abbasi & Abbasi, 2016; Altham, 2007; Büyükbay et al., 2010; Ozturk et al., 2016; Ramjeawon, 2000; Reddick et al., 2008; Van Berkel, 2002; Yi et al., 2001) only. Additional tools such as eco-efficiency (Phungrassami, 2008), theory of inventive problem solving (TRIZ) (Fresner et al., 2010) and theoretical minimum consumption (Fresner & Krenn, 2018) were also recommended to be added as a tool to develop options. There was no systematic methodology to guide the identification process of cleaner production options for the manufacturing industry. Therefore, this work proposed a methodology to fill this gap.

2. Methodology

2.1 Construction of the framework of methodology for identifying CP options

CP options are important in improving the environmental performance and efficiency of a manufacturing premise. CP option is defined as any activities, changes or improvement that can provide positive returns to the industries. The methodology of identifying CP options focuses on reducing sources of carbon emission generation from the production processes and activities. The methodology is developed to provide an appropriate framework for manufacturing industries to identify CP options systematically to overcome environmental issues. The CP option identification methodology was developed in accordance with the steps illustrated in Figure 1.

Figure 1: Construction of CP options identification methodology framework

2.2 Establishing the objective of identifying CP option

The methodology of identifying CP options was developed based on the objective to reduce the sources of carbon emission from production processes and activities. Carbon emission can be generated from production processes and activities through consumption of raw materials, chemicals, additives, water, electricity and fuel and from waste generation. CP options can be implemented through housekeeping practice, modification of production processes, substitution of less harmful materials, adaptation of new technologies, training and 3R (reuse, recover, recycle).

2.2.1 Focus of CP option

CP options focus on material and energy saving. Energy saving includes reduction and minimization of electrical energy wastage and energy for heating and cooling. Material saving includes reduction in raw materials usage and other related materials such as packaging, chemicals, fuel, water and detergent. Meanwhile, safety aspect is also included in this work, as issues that arise due to inefficient operation will cause loss of material and energy in various ways. Hence, prevention of incidents related to safety is also included as the opportunity in conserving materials and energy.

2.2.2 Design of CP option identification methodology

The design of CP options identification methodology was developed according to the fundamental principles of chemical engineering, which are changes in key process parameters - temperature (T), pressure (P) and time (t). CP options can be identified based on changes on the:

(a) Reduction of time usage

Reduction in time usage should be the main CP option for electricity consumption, as the value of kW.hr will be reduced simply by reducing time.

(b) Reduction of operation time

The reduction of operating time, which involves heating or cooling processes, can reduce energy consumption, since the energy consumption is proportional to operating time.

(c) Increase or reduction of operating temperature

Heating or cooling processes consume energy due to change of temperature of the input streams or products. Reducing or increasing the temperature setting can reduce energy requirement due to smaller temperature gradient.

(d) Reduction of operating pressure

Compressor systems for a manufacturing premise are typically operated at a pressure range of 100 to 125 psi. However, it is found that not all the equipment requires the maximum pressure that can be generated by the compressors. Reduction in pressure can reduce electricity usage of the compressor systems and reduce leakages, prolonging the shelf life of the equipment and air compressors. CP options focus on material and energy saving.

There are various types of CP options, ranging from minor changes on certain processes, till major modification of design or changes in technology. However, the options can be fundamentally characterized according to the implementation methodology. In most of the manufacturing industries, the typical CP option is related to housekeeping practices, material substitution, design modification, operation modification, adaptation of new technology, training to workers and 3R. This CP options identification methodology can further be expanded to identify specific opportunities for selected source of carbon emission generation. There are seven categories of implementation practice that can be used by the industries to identify CP options, as follows:

(a) Housekeeping practice

The main focus is to prevent material and energy loss, minimizing waste generation and improving operating procedure. Housekeeping related CP options are the most favourable since the options usually require no or low investment cost.

(b) Design modification

Modification in design can be minor or major. For example, minor modification can be done by installing spillage trap systems, which can reduce raw materials spillage from the conveyor to the storage tank. Meanwhile, major modification can be done by replacing operation

units or increasing production line. Depending on the types of industries, some of the CP options related to design modification may require technical expertise or detailed research studies before being implemented.

(c) Operational modification

Referring to the changes or optimization of processing parameters, which involve time, temperature, pressure, sequence, and other relevant parameters. For example, reduction in operating time can reduce energy consumption. Besides, operational modification can also be done by combining two processes or activities together or eliminating one of the processes.

(d) Raw material substitution

Raw materials substitution can help achieve high yields, reduce processing time, energy consumption, waste generation and toxic materials.

(e) Adaptation of new technology

Adoption of new technology can be considered if productivity can be increased while reducing material loss, waste generation and energy consumption at the same time. New technology can be applied on existing systems as an additional system or replacement of overall or partial systems.

(f) Training to workers

Untrained operators can cause high generation of waste, less productivity and increase in risk. Providing proper training for operators in various aspects can be one of the main CP options. Training is also required when standard operating procedures are developed or when design or operational modifications are implemented in the premise.

(g) 3R (reuse, recover, recycle)

Reusing or recycling of materials is one of the easiest methods that can be implemented by the premise. However, the implementation can be either cheap or costly.

2.3 Targeted returns

In general, CP options aim at solving environmental issues faced by the premise. However, CP options can also be identified to improve certain aspects in the premise. Implementation of CP options directly aims at reducing waste generation, loss of material, energy, risks, raw material consumption and energy usage, increasing productivity and indirectly reducing the amount of carbon emission generated in the premise. There are four key requirements in identifying CP options for a manufacturing premise, which are saving in costs, prevention in pollution, compliance to regulation and reduction in carbon emission.

(a) Cost saving

Implementation of CP options can achieve either direct or indirect returns. Direct cost saving can be achieved through reduction in cost of raw materials, energy usage and waste treatment. Meanwhile, indirect cost saving can be achieved through increase in productivity.

(b) Pollution prevention

CP options emphasize on prevention compared to traditional end-of-pipe method, where the waste generated is treated to comply with the standards.

(c) Compliance in regulation

Reduction in various types of waste generations, mainly toxic waste, indirectly helps any premise to comply with the environmental regulation.

(d) Reduction in carbon emission

CP options generally reduce the generation of carbon emission through control and reduction of the consumption of entities that contribute to generation of carbon emission.

3. Results and Discussion

3.1 CP options identification methodology

CP options are defined as opportunities of improvements that can be implemented to overcome issues that exist in any manufacturing premises or to improve a company's performance. In this work, the CP options identified focused on overcoming issues caused by sources of carbon emission. CP options can be identified through:

(a) Discussion/ brainstorming with the company's representatives - For example, discussion with a production personnel can result in various ideas focusing on the possibility of improvement through modification of production processes and parameters, whereas discussion with a safety personnel can contribute to minimizing safety issues in the premise.

(b) Case studies - There have been many case studies on CP implementation strategies in the manufacturing industry. The implementation studies can focus on reduction of resources, waste generation, risks, etc.

Through the methods, it is important to ensure that:

- (a) Contribution of the company's representatives at different levels is encouraged.
- (b) Ideas generated should be recorded.
- (c) Ideas generated should be seriously considered.
- (d) Feedback should be given to each of the ideas generated.

Brainstorming is typically used to identify CP options. During this session, all management personnel in a company, such as managers, engineers and production operators, together with the auditors are able to identify potential CP options. Various methods can be used to conduct brainstorming activities. The following questions can be used during the brainstorming activities:

(a) Use keywords, such as eliminate, minimize, reduce, prevent and improve. For example, raw rice used in vermicelli production needs to be washed twice. Questions such as whether the second washing process is necessary are asked in order to identify CP options.

(b) Use green methodologies, such as housekeeping, design modification, operation modification, change of

raw materials, new/alternative technologies, training, reuse & recycle. For example, a factory is using chemical based materials for floor cleaning but we can identify if it can be substituted with water-based cleaning agents?

(c) Identify causes through issues. For example, spillage is usually due to inefficient handling of inefficient equipment. We need to identify the causes of this issue and how the issue can be improved?

(d) Identify the causes of waste generation and how the wastes are disposed? The opportunities in reusing the waste should be identified.

(e) Identify the options that can be implemented immediately. The best option may require a longer time. However, it doesn't mean that no other options that can be implemented immediately.

3.1.1 Descriptions on implementing CP options identification methodology

The framework of CP options identification methodology, as illustrated in Fig. 1, is expanded to develop detailed methodology as shown in Table 1. The step-by-step CP option identification methodology starts with investigative questions that have been developed according to the sources of carbon emission. Then, the expected effects of CP options on the consumption and generation of carbon emission sources are determined. The effect could be in terms of material, product and energy loss or in terms of safety, health, productivity and product quality. The determined effects will then be prevented or reduced. Subsequently, CP options will be identified according to the seven-implementation practice, as described above.

Table 1: Methodology of identifying CP options

1. MECHANISM	1. Ask question	2. Determine the effects	3. Fix the target	4. Identify CP options according to implementation practice	5. List the potential CP options
2. DETAILS	Key question	1. Raw material loss 2. Product loss 3. Electrical energy loss 4. Heat energy loss 5. Effect to waste generation 6. Effect to productivity 7. Effect to safety and health 8. Effect to product quality	Reduction Prevention	1. Housekeeping 2. Design modification 3. Operational modification 4. Raw material substitution 5. New technology 6. Training 7. 3R	CP options identified based on real scenario of the premise
No.	Question	Effects/ Issues	General aim	Practices	CP options
Part 1: Basic Information of the Company					
1	Is the company too far from the supplier?				
2	Is the company too far from clients?				
3	Is the company exposed to risk?				
4	Does the company have access to the needed facilities?				
Part 2: Main Products					
1	Are there a wide variety of products?				
2	Is the production rate optimum?				
3	Is the life span of the product(s) suitable?				
4	Is waste generated during the production?				
5	Is the product recipe optimum?				
6	Are the products environmental friendly?				

7	Is it easy to handle the products/ packages?				
8	Is the packaging size suitable?				
9	Does the production generate a large quantity of by-products?				
10	Are the products eco-labelled?				
11	Is the production rate optimum at the factory capacity?				
12	Is the rate of returned products high?				
13	Is the packaging material easily damaged?				
14	Is the packaging material recyclable?				
15	Is the designated storage space optimum?				

Part 3: Raw Materials

1	Is this material needed for production?				
2	Is the material usage optimum?				
3	Is the material environmentally friendly?				
4	Does this material generate waste?				
5	Does this material yield high production?				
6	Does this material have a short life span?				
7	Is this material processed or semi-processed?				
8	Does this material pose risks? (i.e.: toxic, flammable)				
9	Does the packaging material generate waste?				
10	Does the purchase of the material require complicated handling? (i.e. loose items, bulk items)				
11	Is the supplier far from the company?				
12	Is the quality of the supplied material good?				
13	Do handling and storage of raw material generate waste?				
14	Does the handling/ storage of the raw material require special facilities? (i.e. cold room, dry air)				
15	Is the raw material flow in the storage efficient? (i.e. use of inventory)				
16	Does the purchase yield excessive raw materials? (i.e. there is a need to store excessive raw materials)				

Part 4: Utilities

1	Are the utilities environmentally friendly?				
2	Do the utilities pose risk? (i.e. toxic)				
3	Do the utilities generate waste?				
4	Are the utilities efficient?				

5	Are there special needs for the handling/storage of the utilities? (i.e. cold room, compressor, training)				
6	Is the usage of the utilities acceptable (compared to the benchmark)?				
7	Does the utilities handling generate waste?				
8	Are the utilities difficult to handle?				
9	Does the utilities packaging generate waste?				
10	Are the utilities generated at the company?				
11	Are the utilities providers far from the company?				
Part 5: Detailed Usage of Water					
1	Is water needed?				
2	Is water used in a way that will cause wastage?				
3	Is water usage optimum?				
4	Is water used more frequently than needed?				
5	How many times is water used unnecessarily?				
6	Is water used for a long time?				
7	Is the water temperature optimum?				
8	Does the water quality/ specification fit the usage purpose?				
9	Do current ways of using water generate too much wastewater?				
10	Is the generated wastewater highly polluting?				
11	Is used water reusable?				
Part 6: Detailed Usage of Electricity					
1	Is electricity needed?				
2	Is the equipment rating/ power compatible with the target usage?				
3	Is it frequently used?				
4	Is the usage duration long?				
5	Is the efficiency at the optimum level?				
6	Is the logistic/ usage arrangement optimized? (i.e. the motor is only turned on or off based on needs)				
7	Does the company generate electricity itself?				
8	Does the company fix the electricity usage for particular equipment?				
9	Is the setting of the equipment optimized?				
10	Is the equipment energy-saving?				
11	Is the equipment automated?				

Part 7: Detailed Usage of Fuel					
1	Is the fuel environmentally friendly?				
2	Does the fuel pose risk? (i.e. toxic)				
3	Does the fuel generate waste when used?				
4	Is the fuel efficient?				
5	Are there special needs for handling/ storage of the fuel? (i.e. trained workers)				
6	Is the fuel usage acceptable? (Compared to the benchmark)				
7	Does fuel handling generate waste?				
8	Is the fuel difficult to handle?				
9	Does the packaging of the waste generate waste?				
10	Is the fuel provider far from the company?				
11	Is the fuel required? Can it be substituted?				
Part 8: Main Process Flow Chart					
1	Can the process flow/steps/ activities be modified?				
2	Is the processing duration long for the processes/ steps/ activities?				
3	Do the processes/ steps/activities run continuously or intermittently?				
Part 9: Unit Operation / Activity					
1	Is the process/ activity needed?				
2	Can the process/ activity be modified?				
3	Is the process/ activity time optimum?				
4	Is there special requirement for the process/ activity (i.e.: training)				
5	Does the process/activity generate waste?				
6	Does the process/ activity pose risk?				
7	Does the operation unit cause loss of materials?				
8	Does the operation unit cause energy loss?				
9	Is the operation unit efficient?				
10	Does the operation unit use much energy?				
11	Is the operation unit maintained?				
12	Are the capacity and usage of the operation unit compatible?				
13	Is the setting of the operation unit at the optimum level?				
14	Is the surrounding hazardous? (i.e radiation, vapor?)				
15	Is there special requirement for the surrounding? (i.e. ventilation system)				

16	Is the surrounding in appropriate condition? (i.e. temperature, moisture, smell, lighting)				
17	Is the space suitable? (i.e. arrangement plan)				
18	Is the unit operation labelled well?				
19	Is the energy usage of the process/ activity optimum?				
20	Is hot/ cold surface exposed?				
21	Does the unit operation produce noise?				
22	Does the operation unit have automatic system?				
23	Does the unit operation have operational manual?				
24	Does the unit operation require additional fitting? (i.e. milling ball, drilling head)				

Part 10: Wastewater

1	Can wastewater generation be avoided?				
2	Is the wastewater generation rate high? (Compared to the benchmark)				
3	Does the wastewater quality vary with source?				
4	Is all wastewater directed to the wastewater treatment plant?				
5	Is wastewater treated before being released to the environment?				
6	Is wastewater of different qualities mixed together?				
7	Are there any factors that affect the generation/ quality of wastewater (i.e. leakage)				
8	Is there a sharp increase in the quantity/ quality of wastewater?				

Part 11: Solid Waste

1	Can waste generation be avoided?				
2	Is the waste generation rate high? (Compared to the benchmark)				
3	Does the wastewater quality vary with source?				
4	Are all the wastes disposed of?				
5	Is the waste treated before being released to the environment?				
6	Is waste of different qualities mixed together?				
7	Are there any factors that affect the generation/ quality of waste (i.e. leakage)				
8	Is the waste reusable (i.e. packaging material, pellet)				
9	Is the waste reclaimable? (i.e. catalyst, resin)				

10	Does the waste have hazardous characteristics?				
11	Are there special requirements for storage/ handling of the waste?				
12	Does the company have waste production/ handling policy?				
13	Is the waste labelled in detail?				
14	Is the storage space compatible with the waste generation rate?				
15	Is waste kept in a large amount?				
Part 12: Hazardous Waste					
1	Can waste generation be avoided?				
2	Can the toxicity be reduced?				
3	Is waste handled according to the rules and regulations?				
4	Are workers exposed to safety and health risk?				
Part 13: Gas Emission (Other than Steam)					
1	Is energy reclaimable?				
2	Can the emission rate be reduced?				
3	Is there any leakage at the sources of emission?				
Part 14: Loss of Raw Materials					
1	Is there a significant loss of raw materials?				
2	Do the handling methods of raw materials generate waste?				
3	Are there any factors that affect the loss of raw materials (i.e. leakage)				
Part 15: Loss of Heat Energy Through Hot Surface					
1	Is the operating temperature optimum?				
2	Are there exposed surfaces?				
Part 16: Loss of Heat Energy Through Hot Items					
1	Is the operating temperature optimum?				
2	Is the energy reclaimable?				
Part 17: Loss of Heat Energy Through Cold Items					
1	Is the operating temperature optimum?				
2	Is the energy reclaimable?				
Part 18: Loss of Energy Through Latent Heat in Steam					
1	Can the loss be avoided?				
2	Is there any leakage at the pipes or steam tank?				
3	Is there loss, steam or condensate? (i.e. Steam trap)				
4	Is there any open heating process? (i.e. heating tank)				
Part 19: Safety and Health Risk					
1	Can accidents be avoided?				
2	Can accidents be reduced?				
3	Does the company have health and safety policy?				
4	Is the workplace condition suitable? (i.e.: temperature, moisture, smell, lighting)				

5	Is safety practiced at the company? (i.e. display of speed limit, training)				
6	Is the company equipped with adequate safety equipment? (PPE, fire extinguisher, first aid kit)				
7	Are the equipment/ facilities at the company well maintained?				
8	Do accidents generate waste?				
9	Does the company have additional control system?				
10	Is there special requirement for some processes/ activities? (i.e fume hood)				
11	Does the safety equipment function well?				
12	Does the company have easy access/ exit route?				
13	Does the layout of the company pose risk?				
14	Are there blind spots at the company?				
Part 20: Layout Issues					
1	Is the labelling system adequate?				
2	Are walkways obstructed?				
3	Does the layout of the company impair visibility?				
4	Does the layout of the company affect ventilation?				
5	Are the lighting adequate?				
6	Does the product arrangement complicate the transfer process of the products onto the forklift?				

3.2 Demonstration on the application of CP options identification methodology

The practicality of CP options methodology was demonstrated in a food-manufacturing premise located in West Malaysia. The premise was established on 2011, with 22 permanent workers. The premise produced 500 pieces of 1.8 kg-cake per day, with a daily operation of 8 hours. The raw materials were butter, eggs, flour, condensed milk, sugar, additives and colouring. It was found that the premise consumed 300 m³ of water and 9,375 kW.hr and electricity per month. Water was mainly used for cleaning and domestic purposes, whereas electricity usage was mainly due to the use of a cold room operating at 18°C, a chiller at 10°C and a mixer of 5hp. Liquefied petroleum gas was used as the source of fuel for oven with a monthly consumption of 4,732 kg. 261 m³ of wastewater was generated per month from cleaning activities; mainly cleaning of trays and containers, with an average chemical

oxygen demand value of 9,000 mg/l. 2,158 kg of solid waste was generated per month, which included eggshells and packaging of raw materials. Furthermore, it was estimated that 36 kW of heat was lost from the oven bearing a surface area of 1.2 m² of and surface temperature of 88°C. Subsequently, CP options were identified by implementing the developed CP option identification methodology, focusing mainly on the consumption of materials and energy, solid waste and wastewater generation and energy loss. Based on the questions in Table 1, responses were collected according to data collected from the premise. Based on the responses to the questions listed, potential CP options focusing on Part 2, 3, 5, 6, 7, 10, 11, 14, and 15 were identified for the premise. Responses to other parts were either not applicable or did not exhibit any relevant issues. Table 2 shows an example of potential CP options identified for the food manufacturing industry.

Table 2: Examples of CP options identified for food manufacturing industry

Question	Effects/ Issues	General aim	Practices	CP options
Part 2: Main Products				
Is the rate of returned products high?	Product loss	Reduction	Operational modification	1. Implement 'just-in-time' practices for product management. 2. Produce products according to customers' demand.
Is the packaging material easily damaged?	Raw material loss	Prevention	Material substitution	Substitute to recyclable packaging material.
Part 3: Raw Materials				
Does the material generate waste?	Waste generation	Prevention	Material substitution	Purchase liquid egg to prevent eggshell waste generation. Within the scope of this study, taking a lifecycle approach, it was determined that having a central liquid egg producing facility will have greater economy of scale. This will enable premises to exploit eggshells usage a by-product compared to a single premise that uses egg as raw material. More extensive studies are required to further develop methodologies to measure carbon emissions throughout the supply chain.
Does the packaging material generate waste?	Waste generation	Prevention	Operational modification	Buy raw materials in bulk.
Part 5: Detailed Usage of Water				
Is water used in a way that will cause water wastage?	Wastewater generation	Reduction	Design modification	Installation of water handgrip control nozzle.
Part 6: Detailed Usage of Electricity				
Is the setting of the equipment optimized?	Energy loss	Reduction	Operational modification	Increase operating temperature in the chiller and cold room.
Is the equipment energy-saving?	Energy loss	Reduction	Operational modification	Install LED lighting or energy-saving bulb.
Part 7: Detailed Usage of Fuel				
Is fuel required? Can it be substituted?	Energy loss	Prevention	Material substitution	Substitute to electrical oven.
Part 10: Wastewater				
Can wastewater generation be avoided?	Waste generation	Prevention	Material substitution	Use tissue papers to clean trays instead of using water. The used mixing trays were soiled with cake batter. Washing the trays with water directly generates wastewater with very high chemical oxygen demand (COD) content. If the remaining batter in the tray are first

Question	Effects/ Issues	General aim	Practices	CP options
				wiped down with paper tissue, the COD and volume of wastewater generated would be reduced greatly. Although, generally solid waste has higher carbon emission factor compared to wastewater, there is a balance achieved here because the amount in weight of solid waste generated are significantly smaller, hence producing lesser carbon emissions.
Part 11: Solid Waste				
Is the waste reusable?	Waste generation	Prevention	Recycling	Recycle containers of raw materials, wood pellets.
Is waste labelled in detail?	Waste generation due to expired product	Prevention	Operational modification	1. Label product details according to production number. 2. Implement 'just-in-time' practice for product.
Part 14: Loss of Raw Materials				
Do the handling methods of raw materials generate waste?	Raw materials loss	Reduction	Training to workers	Provide training to workers in material handling.
Are there any factors that affect the loss of raw materials	Raw materials loss	Prevention	Housekeeping practices	Regular inspection on expiry date of raw materials.
Part 15: Loss of Heat Energy Through Hot Surface				
Is the operating temperature optimum?	Heat loss	Reduction	Operational modification	Identify optimum temperature required by the oven.
Are there exposed surfaces?	Heat loss	Prevention	Design modification	Install insulator at the oven.

4. Conclusions

In this work, a self-implementable methodology for identifying CP options for the manufacturing industry was developed. This methodology aims at identifying CP options to reduce the amount of carbon emission generated from production processes and activities. This case study showed that CP options could be implemented through modification of operating parameters in production processes, including operating temperature, operating pressure and processing time. Other CP options included housekeeping practice, modification of production process, substitution of greener materials, adaptation of new technologies, training to workers and 3R. With the use of specific investigative questions, CP options can be identified easily with the answers to the investigative questions being used as guidance in identifying specific CP options. The practicality of the developed CP options identification methodology was proven in this case study, with 15 CP options being generated successfully. This case study also showed that

the investigative questions developed could help generate various CP options for the manufacturing industry.

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