NEW STANDARD METHODOLOGY IN CLEANER PRODUCTION FOR SMALL & MEDIUM INDUSTRIES

RAZUANA BINTI RAHIM

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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ABSTRACT

Many countries are taking initiatives to reduce greenhouse gases emission, mainly carbon dioxide (CO_2) due to growing pressure to tackle global warming effects. There are many strategies available for this purpose. Cleaner Production (CP) is one of the main strategies that can be considered to reduce greenhouse gases and it is a powerful tool for greening the industries. However, the strategy is not widely used because there is no systematic implementation methodology for industries with minimum expertise requirement. Therefore, in this work, a new methodology for conducting a CP audit was developed by taking into consideration various CO_2 generating activities and processes in a typical manufacturing premise. Subsequently, the methodology was used to gather information. The CP audit tool proposed consisted of 17 key components including quantification of entities that contribute to the generation of CO_2 emission, which are water, electricity and fuel consumption together with solid waste and wastewater generation. The gathered information was analysed and the major contributors for CO_2 emissions were identified and estimated. Subsequently, systematic CP option generation and prioritization methodology were developed. The CP option generation tool comprised investigative questions that were developed according to the 17 components in the CP audit tool, whereas the answers for the questions would guide the CP options generation. The options were generated based on the changes or modifications in the operation, design, materials, housekeeping, recycling and training. The options generated were further evaluated and prioritized in terms of economic, environmental and other tangible and intangible returns. The economic evaluation showed the payback period for the CP options, while the environmental evaluation estimated the CO_2 reduction quantitatively. The practicality of the methodology developed was then validated through demonstration in three case studied manufacturing premises, which are printing, plastic resin and beverage. The premises were selected due to their significant contribution to environmental issues in Malaysia. Major CO_2 emission contributors in each of the premise were identified and estimated per unit of product. The CP audit tool developed was able to comprehensively cover the overall activities and processes in the premises. The estimated CO_2e generation in the printing, plastic resin and beverage premises were 0.81 kg CO_2e/kg of paper processed, 0.84 kg CO_2e/kg of resin and 0.07 kg CO_2e/L of beverage, respectively. Various CP options were generated, evaluated and prioritized accordingly for these premises. From this analysis, it can be concluded that it is possible to reduce CO_2 emission by 10-15% even without any monetary investment by administrating the identified CP options. In addition, about 5-10% of the CP options implemented with monetary commitment could be recovered within a year. Furthermore, it is confirmed that the CP audit, CP option and CP evaluation tools developed could be used to initiate a greening program for Small and Medium Industries.

ABSTRAK

Kini, kebanyakkan negara sedang mengambil pelbagai inisiatif untuk mengurangkan emisi gas rumah hijau, terutamanya gas karbon dioksida (CO_2), berikutan tekanan yang semakin meningkat untuk menangani kesan pemanasan global. Terdapat pelbagai strategi yang wujud bagi tujuan ini. Pengeluaran Bersih (CP) merupakan salah satu strategi yang boleh dipertimbangkan untuk mengurangkan emisi gas rumah hijau dan merupakan tool yang sangat berkesan untuk menghijaukan industri. Walaubagaimanapun, strategi ini tidak dapat digunakan secara meluas akibat ketiadaan metadologi pelaksanaan yang sistematik untuk kegunaan industri dengan keperluan kepakaran yang minima. Maka, di dalam kajian ini, metadologi yang sistematik bagi menjalankan audit CP telah dibangunkan dengan mengambilkira pelbagai jenis proses pengoperasian dan aktiviti yang menyumbang kepada penghasilan emisi CO_2 di dalam sesebuah premis pembuatan yang lazim. Seterusnya, metadologi ini telah digunakan untuk mengumpulkan maklumat. Tool audit CP yang dibangunkan mengandungi 17 komponen utama, termasuk kuantifikasi kesemua entiti yang menyumbang kepada penghasilan emisi CO_2 iaitu penggunaan air, elektrik dan bahan api, berserta penghasilan sisa pepejal dan air sisa. Maklumat yang diperolehi telah dianalisa dan penyumbang emisi CO_2 yang utama telah dikenalpasti dan kuantiti penghasilan telah dianggarkan. Seterusnya, metadologi penjanaan opsyen CP dan pengutamaan opsyen CP yang sistematik telah dibangunkan. Tool penjanaan opsyen CP mengandungi soalan-soalan menyelidik yang telah dibangunkan berdasarkan kepada 17 komponen utama di dalam tool audit CP, di mana jawapan kepada soalan-soalan ini akan membantu dalam menjana opsyen CP. Opsyen-opsyen yang dijana adalah berdasarkan kepada perubahan atau modifikasi dalam rekabentuk, pengoperasian, bahan, tatasusun, kitar semula, dan latihan. Opsyen-opsyen yang dijana seterusnya dinilai dan pengutamaan dilakukan

dalam aspek ekonomi, alam sekitar, dan lain-lain pulangan langsung dan tidak langsung. Penilaian ekonomi bagi opsyen CP menunjukkan tempoh pulang modal, manakala penilaian alam sekitar menganggarkan pengurangan emisi CO_2 secara kuantitatif. Metadologi yang dibangunkan ini seterusnya telah ddigunakan untuk menilai tiga premis pembuatan, iaitu percetakan, makanan dan minuman. Premis-premis ini telah dipilih akibat sumbangan yang ketara kepada isu-isu alam sekitar di Malaysia. Penyumbang utama kepada penghasilan emisi CO_2 telah dikenalpasti dan dianggarkan dalam unit (kg CO_2/unit produk). Didapati, protokol audit CP yang dibangunkan berupaya untuk merangkum kesemua proses dan aktiviti di premis secara komprehensif. Emisi CO_2e yang dianggarkan di premis percetakan, pembuatan resin plastik dan minuman adalah masing-masing sebanyak 0.81 kg CO_2e/kg kertas di proses, 0.84 kg CO_2e/kg resin dan 0.07 kg CO_2e/L minuman. Pelbagai opsyen CP telah dijana, dinilai dan diutamakan bagi kesemua premis ini. Didapati pengurangan emisi CO_2 sebanyak 10-15% mampu dicapai bagi pelaksanaan opsyen CP meskipun tanpa sebarang pelaburan kewangan. Tambahan, sebanyak 5-10% daripada opsyen CP yang dilaksanakan dengan penggunaan pelaburan kewangan boleh diperolehi semula dalam tempoh setahun. Maka, analisis bagi ketiga-tiga premis kajian ini mengesahkan bahawa protokol audit CP, dan prosedur penjanaan dan penilaian opsyen CP yang telah dibangunkan boleh digunapakai sebagai salah satu langkah untuk memulakan program penghijauan industri kecil dan sederhana.

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LIST OF SYMBOLS AND ABBREVIATIONS

List of abbreviations

AF	:	Adaptation Fund	[-]
BOD	:	Biological Oxygen Demand	[mg/l]
BSI	:	British Standard Institute	[-]
COD	:	Chemical Oxygen Demand	[mg/l]
CP	:	Cleaner Production	[-]
CPIM	:	Cleaner Production Implementation Methodology	[-]
CIP	:	Clean In Place	[-]
CPIT	:	Cleaner Production Implementation Tool	[-]
CPVC	:	Cleaner Production Virtual Centre	[-]
CT	:	Cleaner Technology	[-]
CTES	:	Cleaner Technology Extension Service	[-]
CTIS	:	Cleaner Technology Information Centre	[-]
DANIDA	:	Danish International Development Agency	[-]
DANCED	:	Danish Co-operation for Environment and Development	[-]
DOE	:	Department of Environment	[-]
EIO	:	Environmental Input-Output Analysis	[-]
EMAS	:	Eco Management and Audit Scheme	[-]
EMS	:	Environmental Management System	[-]
EOP	:	End of Pipe	[-]
EPA	:	Environmental Protection Agency	[-]
FIFO	:	First In First Out	[-]
GCF	:	Green Climate Fund	[-]
GDP	:	Gross Domestic Product	[-]

GEF	:	Global Environment Facility	[-]
GHG	:	Greenhouse Gas	[-]
GIVC	:	Green Industry Virtual Centre	[-]
GWP	:	Global Warming Potential	[-]
HACCP	:	Hazard Analysis and Critical Control Points	[-]
HALAL	:	Malaysian Islamic Dietary	[-]
IPCC	:	Intergovernmental Panel of Climate Change	[-]
LCA	:	Life Cycle Assessment	[-]
LDCF	:	Least Developed Countries Fund	[-]
LPG	:	Liquefied Petroleum Gas	[-]
NSDC	:	National SME Development Council	[-]
OHSAS	:	Occupational of Safety and Health Series	[-]
OPP	:	Oriented Polypropylene	[-]
PA	:	Process Analysis	[-]
PP	:	Polypropylene	[-]
SCCF	:	Special Climate Change Fund	[-]
SETAC	:	Society of Environmental Toxicology and Chemistry	[-]
SIRIM	:	Standards and Industrial Research Institute of Malaysia	[-]
SMI	:	Small and Medium Industries	[-]
SMIDEC	:	Small and Medium Industries Development Corporation	[-]
UNEP	:	United Nation Environment Programme	[-]
UNFCC	:	United Nations Framework Convention on Climate Change	[-]
UNIDO	:	United Nations Industrial Development Organization	[-]

List of Chemical Formulas

CO	:	Carbon Monoxide	[-]
CO_2	:	Carbon Dioxide	[-]
CO_2e	:	Carbon Dioxide Equivalent	[-]
CH_4	:	Methane	[-]
N_2O	:	Nitrous Oxide	[-]
NO_x	:	Nitrogen Oxides	[-]
HFC	:	Hydrofluorocarbon	[-]
PFC	:	Perfluorocarbon	[-]
SF_6	:	Sulphur Hexafluoride	[-]
SO_x	:	Sulphur Oxides	[-]

List of Symbols

A	:	Area	[m^2]
m	:	Mass flowrate	[kg/s]
P	:	Pressure	[Pa]
h	:	Thermal conductivity	[W/m^2K]
t	:	Time	[s]
T_s	:	Surface Temperature	[K]
T_a	:	Ambient Temperature	[K]
T_b	:	Material Temperature	[K]
Q	:	Heat loss	[W]
Cp	:	Heat Capacity	[kJ/kgK]
Σ	:	Summation	[-]
psi	:	Pound per square inch	[-]

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Preface

At the 15th Conference of the Parties (Nation's Climate Change Summit) in 2009, Malaysia pledge a commitment to reduce 40% of carbon dioxide (CO_2) intensity per unit gross domestic product (GDP) by 2020, relative to 2005 level. According to International Energy Statistics, (2014), Malaysian CO_2 intensity for year 2005 was 1.07 Mt/1,000 USD that will be used as the benchmark. Based on Biennial Update Report to the UNFCC, Malaysia has achieved 33% reduction of CO_2 level in 2014, with carbon intensity of 0.72 Mt/1,000 USD. In view of government to drive the commitment made, several approaches have been used in quantifying CO_2 emission and outlining mitigation measures. Major mitigation actions include implementation of renewable energy and energy efficiency initiatives, green technologies, and sustainable forest and waste management (MNRE, 2015). Furthermore, Malaysia also implemented various national policies, such as National Policy on Climate Change and National Green Technology Policy. Hence, one of the initiatives is reduction of CO_2 emission through implementation of Cleaner Production (CP) strategies. This initiative focuses on strategies for greening manufacturing premises of Small and Medium-sized Industries (SMIs) through implementation of CP strategies. SMIs can play an important role in strengthening a nation's economic development. However, it's negative environmental impacts due to limitations in financial capabilities in treating effluents, remain a serious concern. Many studies have been carried out on the implementation of CP in SMIs but could not be sustained, due to the absence of established standard methodology of CP implementation for SMIs.

1.2 Research Background

Small and Medium-sized Industries (SMIs) form a significant number of establishments in Asian countries and their contribution to the development of national economy is widely recognized by many countries. SMIs consist of 99% of the total industrial establishments in Asian countries (Harvie, 2015). Further, SMIs account for between 50 to 95% of employment in many Asian countries, where about 20% of employment are from manufacturing industries (Kimura et al., 2014). In Malaysia, there were 645,136 registered SMIs that make up 97.3% of total business establishment in the country (Department of Statistics, 2011). Services and manufacturing sectors recorded higher growth rates compared to the other sectors where services sector accounted for 90.1%, followed by manufacturing sector for 5.9%. The remaining percentages were contributed by construction, agriculture, and mining with 3%, 1% and 0.1% respectively (SME Annual Report, 2012). In terms of GDP in 2011, contribution of SMIs increased to 32.5%, compared to 29.4% in 2005. The growth rate of SMIs surpassed the overall economic growth with a growth value of 6.8%, being higher than the overall growth of 5.1%.

Hence with the increase number of SMIs, Malaysia experienced a significant rise in energy consumption and pollutant emissions (Ang, 2008). It is widely accepted that SMIs contributed to 70% of environmental problems through their inefficient use of energy and other resources (Ras & Dmr, 2011). CO_2 emission was generated from manufacturing activities through many factors mainly through consumption of resources (raw materials, chemicals, water and energy) and generation of wastes and wastewater. Energy requirements for SMIs commonly contributed by energy used, mainly electricity and fuel combustion for activities in manufacturing processes (Mugwindiri et al., 2013), which directly related to the generation of CO_2 emission. In 2013, a total of 234.7 million Mt CO_2 was emitted in Malaysia, where a total of 208 million Mt of CO_2

emissions were emitted from the energy sector (IEA, 2014). Electricity generation, transportation, manufacturing and other sectors contributed to 46%, 22%, 19% and 13% of the total CO_2 emission with an annual growth rate of 6.4%, 4.4%, 3.6% and 13.9%, respectively (IEA, 2014). The industrial sector is among the largest emitters after the transportation sector. This indicates the significant impact of this sector on the country's overall emission and more effort should be taken to mitigate and reduce CO_2 emission.

CO_2 emission are generated by the industrial sector mainly from energy consumption (Abdullah Chik & Abdul Rahim, 2012) and waste generation. Manufacturing processes generates high amount of untreated wastewater, mainly from cleaning activities, which contains high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Maxime et al., 2006; Pap et al., 2004). Based on the report on environmental performance of different industries by Department of Environment Malaysia, SMIs usually had low compliance level to law and regulations, mainly due to the absence of on-site wastewater treatment facilities, poor maintenance of treatment systems or insufficient treatment capacity (Hafiz et al., 2016). On top of that, inefficient use of material resources causes generation of high amount of solid wastes mainly from the loss of raw materials, rejected packaging materials, off-specification products and domestic wastes generated from overall activities in the manufacturing premises, which may increase the load of the treatment facility, indirectly resulting in generation of CO_2 emission. Inefficient waste management in the manufacturing premises also causes high generation of solid wastes, where pre treatment activities such as recycling, segregation and classification of wastes are not implemented. Although end-of-pipe treatment methods seem to be the easiest strategy of managing wastes generated from manufacturing premises (Mohamed, A.F. 2009), treatment typically involves cost such as operating cost of treatment facilities, chemicals and maintenance. There are also some limitations of end-of-pipe treatments, for example certain wastes are not treatable due to high toxicity or complexity, where advanced post treatment is needed. In addition, CO_2 emission is also generated by the operation of treatment facilities due to resources consumption, mainly electrical energy and chemicals usage. Hence, SMIs will foresee difficulties in sustaining the end-of-pipe treatment strategies and cause inefficient waste management in future.

CO_2 emissions from manufacturing activities may involve costs implication through implementation of carbon tax for every ton of CO_2 emission produced (Othman & Yahoo, 2014). Although Malaysia is not implementing this concept yet, there are few developed countries that have already implementing it (Lin & Li, 2011) and many other countries are expected to be participating in the future. Thus, industrial sectors in Malaysia are being urged by the government to develop systematic strategies to reduce CO_2 emission that keeps increasing annually. There are many methodological approaches available in quantifying CO_2 emission (Dias & Arroja, 2012) such as Life Cycle Assessment (LCA), product declarations, and greenhouse gas accounting (ISO 14040/44, ISO 14025, and ISO 14064) (Weidema et al., 2008). CP has been adopted by the Malaysian government and actively promoted to industries especially SMIs since 1996. CP strategies have been proven useful in improving the environmental performances of industrial processes through efficient use of raw materials, water and energy which is associated with reduction of pollution and waste generation (Rao, 2004). It helps sustainable development through production of new opportunities for optimization, cost savings, better returns in the business and compliance to environmental regulations. This strategy focuses on minimization of environmental impact of manufacturing processes and products. Compared to the end-of-pipe treatment methods, CP-based techniques and technologies consume materials, energy and by-products effectively while reducing generation of waste and hazardous materials. Furthermore, CP assists in onsite and offsite reuse and recycling practices

(Cagno et al., 2005), thus leads to systematic and organized waste management. In addition, CP strategies have significant advantages in both economy and environment at a global level. Implementation of CP aims at reducing global CO_2 emission, which is related to climate change. However, in order to ensure positive and optimal returns, CP strategies have to be implemented systematically. Hence, there is a need for a standard methodology that can be used as a guideline to implement overall CP strategy, mainly for manufacturing industries. Therefore, the importance of this study is to develop a new methodology of CP implementation for SMIs, together integrated with methodology on estimating CO_2 emission for manufacturing premises. The other purpose is to identify the effectiveness of implementing CP based on standard methodology in order to overcome pollution problem caused by SMIs.

1.3 Problem Statement

SMIs are yet to be exposed to the concepts and effective approach of CO_2 emission reduction comprehensively. The absence of systematic CP implementation methodology may results in non-optimal return or achievement for the industries. Although there are several existing methodologies for implementing CP initiatives globally, there has been no systematic research on introducing CP strategy into the industry and improving the whole process (Li, Zhang et al., 2016. Furthermore, a standard methodology for implementing CP specifically for SMIs is yet to be established. In fact, environmental initiatives in Malaysia are still not linked directly to the quantification of CO_2 emission. Thus, a new standard and simplified methodology of CP implementation for SMIs needs to be developed, which consists of detailed auditing steps, systematic methods of generating improvement options, evaluating options and finally a plan for monitoring performance of the implementation. Each step represented by a simplified and concise checklists and forms, and integrated with methodology for quantification of CO_2 emission for manufacturing processes. This methodology is proposed as Cleaner

Production Implementation Methodology for Small and Medium Industries (CPIM). The methodology will serve as a reference tool and guidance for SMIs to implement CP strategies with organized and systematic procedures.

1.4 Research Aim

The study aimed to develop a new standard methodology for the implementation of CP strategies in SMIs.

1.5 Research Objectives

The objectives of this study are as follows:

1. To develop a new standard methodology in implementing cleaner production strategy for SMIs, proposed as Cleaner Production Implementation Methodology for SMIs (CPIM).
2. To validate the practicality of using CPIM in implementing cleaner production strategy in SMIs using appropriate case studies.

Thus, the following activities are done to achieve Research Objective number 1:

1. Identify components of the CPIM design.
2. Designing and developing tools of Cleaner Production Implementation Methodology.

Whereas, the following activities are done to achieve Research Objective number 2:

1. Develop criteria for selection of premises as case studies.
2. Validate the practicality of CPIM through real case studies.

1.6 Research Scope

This research focuses on SMIs with intention to provide additional environmental initiative for the industries. For a practical application of this research, three different types of SMIs were selected as the case studies. The focus boundary covers entire manufacturing processes and activities, including wastewater treatment facilities. However, transportation of raw materials and products to the consumers are not accounted in this study.

1.7 Research Novelty and Significance of Work

In order to reduce carbon emission in a manufacturing sector, a systematic method of quantifying CO_2 emitting activities are required. Currently, the methods available are based on approaches that require special expertise. Therefore, there is a need for simple yet comprehensive methodology to quantify CO_2 emission by obtaining relevant information. In this work, a systematic methodology to quantify CO_2 emitting activities is developed. Subsequently, a systematic approach is also developed for synthesizing CO_2 emission reduction options. With the existence of both methodologies, which will be validated with actual premises, specific expertise is not required to implement CP strategies. In addition, the methodology also ensures all possible CO_2 emitting activities are included in the quantification. This methodology will be helpful for premises to implement CP strategies. Currently, no such comprehensive methods are available. This forms the novelty and significance of work.

1.8 Thesis Outline

The thesis consists of the following chapters:

Chapter 1 describes the introductory aspects of work comprising of the research problem statement, research aim, objectives, scope and novelty.

Chapter 2 discusses the reviewed literature comprising of overview of global warming and climate change issues, sources of emissions in manufacturing premises, impacts to the industries and application of CP strategy as an initiatives to reduce emissions. Research gap and the need for enhancement of existing CP strategy, with justification, also has been defined in this chapter.

Chapter 3 describes relevant methodologies that have been used in developing CPIM. It comprises of development of research philosophy, generating research questions, identification and development of design components, together with the justifications, development of criteria for selecting premises as case study and descriptions on the feasibility studies of CPIM.

Chapter 4 discusses product obtained for this research presented as a standard methodology in implementing CP strategies for SMIs. The CPIM comprises of three sub-methodologies, which are CP audit, CP option generation and CP option evaluation. Each sub-methodology consists of standard tool, together with the comprehensive descriptions on the implementation methods. Further, the findings of the case studies are also discussed.

Chapter 5 discusses conclusions derived from this research work and recommendations to enhance the research for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews global environmental issues and sources of CO_2 emission in manufacturing industry, available Environmental Management Strategies in reducing CO_2 emission and subsequently identifies strength and limitation of each strategy. The chapter also reviews previous researches and examples on the application of CP strategies in reducing CO_2 emission in manufacturing industry. Therefore, the subjects reviewed in this chapter provide a clear picture on the need of systematic CP implementation framework.

2.2 Global Warming and Greenhouse Gases

Global warming is a phenomenon referring to the accumulation of greenhouse gases (GHGs) in the atmosphere, which cause changes in the global climate and increase of temperature (Easterling et al., 2000). GHGs are generated from natural and anthropogenic activities. Anthropogenic defines the effect caused by human activities, such as burning of fossil fuels, automotive exhaust, land-use and open burning in agricultural sector. According to the Kyoto Protocol, the six main GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbon (HFC), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) (Garg et al., 2006). Montreal Protocol claims that halocarbons and other chlorine and bromine contained substances are also considered as GHGs. Subsequently, the concentrations of GHGs have increased over the last 2,000 years as shown in Figure 2.1.

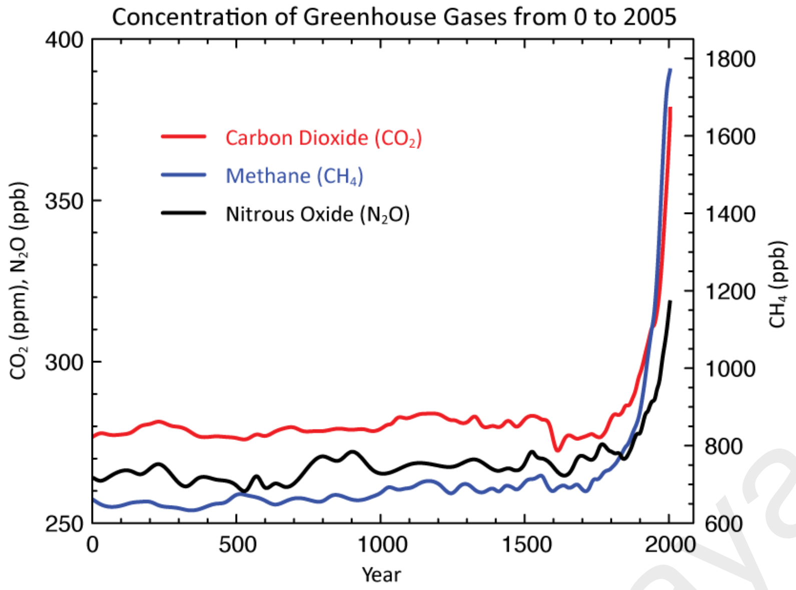

Figure 2.1: Atmospheric concentrations of primary GHGs (Solomon et al., 2007)

Table 2.1 shows the global warming potential (GWP) of primary GHGs. According to the table, the warming effect of CO_2 has been assigned a value of one, while the GWP of other GHGs are used to convert the non-CO_2 gases into CO_2 equivalent (CO_2e). For example, 1 kg of CH_4 with a GWP of 25 has the same warming effects as 25 kg of CO_2, while 1 kg of N_2O with a GWP of 298 has the same warming effects as 298 kg of CO_2.

Table 2.1: GWP of primary GHGs (Johnston & Karanfil, 2013)

Gas	GWP_{100}	Source
Carbon dioxide (CO_2)	1	Fossil fuel use
Methane (CH_4)	25	Ruminant animals and organic waste
Nitrous oxide (N_2O)	298	Agriculture

2.2.1 Global Effort in Reducing Global Warming

In the global effort to reduce global warming, U.S. international negotiations for Post-Kyoto framework have shown insufficient progress since the voluntary national reduction targets of the Copenhagen Accord. United Nations Environment Programme (UNEP) estimates that the pledge would lead to a 20% overshoot in emissions in 2020 compared with the global warming limit to 2°C and stabilize at 450 ppm of CO_2e. Emissions from increased production of internationally traded products have more than offset the emissions reductions achieved under the Kyoto Protocol, which is shares the convention ultimate on 1997 to stabilize atmospheric concentrations of GHGs.

In 2012, Doha government supported to record developing countries mitigation actions that seek financial support (Coetzee & Winkler, 2014). The registry will be a flexible, dynamic and web-based platform. Under the Kyoto Protocol's Clean Development Mechanism, governments will adopt procedures to allow carbon-capture and storage projects. These procedures will be reviewed every five years to ensure environmental integrity. Governments will agree to develop a new market-based mechanism to assist developed countries in meeting part of their targets or commitments under the Convention. Developed country Parties shall provide financial resources to assist developing country Parties in implementing the Convention through the Green Climate Fund (GCF). To facilitate this, the operation of the financial mechanism is partly entrusted to the Global Environment Facility (GEF) on an on-going basis. Two special funds were established, which are Special Climate Change Fund (SCCF) and Least Developed Countries Fund (LDCF), both managed by the GEF.

The Kyoto Protocol also recognizes the need for the financial mechanism to fund adaptation activities by developing country Parties. Therefore, the Adaptation Fund (AF) has been established under the Kyoto Protocol. Funding to climate change activities is also available through bilateral, regional and multilateral channels. Thus, during the Kyoto Protocol, relevant parties have agreed to reduce 5% of GHGs from 2008 to 2012.

2.3 Small and Medium Industries

The importance of SMIs to the country's economy has been well established, where SMIs are considered the most dynamic business in both developed and developing countries (Sumaiyah & Rosli, 2011). In Organization for Economic Co-operation and Development (OECD) countries, SMIs accounted over 95% of industries, which offered 70% of employment in most of these countries. The increasing numbers of SMIs are due to the downsized and outsourced of large firms. Most of SMIs jobs are in the service sector, such as hotels, communications and retails, which accounted for two-third of economic activities and employments in OECD countries. Furthermore, SMIs also accounted for half percentage of manufacturing employment in these countries (OECD, 2007). In addition, various international agencies have defined SMIs, which is shown in Table 2.2.

Table 2.2: Definitions of SMIs

Source (International Agencies)	Definition
World Bank	Small - firms with fixed assets (excluding land) < US$250,000 in value
UNIDO (Developing Countries)	Micro – firms with < 5 employees Small – firms with 5 – 19 employees Medium – firms with 20 – 99 employees Large – firms with > 100 employees
UNIDO (Industrialized Countries)	Small – firms with < 99 employees Medium – firms with 100 – 499 employees Large – firms with > 500 employees

In Malaysia, SMIs play a vigorous role in the economy and are considered as the backbone of industrial development in the country (Radam et al, 2008; Rosnah et al., 2004). In 2010, SMIs accounted for 35.9% from overall GDP or RM363.5 billion from SMEs GDP and employed 59% of the country's employment. By the year 2020, SMIs are expected to contribute 41% to GDP, almost 62% of employment and 25% for exports (Zin & Adnan, 2016). In 1996, Small and Medium Industries Development

Corporation (SMIDEC) was established to increase the development of SMIs by providing financial assistance, advisory services, infrastructure facilities, market access and other support programs. The aim was to develop SMIs to be competitive in the global market. In 2004, National SME Development Council (NSDC) was established aiming to formulate strategies for SMIs development in all economic sectors, to organize tasks of relevant Ministries and Agencies, encourage partnership with private sectors and to ensure effective implementation of SMIs development programs (Hashim, 2012). Subsequently, SMIDEC was tasked to assume the role and the official transformation into Small and Medium Enterprise Corporation Malaysia (SMEs Corp. Malaysia) in 2009. According to SMEs Corp. Malaysia, SMIs are defined as follows:

(i) *Manufacturing:* Sales turnover not exceeding RM50 million OR full-time employees less than 200; and

(ii) *Services and other sectors:* Sales turnover not exceeding RM20 million OR full-time employees less than 75.

An enterprise is considered to be an SMI based on the annual sales turnover or number of full-time employees, as indicated in Table 2.3.

Table 2.3: Definition of SMIs in Malaysia (Amrina & Vilsi, 2015)

Sector	Annual sales turnover (RM)			Full-time employees		
	Micro	Small	Medium	Micro	Small	Medium
Manufacturing	< 300,000	300,000 - 15 million	15 million - 50 million	< 5	5 - 74	75 - 200
Services & other sectors	< 300,000	300,000 - 3 million	3 million - 20 million	< 5	5 - 29	30 - 75

2.3.1 Small and Medium Industries in the Manufacturing Sector

The role of SMIs in manufacturing sector is significantly acknowledged. SMIs are mainly involved in activities such as processing of food, beverages, textiles, petroleum, wood, rubber and the assembling and manufacturing of electrical and electronics appliances and components (Saleh & Ndubisi, 2006;Cheok Sin, 2010). SMIs accounted for 95.4% (37,861 establishments) of the total manufacturing sector of 39,669 establishments in Malaysia in 2010 as indicated in Table 2.4. More than half of the total SMIs establishments were microenterprises, accounting for 21,619 establishments, while small-sized enterprises represented 13,934 (36.8%) and medium-sized enterprises of 2,308 (6.1%).

Table 2.4: Establishment of SMIs (SMEs Annual Report Malaysia, 2011/2012)

Sector	No. of Establishment				Total SMEs	Total Establishments
	Micro	Small	Medium	Large Firms		
Services	462,420	106,061	12,504	10,898	580,985	591,883
Manufacturing	21,619	13,934	2,308	1,808	37,861	39,669
Agriculture	3,775	1,941	992	2,121	6,708	8,829
Construction	8,587	6,725	3,971	2,857	19,283	22,140
Mining & Quarrying	57	126	116	119	299	418

As indicated in Table 2.5, the value of gross output produced by the SMIs in 2010 was RM194.0 billion (23.2%) as compared to the total gross output in the manufacturing sector of RM836.5 billion. The corresponding value added was RM38.1 billion or 22.3% of the total value added for the manufacturing sector, RM170.7 billion. Medium-sized enterprises contributed to about two-third of the gross output with RM130.6 billion, with the remaining one-third contributed by small-sized enterprises and microenterprises. The major contributor to value added was also the medium-sized enterprises, accounting for 58.8%. The total employment generated by SMIs was 698,713, representing 38.6% of the total employment of 1,812,360. Small-sized enterprises employed about half of these employees, followed by medium-sized enterprises, which accounted for 38.7%.

Table 2.5: SMIs in Manufacturing Sector (Economic Census, 2011)

Establishment by Manufacturing Sector

Category	Establishment	Percentage
Micro	21,619	57.1
Small	13,934	36.8
Medium	2,308	6.1

Macro Indicators

Variables	Total	SMEs	%	Micro	%	Small	%	Medium	%
Value of gross output (RM million)	836,494	194,032	23.2	3,853	2.0	59,540	30.7	130,639	67.3
Value added (RM million)	170,673	38,058	22.3	1,344	3.5	14,348	37.7	22,366	58.8
Employment (person)	1,812,360	698,713	38.6	67,892	9.7	360,299	51.6	270,522	38.7

Gross Output and Value Added

Description	Gross output (RM billion)	%	Value added (RM billion)	%
Manufacture of food products	69.5	35.9	8.3	21.9
Manufacture of rubber and plastic products	22.0	11.3	4.1	10.8
Manufacture of chemicals and chemical products	20.3	10.5	4.9	12.9
Manufacture of fabricated metal products, except machinery and equipment	11.8	6.0	2.9	7.5
Manufacture of basic metals	11.4	5.9	1.8	4.7

Food manufacturers contributed the highest with a gross output of RM69.5 billion (35.9%) and value added of RM8.3 billion (21.9%) while rubber and plastic manufacturers produced a gross output of RM22.2 billion (11.3%), chemicals and chemical manufacturers produced RM20.3 billion (10.5%), fabricated metal products, except machinery and equipment manufacturers accounted for RM11.8 billion (6.0%) and basic metals manufacturers produced RM11.4 billion (5.9%). These five main sub-sectors accounted for more than two-third of the value of the gross output (RM135.0 billion) and half of value added (RM22.0 billion).

2.4 Environmental Footprinting in Manufacturing Industry

Manufacturing sector are becoming increasingly interested in measuring and reducing the environmental footprint of their products and activities. The interest is driven by both marketing requirements and pressure from the society. From a legislative point of view, the pressure is increasing from society to declare the effect of products and activities to the environment. Subsequently, water footprint and carbon footprint is the most typical environmental footprint that were used as an indicator to measure resources consumed in the production to the utilization of the product, or as indicator to measure pollutants in the industries. Carbon footprint and water footprint, both address environmental issues but on different levels, of which carbon footprint refers to climate change, whereas water footprint refers to freshwater scarcity (Ercin & Hoekstra, 2012).

2.4.1 Water Footprint

Life standards in developing countries have increased due to economic growth, which had a direct effect on water resources due to the increase of production and goods consumption (Stoeglehner et al., 2011). In line with increasing of climate change, the stress on fresh water resources is also rising. The water footprint is calculated by determining the total of water consumed in the manufacturing chain to produce specific product (Mekonnen & Hoekstra, 2011) or polluted per unit of time. It quantifies the potential environmental impact on water of a product or process.

Water footprint has three components, which are green, blue and grey. The green water footprint is the volume of rainwater consumed, which is particularly related in crop production. The blue water footprint refers to the consumption of surface and ground water. Whereas the grey water footprint is an indicator of the degree of freshwater pollution. It is defined, as the volume of freshwater that is required to dilute the pollutants to ensure the quality of water is compliant to regulatory requirements. As for the manufacturing premise, the blue water footprint is the total amount of incoming water that is consumed within the entire manufacturing process, while the measurement of grey water is based on the total amount of water that is discharged in the effluent system. However, green water footprint is not applicable for the manufacturing premise. For example, a study conducted by Wessels, (2015) in a soft drinks manufacturing premise shows that for a production year of 2013, blue water footprint and grey water footprint are 6.42 l/l and 0.18 l/l, respectively, with total value of COD, phosphates, nitrates and suspended solid are 5.77 mg, 0.61 mg, 0.07 mg and 2.22 mg, respectively.

The water footprinting assessment can be conducted through quantification of the amount of water consumed, type of water, timing and location, followed by the evaluation of environmental, social and economic impacts of the water footprint. Finally, recommendations regarding options to reduce the three different components of the water footprint are formulated (Mekonnen & Hoekstra, 2011).

Subsequently, water footprint assessment can facilitate in assessing the potential environmental impacts related to water, identifying strategies to reduce potential water-related impacts of products at various life-cycle stages and facilitates water efficiency and optimization of water management of product and process.

2.4.2 Carbon Footprint

Due to the increasing concern on the global climate change and CO_2 emission, the term carbon footprint has become popular over the last few years. Carbon footprint is the amount of GHGs emitted, expressed as carbon dioxide equivalent (CO_2e), relative to a unit of activity (British Standards, 2011). It is used to quantify the contribution of various activities to climate change (Hoekstra, 2008). According to Wiedmann & Minx, (2007), carbon footprint is the direct and indirect total CO_2 emission that are emitted during the life cycle of a product.

There are both natural and human sources of CO_2 emission. Natural sources include decomposition, ocean release, respiration and volcanoes, while human sources CO_2 generated from activities like cement production, deforestation and the burning of fossil fuels. As shown in Figure 2.2, 42.8% of all naturally produced CO_2 emission generated from ocean-atmosphere exchange. Other important natural CO_2 sources include plant and animal respiration (28.56%) as well as soil respiration and decomposition (28.56%). A minor amount is also created by volcanic eruptions (0.03%).

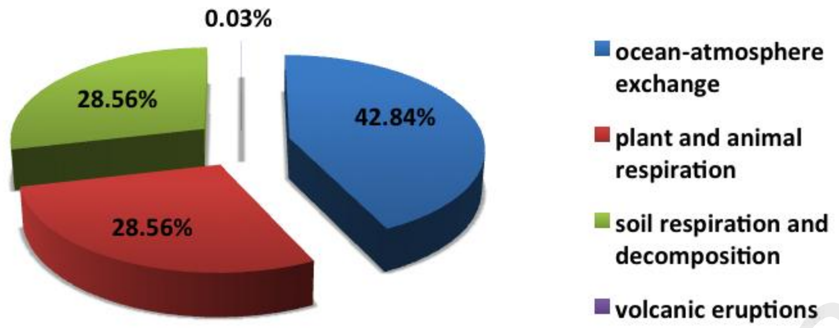

Figure 2.2: Natural sources of global CO_2 emission (Le Quéré et al., 2013)

Whereas, 87% of human CO_2 emission were generated from the burning of fossil fuels like coal, natural gas and oil. Other sources include deforestation (9%), and industrial processes such as cement manufacturing (4%) as shown in Figure 2.3. Subsequently, the amount of CO_2 generated by natural sources is completely offset by natural carbon sinks and has been for thousands of years.

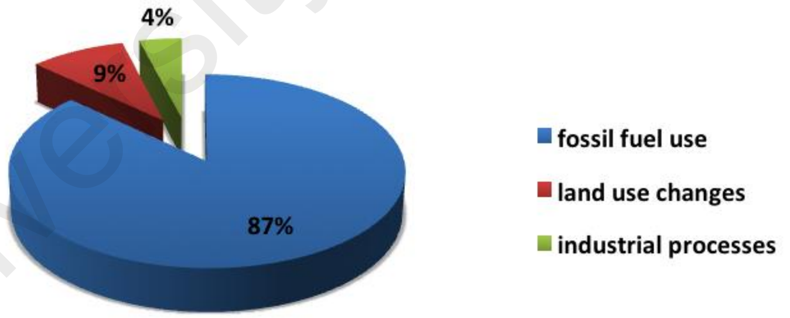

Figure 2.3: Human sources of global CO_2 emission (Le Quéré et al., 2013)

Before the influence of human activities, CO_2 levels were quite steady due to the natural balance. However, human sources of CO_2 emission have been growing due to industrial activities. Figure 2.4 shows burning of fossil fuels for the purpose of industrial activities, energy generation, transportation and residential usages.

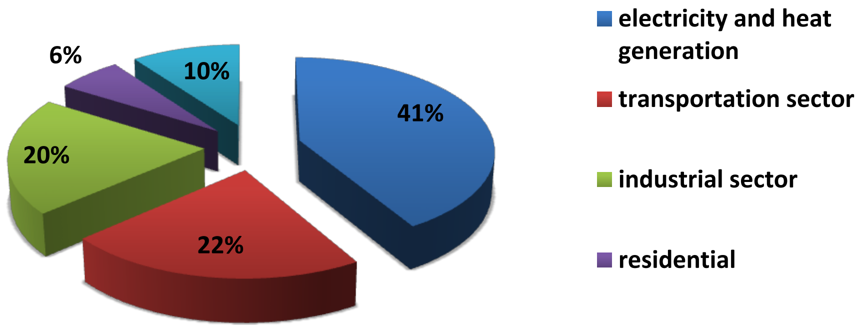

Figure 2.4: Global CO_2 emission from fossil fuel combustion (Le Quéré et al., 2013)

2.4.3 Carbon Footprint Estimation Methodologies

In general, methodologies for estimating carbon footprint can be classified into two main categories, which are methodologies for calculating carbon footprint of a premise and methodologies for calculating carbon footprint of a product, which identify emissions from all activities in the premise, including manufacturing processes and transportation vehicles and, which identify emissions of the whole life cycle of a product from the mining of raw materials, manufacturing, utilization and final reuse, recycling, treatment or disposal. There are many methodological approaches available in quantifying carbon footprint (Dias & Arroja, 2012). According to Wiedmann & Minx, (2007), carbon footprint could be quantified using two main methodologies, which were Process Analysis (PA) and Environmental Input-Output Analysis (EIO). The combination of PA and EIO produces a comprehensive strategy for carbon footprint quantification. PA focuses on identification of environmental impacts of products while EIO provides relevant analytical data for further studies on carbon footprint quantification.

Carbon footprinting methods are generally based on Life Cycle Analysis-based approaches. Life cycle assessment (LCA) produces complete picture of inputs and outputs with respect to generation of air pollutants, water use and wastewater generation, energy consumption and GHGs emitted. This assessment is often called as Environmental LCA. Table 2.6 shows some methodologies to estimate carbon footprint associated with premises and products. Subsequently, some of the methodologies listed in Table 2.5, generally corporate carbon footprint methodologies such as Greenhouse Gas Protocol, classifies three scopes of carbon emissions, which are Scope 1: direct GHG emissions, Scope 2: electricity indirect GHG emissions, and Scope 3: other indirect GHG emissions (Lee, 2011).

Table 2.6: Methodology for carbon footprint estimation (European Commission, 2011;Finkbeiner, 2009;Pandey et al., 2010)

Level	Organization	Methodology	Premise	Product
International	ISO	ISO 14064		/
		ISO 14067	/	
		ISO 14069		/
Europe	European Commission	Corporative & Product Carbon Footprint	/	/
UK	British Standard Institution	PAS 2050	/	
France	AFNOR	BP X30-323	/	
	ADEME	Bilan Carbone		/
Sweden	SEMCo	EPD System	/	
Japan	JISC	TS Q 0010	/	

2.4.4 Carbon Footprint Estimation in Manufacturing Process

Studies have been conducted by researchers on the estimation of carbon footprint related to various types of manufacturing industry. As for food and beverage manufacturing industry, the LCA study by Becalli, et al., (2009) reported that 1.0 kg of CO_2e emission was generated from the production of 40 tons of natural orange juice while 6.0 kg of CO_2e emission were generated from the production of 40 tons of concentrated orange juice. Furthermore, Wessels, (2015) reported that a study conducted in a soft drinks manufacturing premise shows that approximately 90 g of CO_2e were generated per liter of soft drink produced. Whereas Blignaut, (2014) indicated total emissions generated from white and red wine manufacturing are 0.70 kg CO_2e/l of white wine produced and 0.80 kg CO_2e/l of red wine produced, respectively.

Karakaya & Özilgen, (2011) studies on how to calculate the energy utilization and CO_2 emission during the production of fresh, peeled, diced, and juiced tomatoes. It considers the energy utilization for production of raw and packaging materials, transportation, and waste management. The energy utilization to produce one-ton retail packaged fresh tomatoes is calculated to be 2412.8 MJ. The respective CO_2e emission is determined by the source of energy used and is 189.4 kg CO_2e/ton of fresh tomatoes in the case of retail packaging, and did not change considerably when made into paste. CO_2e emission increased twofold with peeled or diced-tomatoes, and increased threefold when juiced. Chemical fertilizers and transportation made the highest contribution to energy utilization and CO_2e emission. Environmentally conscious consumers may prefer eating fresh tomatoes or alternatively tomato paste, to minimize CO_2e emission.

Pasqualino et al., (2011) who evaluated the environmental impact of manufacturing processes and disposal of the packaging materials for three beverage products (juice, beer and water) reported that 0.11 kg of CO_2e emission were generated for one life cycle of a 1-litre packaging bottle. They found that the amount of CO_2e emission was directly proportional to the amount of waste packaging materials generated.

For a dairy sector, studies by Vergé et al., (2013) found that carbon footprint of the raw milk produced in western provinces were 0.93 kg of CO_2e/l of milk, which was lower, as compared to 1.12 kg of CO_2e/l of milk produced in the eastern, due to differences in climate conditions and dairy herd management. However, the production of dairy products such as cheese, butter and milk powder generated 5.3 kg of CO_2e/kg, 7.3 kg of CO_2e/kg, and 10.1 kg of CO_2e/kg, respectively, where the results depended on the milk volume needed, milk solids content and the amount of energy used.

For a plastic manufacturing industry, Greene, (2014) reported that 0.51 MJ of energy, 0.13 L of water and 9.93 g of fossil fuel were consumed for each bag for production of 1,500 polyethylene bags, with mass of 5.78 g/bag, hence generating 4.7 g of municipal solid waste and 26.7 g of CO_2e. Whereas Dormer et al., (2013) found that the cradle-to-grave carbon footprint of 1 kg of recycled polyethylene terephthalate trays containing 85% recycled content was 1.538 kg CO_2e, of which the raw material, manufacturing, secondary packaging, transport and end-of-life stages each contributed 45%, 38%, 5%, 3% and 9% of the total life cycle GHGs respectively.

In summary, it can be concluded that for a similar manufacturing industry, various studies on the carbon footprint estimation have been conducted by researchers. Hence, comparisons on the findings can be done to identify the best finding that can be used as the benchmark value to improve environmental performance of manufacturing premises.

2.5 Implementation of Environmental Management Strategies

Industrial sectors began in Britain in the 1700s, and spread to the rest of the world, beginning with the United States (Eco Issues, 2012). However, the effects on the environment and societies would only be seen clearly years later. In 19^{th} century, pollutions have caused outbreaks of disease such as cholera and typhoid. This unfortunate incident has caused policymakers and the public had little awareness of the extent of industry's impact on the environment. Lack of policies and poor enforcement drive is among the causes of industrial pollution that have resulted in mass scale pollution that affected lives of many people.

Therefore, the creation of environmental laws and regulations began in 1970s where American and European companies began to formalize their approaches to pollution prevention and adopt voluntary eco-auditing (Culley, 1998). There were growing recognition of the need to standardize such procedures. This need, combined with developments in the international arena, gave momentum to the environmental management system movement.

In the meantime, UNEP was established and Environmental Management System (EMS) was introduced. EMS is a framework that helps a company achieve its environmental goals through consistent control of its operations (US Environmental Protection Agency, 2015). There are numerous models that can be used to implement EMS. The model acts as a basis for establishing a plan, which sets objectives and targets for improving environmental performance.

ISO 14001 is the specification standard used as a model for EMS. Furthermore, ISO 14001 is the first such standard that allows organizations from around the world to pursue environmental efforts and measure performance according to internationally accepted criteria. By complying with this standard, a company can demonstrate to the outside world that it has an appropriate and effective management system in premise. Up to the end of December 2013, at least 301,647 of ISO 14001:2004 certificates had been issued in 171 countries which shows an increment compared to previous year (ISO, 2012).

Another model used as the basic for EMS is Eco Management and Audit Scheme (EMAS). EMAS is a voluntary initiative designed for companies and other organizations to evaluate, report, and improve their environmental performance. It should be highlight that EMAS is a European Union Regulation, which applied within the European Union and the European Economic Area (Northern Ireland Environment

Agency, 2009). EMAS has been available for participation by companies since 1995 and was originally restricted to companies in industrial sectors. It is a set of common guidelines that would reduce costs and facilitate trade. In April 2001, EMAS II has been published and open to all economic sectors including public and private services (Chen, 2004). EMAS goes one step further than ISO 14001. The most visible difference is the need under these regulations for organizations to make public available for their environmental policy, objectives and targets and also their performance against the targets.

On top of that, there is also BS 8555, a new British Standard published by the British Standard Institute (BSI) in April 2003 (BIO Intelligence Service, 2009). The aim of BS 8555 is to provide guidance to all type of companies but particularly small and medium-sized enterprises (SMEs) to achieve externally certified environmental management systems using a phased rather than all-or-nothing approach to implementation (IEMA, 2003). BS 8555 is the standard that takes the form of guidance towards achieving ISO14001 or EMAS. There are six phases of BS 8555 that companies need to follow, which are:

(1) Commitment and Establishing the Baseline.

(2) Identifying and Ensuring Compliance with Legal, and other Requirements.

(3) Developing Objectives, Targets and Programmes.

(4) Implementation and Operation of the Environmental Management System.

(5) Checking, Audit and Review.

(6) Environmental Management System Acknowledgement.

After the implementation of each phase, the companies can either evaluate themselves through internal audits, allow major customers to evaluate them according to appropriate criteria or be evaluated by a third party to ensure that the requirements of each phase have been met. The companies may also choose to wait until two or more levels have been completed. A certificate can be issued following successful external assessment, so the company can demonstrate progress to its key customers and other interested stakeholders.

Besides ISO 4001, EMAS and BS 8555, there is also an EMS model that acts as a tool for assessing the total environmental impact of a product through its life cycle from raw materials extraction all the way through making it in a factory, selling it in a store, utilizing, and disposing of it (Adair, 2003). The tool is called Life Cycle Assessment (LCA). LCA analysis can be used in various ways. It can assist a company in comparing products or processes and considering environmental factors in material selection since it produces a list containing the quantities of pollutants released to the environment and the amount of energy and material consumed. In addition, inventory analysis can be used in policy-making, by helping the government to develop regulations regarding resource use and environmental emissions. SETAC (the Society of Environmental Toxicology and Chemistry) was the first international body to act as an umbrella organization for the development of LCA in 1989. Followed by US Environmental Protection Agency (EPA) in 1993 where they produced "Life-Cycle Assessment: Inventory Guidelines and Principles".

Cleaner Production is an integrated preventive environmental strategy applied during the manufacturing process and services (Constantin et al., 2008). It applies to manufacturing process by conserving raw material and energy, eliminating toxic materials, reducing the quantity, toxicity, hazard of emissions and wastes at sources of their generation. The concept of CP applies to industrial units, production departments, technological installations, and manufacturing process. CP was developed as a result of inefficiency of End-of-Pipe (EOP) technologies in 1970s (Mol & Liu, 2005). As compared to EOP, implementation of CP strategies requires none or lower investment costs. Table 2.6 consists of comparison of all EMS models. According to Table 2.7, it shows that CP suits more to concept of sustainability as compared to other EMS concepts. It is because CP focuses on preventing the generation of wastes from the sources. CP strategies use resources such as energy, raw materials and other inputs more efficiently, generate less waste, facilitate recycling and reusing resources and handle residual wastes in a more acceptable manner (Rigamonti et al., 2014). In other words, CP is about achieving the same production output with less inputs (materials and energy) and consequently with less pollution. Besides that, CP encourages greater degree of partnerships and communication with local governments, universities, and communities to ensure local participation and encourage equity. In addition, CP is not only protects the environment and human health, but also improves the economic efficiency, competitiveness and profitability of enterprises. The application of CP can significantly improve the resource efficiency and environmental performance of existing manufacturing processes, with no or lower investment.

Table 2.7: Summary of Environment Management Strategies models

EMS	Focus	Case Study	Strength	Limitation	Reference
ISO 14001	Covers the environmental legislative requirements for a company, as well as provides information about significant environmental impacts and environmental aspects, which the organization can control, and influence.	Alps Industries Ltd, India • Textile industry. • Applied ISO 14001 guidelines to determine activities and its impact towards environment. • Results of implementation: reduced energy consumption, oil spillages, air pollution and better housekeeping. • Awarded ISO 14001 in 1996 by KPMG Quality Registrars, Netherland.	• Well-recognized international standard. • More ethical and potentially attractive. • Green corporate image to organization. • Assist in relationship with local government.	• Lack of awareness, transparency and problem solving ability. • Inconsistent cost of ISO 14001 implementation and certification. • Voluntary-based process.	Commission for Environmental Cooperation, 2005; Khas, 2001; Australian Government, 2001; Marsh, 2012; Whitelaw, 2004
EMAS	Encourage companies to publish rigorous and independently verified environmental performances report.	Franz Dorner, Austria • Agriculture industry. • Registered EMAS in 2009. • Results of implementation: increased output of poultry farming, reduced CO_2 emission and fossil fuel usage.	• More sales opportunities, credibility and transparency. • Enhance reputation. • Broader range of stakeholders.	• EMAS registration does not pay off. • Limited to EU and European Economic Area. • Voluntary-based initiatives.	Tinsley, 2002; European Commission, 2009; IEMA, 2000; Moosmayer, 2011; Baltic University Program, 2002

Table 2.7: Continued

EMS	Focus	Case Study	Strength	Limitation	Reference
BS 8555	Provide guidance to all type of companies but particularly SMEs to achieve externally certified environmental management systems using a phased rather than all-or-nothing approach to implementation.	Kennedy Utility, UK • SME Company, that provides civil engineering services. • Introduced to BS 8555 by their mentor, United Utilities. • Followed all phases in BS 8555 and decided to implement ISO 14001. • Results of implementation: introduced ISO 14001 in their services, raised awareness of EMS to their customers.	• Formal standard based predominately on ISO 14001 and EMAS, easier for SMEs to progress. • Stand alone standard with certificate at each stage. • Use of environmental performance indicators based on ISO 14301. • Provides flexibility and organizations can choose their own pace of implementation.	• Participants may not progress further to higher phase or towards achieving accreditation to ISO14001 or EMAS regulation. • Actual costs for implementation, and certification are unknown. • Not proven in isolation from good funding, support, and marketing. • Limited to EU and European Economic Area.	IEMA, 2003; Chen, 2004; Northern Ireland Environment Agency, 2009; Martin & Chris, 2012; Eccleston, 2011
LCA	Evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes and emissions released to the environment, and to evaluate opportunities to achieve environmental improvements.	Automobile Battery Industry, Thailand • LCA was carried out according to the steps in ISO 14040 and focused on manufacturing process and transportation of products. • Results of implementation: confirmed that calcium-maintenance free technology is more environmental friendly compared to conventional technology. Calcium-maintenance free technology battery had 28% less impact towards environment.	• Identifies and quantifies energy and materials used and wastes released to the environment. • Allows proactive rather than reactive actions. • Provides a standard scientifically based method.	• Data collection is time-consuming and costly. • Traces back impacts from a product. • Focuses on environmental impacts. There is no consensus on how to address trade-offs between environmental production and social and economic impacts. • Differing views exist on some methods.	Metal & Premrudee, 2013; Adair, 2003; Guinée & Heijungs, 2005; Curran, 2006; Rebitzer et al., 2004

Table 2.7: Continued

EMS	Focus	Case Study	Strength	Limitation	Reference
Cleaner Production	Eliminate or reduce pollutants at the source during the course of production processes	Shouguang Alcohol Factory, China • Produces alcohol. • CP analysis is done by material balances to determine water consumption. • Results of implementation: productivity and quality of alcohol were improved; reduced wastewater produced and water consumption, costs savings.	• Promoted globally by the UN. • Preventive approach rather than control. • Can be adopted in any sector and size of organization. • Innovation developed within the company, thus no need for experts.	• Absence of national policies that support the CP activities. • Insufficient resources to achieve a significant impact at a global level. • Lack of awareness.	Guo et al., 2006; Constantin et al., 2008; Stone, 2006; Schramm, 1998

2.6 Cleaner Production and Manufacturing Industry

2.6.1 Development of Cleaner Production

Cleaner Production started to develop in industrial sector in mid of 20th century when humanity started to prevent pollution instead of ignoring and controlling it. At the beginning, in 1960s, industries began to install purification units at the end of the effluent pipes of various manufacturing processes. This reactive waste management is called End-of-Pipe approach (EOP) (Lei et al., 2002). From a historical point of view, EOP approaches played an important role in controlling industrial pollution to a certain extent. However, the EOP approach is not the solution because it usually causes secondary pollution and increases both the capital costs and operation costs that are burdensome to most enterprises (Phan & Phan, 2008). Therefore in 1970s, with the emerging of the concept of sustainable development, CP was proposed and advocated based on the lessons learned from traditional industrial pollution control practices (Hans, 2007).

CP is a pro-active and integrated solution to pollution problems by eliminating or reducing pollutants at the source during the manufacturing processes (Staniškis & Jayaraman, 2010). These pollution prevention and waste minimization strategies appeared necessary to reduce the enormous costs of cleanup actions, certainly from the moment that the polluter pays principle was brought into legislation. By bringing the environmental and the business concern together, the new approach of CP has proven its benefits and will be promising in the 21st century. In 1980s, there were a great number of competing concepts related to pollution prevention principles, such as pollution prevention, cleaner technologies, low-and non-waste technologies, waste prevention, waste minimization, etc. Against this background, UNEP first put forward CP in 1989 as "Cleaner Production is the continuous application of an integrated preventative environmental strategy applied to processes, products and services to reduce risks to humans and the environment" (Nicholson, 1981).

The promotion and implementation of Cleaner Technology (CT) in Malaysia was started in 1996 under the auspices of several parties spearheaded by the Department of Environment Malaysia (DOE), the Standards and Industrial Research Institute of Malaysia (SIRIM BERHAD) and international funding agencies such as Danish Co-operation for Environment and Development (DANCED) (Department of Environment, 2010). DANCED is a technical collaborative program between Malaysia and Denmark. The projects were denoted with 4P objectives, which are Pollution Prevention, Productivity and Profitability. Furthermore, the projects were conducted to promote adoption of CT in three specific industrial sectors, which are food, electroplating and textile industry. Activities conducted includes environmental and energy audits establishment of a clean technology database and dissemination of information through seminars, workshops and publications. Six demonstration projects were conducted to showcase the benefits of pollution prevention strategies in increasing productivity and profitability (Department of Environment Malaysia, 2009; Vincent & Sivalingam, 2006). Besides, two types of services, which are Cleaner Technology Extension Service (CTES) and Cleaner Technology Information Centre (CTIS), were provided by SIRIM (Department of Environment Malaysia, 2009). A project titled *Cleaner Technology for Improved Efficiency and Productivity of Malaysian Industry* was conducted in 1999, targeting to reduce the environmental pollution from SMIs and improve their compliance with the environmental regulations (Department of Environment Malaysia, 2010).

In 2003, DOE continues to promote CP in Malaysia through implementation of various projects and CP awareness programs for SMIs. National CP Promotion Program was formulated through the study collaboration with University of Technology Malaysia, where *Cleaner Production Blueprint for Malaysia* was published. The blueprint consisted the conceptual framework and strategic plans for the promotion and implementation of CP in Malaysia, especially for SMIs. The strategic plans includes action plans for formulation of national policy, educational and awareness campaign, establishment of networking and dissemination of information, training and audit, incentives strengthen regulatory-policy framework, capacity building and CP coordination centre. The blueprint also addressed the need for CP technologies in priority SMIs manufacturing and other sectors. Under the 10^{th} Malaysia Plan (RMK10), CP Training Program for SMIs was introduced with the aim to increase capacity of all stakeholders to adopt CP practices, mainly in CP audit program (Department of Environment Malaysia, 2014).

Moreover, in terms of information and knowledge dissemination of CP in Malaysia, a series of CP guidelines and industry specific handbooks were also published by the Department of Environment Malaysia, which are CP implementation guidelines for printing, juice manufacturing, batik making, crude palm oil, vermicelli manufacturing, raw natural rubber and metal finishing electroplating industry. The guidelines highlighted major environmental issues related with the respective industries, thus describes methodology of conducting CP audit, quantifying carbon emission and list out specific CP options for the respective industries. The guidelines also describe a monitoring plan for CP implementation, which highlighted key parameters to be monitored. In addition, Department of Environment Malaysia also published annual reports, CP bulletins and newsletters, which reporting on the CP programs and activities conducted.

A number of industry specific handbook were also published by researchers globally. For example, UNEP has actively published series of industry specific handbook since year 2000. The handbooks included guidelines on CP assessment in meat processing (COWIconsult, 2000b), CP assessment in dairy processing (COWIconsult, 2000a), and CP assessment in fish processing industry (COWIConsult, 2000). The guidelines highlighted the application of CP in the slaughtering processes, milk and dairy products processes and fish fillet and fish oil manufacturing processes, respectively with purpose to create awareness on environmental impact of the manufacturing industry and to promote CP approach to minimize the impacts. However, these guidelines are not integrated with the methodology of quantifying carbon emissions generated from the respective manufacturing processes and activities. In addition, a handbook on pollution prevention and CP implementation in agrochemical industry was also published in 2011 (Cheremisinoff & Rosenfeld, 2011). The handbook highlighted methodologies for estimating and reporting of emissions, treatment and control technologies and CP prevention best practices for wood and paper industry.

Furthermore, an official website namely *Cleaner Production Virtual Centre* (CPVC) was launched in 2007 and renamed as *Green Industry Virtual Centre* (GIVC) in 2009. The website is continuously administered by DOE Malaysia, which consists of specific information on CP program and activities, list of CP auditors and various academic references, such as books, journals and case studies. In addition, a web based tool namely *Cleaner Production Implementation Tool* (CPIT) was also developed to assist SMIs in conducting self implemented CP audit at their premise.

CP is one of the government's initiatives to get the manufacturing industry in Malaysia especially SMIs to support and commit in preventing and controlling pollution and, thus, improving the compliance for the Environmental Quality Act 1974 (Rahman, 2013). Furthermore, DOE aims to enhance the capability of SMEs in adopting CP that is vital for economic and sustainable development. However, the adoption of CP by most premises, in particular, SMIs are yet to be seen due to the lack of awareness and financial limitation.

Management systems in SMIs generally focus on every day business and tend to be immediate, responding to critical incidence situation management. In spite of this, SMIs are less likely to have environmental plans or implement environmental management practices as compared to large firms. Furthermore, SMEs are burdened with the cost associated with environmental management. Because of these reasons, SMIs need to be engaged appropriately if they are to participate in better environmental practices (Yacob, 2013).

A number of studies have sought to explain the motivations behind the choice of practices and the rationale for environmental practices. In most cases, the SMIs believe that the environment is an important issue, and they support protection of the environment. However, awareness of formal environmental management systems, specific environmental laws and/or remediation processes is generally very poor and quite limited. SMIs are generally much less likely to embark on environmental improvement programs than large firms, to adopt a written environmental policy, to utilize a formal environmental management standard, or to undertake an environmental audit (Yacob, 2013).

2.6.1.1 Laws and Regulations for Promoting Cleaner Production

In Malaysia, there are no specific laws and regulations that enforce the industries to implement CP practices, where the implementations are done according to voluntary basis. According to a survey conducted by DOE in 2009, 369 of 619 SMIs have implemented fully or partly of CP practices at their premise. This proved that SMIs were practicing CP program with their own initiative. However, elements of CP practices were embedded into some of the regulations under EQA 1974 (Department of Environment Malaysia, 2011). Among the regulations are:

- Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987. The order requires preventive planning for new development projects. 19 prescribed activities subject to Environment Impact Assessment (EIA) to be approved by Director General of DOE.
- Section 33A, Amended Environmental Quality Act 1974 Order 1996. The order requires for environmental auditing to be made compulsory upon request from the Director General of DOE.
- Environmental Quality (Scheduled Wastes) Regulations Order 2005. New regulations for managing, treating, storing and disposing of scheduled waste, which include minimizing waste.
- Environmental Quality (Industrial Effluent) Regulations Order 2009. Regulation 9 requires the owner to conduct performance monitoring of the components of the effluent treatment system.
- Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations Order 2009. Regulation 11 requires the owner to conduct performance monitoring of the components of the leachate system.

2.6.2 Case Study: Application of Cleaner Production Strategy in Manufacturing Industry

CP is a win-win strategy since it benefits the environment, communities and industries. CP is a practical tool for improving the production efficiency. In terms of industrial, CP can also be seen as a four-in-one tool: A management tool, an economic tool, an environmental tool and a quality improvement tool (Kazmierczyk et al., 2002).

Thus, CP emphasizes on environmental performance without ignoring the economic and productivity aspects in the company. Application of CP strategies will bring numerous advantages to the company, such as reduction in CO_2 emission, reduction in wastes and pollution, improvement in products and services, savings in production costs, improvement in workers health and safety conditions and improvement in company's image (Persson, 2011; Yusup et al., 2013; Department of Environment, 2010). Subsequently, CP strategies have been actively implemented in the industries, mainly focusing on economic and environmental returns. Table 2.8 shows some examples on case studies of CP implementation.

Table 2.8: CP implementation case studies (Department of Environment Malaysia, 2016;Masike & Chimbadzwa, 2013;Özbay & Demirer, 2007; Abbasi & Abbassi, 2004;Gurbuz et al., 2004;Abou-Elela et al., 2007)

Company Name	Product	Annual Production	Issues Identified	CP Options Implemented	Investment Costs	Economic Return		Environmental Return
						Net Annual Saving	Payback Period	
Fermpro Sdn. Bhd.	Industrial ethanol	5 million liters	High wastewater generation.	• Installation of evaporator system to replace exiting biological treatment plant. • Recover wastewater and reuse in process.	4 million RM	0.5 million RM	4 years	• Reduction in wastewater generation and odor.
Taiyo Yuden (Sarawak) Sdn. Bhd.	Multilayer ceramic chip capacitor	15 million pieces	Non-compliance of effluent and air quality, high sludge generation and energy consumption.	• Installation of scrubber system. • Installation of filter press and sludge dryer machine. • Installation of pet-film scrapper machine. • Installation of regenerative thermal oxidizer.	10.7 million RM	1.5 million RM	Not available	• Effluent and air quality comply with regulation. • 70% reduction in sludge generation. • 100% plastic pet-film recycled. • 95% thermal efficiency.
Malayan Cement Industries Sdn. Bhd.	Portland cement and clinker	3.3 million tons	Non-compliance of effluent and air quality, noise level.	• Installation of electrostatic precipitator, bag filter plants, water spray. • Installation of oil traps. • Installation of noise suppressors.	70 million RM	Not available	Not available	• Reduction in dust emission, noise level and water pollution.

Table 2.8: Continued

Company Name	Product	Annual Production	Issues Identified	CP Options Implemented	Investment Costs	Economic Return		Environmental Return
						Net Annual Saving	Payback Period	
Samsung SDI (M) Sdn. Bhd.	Color picture tubes	12.8 million pieces	High raw material and waste disposal cost.	• Installation of distillation machine to recover degreasing agent for recycling purpose.	0.2 million RM	454 million RM	7 months	• Reduction in raw material usage and waste generation.
National Semiconductor Sdn. Bhd.	Integrated circuit	4 billion unit	High wastewater generation.	• Installation of ultrafiltration system to recycle wastewater from wafer saw process.	0.68 million RM	0.08 million RM	8 years	• Reduction in water consumption of 39,000 m^3 annually. • Reduction of sludge generation of 5.4 tons annually.
Turkey Olive Oil Enterprise	Crude olive oil	9,000 tons	High wastewater generation.	• Installation of two-phase continuous extraction system to replace three-phase system.	Not available	0.1 million £	Not available	• 95% reduction in wastewater generation (59,400 m^3 annually).
Chemical Industry	Sulfonated naphthalene	30,000 tons	High wastewater generation and raw material loss.	• Recycling of retained water in filter press and washing water of reactors. • Eliminate leakage of raw material, products and water.	0.1 million L.E.	0.34 million L.E.	2 months	• Reduction in water consumption of 10,950 m^3 annually. • Reduction in product loss of 1,150 tons annually.

Table 2.8: Continued

Company Name	Product	Annual Production	Issues Identified	CP Options Implemented	Investment Costs	Economic Return		Environmental Return
						Net Annual Saving	Payback Period	
Jordan Paper and Cardboard Factory	Corrugated boxes	15,000 tons	High wastewater generation and raw material loss.	• On site reuse of steam condensation by enclosed dryers' hood. • Separation of water stream. • Replacement of floatation pump. • Proper shelter and pavement for storage area. • Implementation of de-inking process. • Modification of sorting and collection system.	0.12 million USD	0.34 million USD	1.5 year	• Reduction in water consumption of 396,000 m^3 annually. • Reduction in raw material loss
Zimbabwe Sand Casting Foundries	Casting product	7 million unit	Dust emission and solid waste.	• Installation of dust removal and ventilation system. • Powdered additives and mixtures are handed in a sludge form (mixed with water). • Apply gating system design software for proper gating. • Installation of rotary screen and shot blasting reclaimers.	Not available	Not available	Not available	• Reduction in sand waste, raw material costs and disposal costs. • Elimination of health hazard from dust, regulation penalties and fines. • Better working environment for workers. • Better housekeeping.

Table 2.8: Continued

Company Name	Product	Annual Production	Issues Identified	CP Options Implemented	Investment Costs	Economic Return		Environmental Return
						Net Annual Saving	Payback Period	
Ankara Dairies	Processed milk	18 million liters	High wastewater generation.	• Recycling of clean water from the clarifier and separator and condensate for equipment cleaning. • Changing the damaged hose in the homogenization unit. • Prevent raw milk spillage by connecting raw milk storage tanks through single pipe to the pasteurization unit. • Installation of level control to prevent overflow of excess water used for liquefaction of sludge. • Implementation of CIP system for cleaning of pasteurization unit. • Installation of shut off spray nozzle at the end of water hose.	Not available	Not available	Not available	• Reduction in water consumption of 17,038 m^3 annually.

2.7 Summary of Literature Review

The literature review conducted in this study reveals that there are various initiatives to reduce carbon emission, especially in SMIs. The methodology adopted by these premises to assess carbon emission and procedures used to generate CP options are not comprehensive and usually focused around energy usage and waste generation. Analysis of the typical activities in the premise also reveals that there are various direct and indirect sources of carbon emission which need to be incorporated in the overall carbon emission calculation, which include aspects such as safety, productivity and raw material loss. The review also reveals that persons who are familiar with a specific industry or someone with strong technical background commonly develop CP options. This situation has resulted in CP not being adopted by a wide spectrum of SMIs. Therefore, there is need to develop a methodology that can be used by anyone to generate CP options based on information available on the premise and by answering some generic questions. The case studies found in the literatures also consider minimum payback period and percentage of carbon emission reduction as the main performance indicator to evaluate the effectiveness of a selected CP option. Therefore in this work, a new standard generic methodology to conduct CP audit and CP option generation are developed and validated using appropriate case studies.

CHAPTER 3: DESIGN AND DEVELOPMENT MECHANISM

3.1 Introduction

Implementation of CP strategy requires a structured and systematic methodological framework. It is vital to ensure that collection of information is complete. Hence, Cleaner Production Implementation Methodology (CPIM) is developed as a new standard tool for guiding Malaysian SMEs in implementing CP strategies mainly in manufacturing premises, thus facilitates industry to comply in various aspects of Malaysian Environmental Regulations. CPIM provides principles and detailed step-by-step procedures of implementing CP strategies in manufacturing premises. Hence, this methodology can be used to formulate a detailed plan for the overall implementation of CP strategies. The following sections describe the detailed methodology on mechanism of design and development of CPIM.

3.2 Flowchart for the Overall Research Methodology

The overall methodology of developing Cleaner Production Implementation Methodology is illustrated in Figure 3.1.

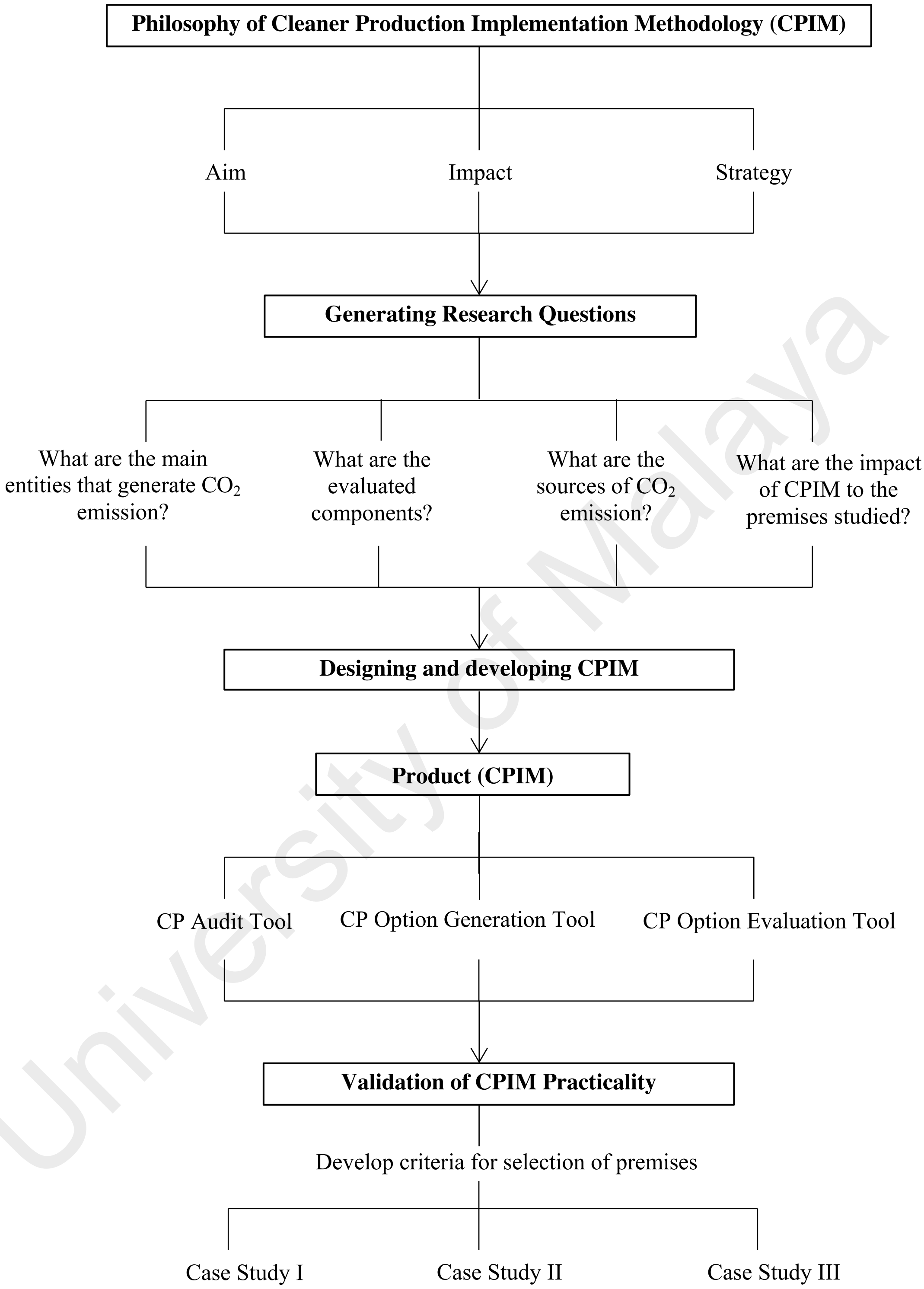

Figure 3.1: Overall methodology in developing Cleaner Production Implementation Methodology

3.3 Philosophy of Cleaner Production Implementation Methodology

Cleaner Production Implementation Methodology was developed based on a philosophy of three main components, which are determination of aim, impact and implementation strategy. The first component is to identify aim of the CPIM, which is to assist SMIs in reducing CO_2 emission generated from manufacturing activities through the implementation of CP initiatives. Strategies for reducing the generation of CO_2 emission can be implemented by controlling the consumption and generation of main entities in the manufacturing processes and activities that contributed to the generation of CO_2 emission. The second component is to identify the impacts of CP initiatives implementation in manufacturing premises. The impacts can be divided into two types of returns, which are in economic and environmental aspects. Subsequently, the returns are directly contributed to the reduction of CO_2 emission. The third component is the strategy of implementing CP initiatives. The strategy focuses on three main elements, namely prevention, reduction and improvement. Typically, the strategy focuses on prevention and reduction of CO_2 emission generation. Specifically, CP strategies prevent and reduce the main entities that contributed to the generation of CO_2 emission, while the strategy of improvement in other aspects such as plant layout, safety in workplace, and standard operating procedures indirectly contributed to the reduction of CO_2 emission. The respective components of CPIM philosophy was expanded in details to develop research questions, that will serve as a basis for designing and developing methodologies of CPIM.

3.4 Generating Research Questions

The application of a structured framework for the development of CPIM should give ideas to generate list of improvements that can be done to overcome the weakness in the implementation of CP strategies. The objectives of this research are to develop a new standard methodology for the implementation of CP strategies in SMIs and evaluate the practicality of the methodology by using actual case studies. To meet the objectives, the methodology of this work was developed by focusing on answering the Research Questions. Thus, the three following Research Questions need to be answered, for designing and developing the framework of CPIM and meet the first objectives of the study.

OBJ 1: Develop a new standard methodology in implementing cleaner production strategy for SMIs, proposed as Cleaner Production Implementation Methodology for SMIs.

RQ 1: What are the main entities that contributed to CO_2 emission generation in manufacturing industry?

RQ 2: What are the sources of generation for entities that contributed to CO_2 emission generation in manufacturing industry?

RQ 3: What are the evaluated components in term of returns?

The practicality of CPIM implementation towards various types of manufacturing industries will then be validated through demonstration in real case studies. Thus, the Research Questions below should be answered to meet the second objective of this work.

OBJ 2: Validate the practicality of using CPIM in implementing cleaner production strategy in SMIs using appropriate case studies.

RQ 1: What are the impacts of the application of CPIM to the premises studied?

3.5 Design of Cleaner Production Implementation Methodology

The main objective of this work is to develop a standard Cleaner Production Implementation Methodology, which will address the problems associated with various CP implementation methods available in global, and will contain enough information and guidance so that industries can accurately, effectively and efficiently implement CP strategies and receive quick and optimal returns. To do so, CPIM adopted CP methodology developed by United Nations Environmental Programme and United Nations Industrial Development Organization (UNEP/UNIDO) as the basis for the design of CPIM. However, CPIM goes beyond the UNEP/UNIDO methodology by incorporating the quantification of CO_2 emission into the design. The CPIM is developed to perform three phases of implementation strategy: Sub-methodology I: CP audit; Sub-methodology II: CP option generation; and Sub-methodology III: CP option evaluation. A detailed description of the components of each CPI sub-methodology will be discussed in the next section.

3.5.1 Components of Cleaner Production Implementation Methodology Design

The CPIM is designed based on answers of Research Questions developed. Three key components were developed as the features of CPIM design to create overall implementation plan of CP strategy, starting from the planning phase, till the evaluation of implementation effectiveness. The first component is identification of key entities that contributed to the generation of CO_2 emission. Answering to the Research Question number 1 for Research Objective number 1, three key entities that contributed to the generation of CO_2 emission in manufacturing industry was identified as follows: (1): Material consumption; (2): Energy consumption; and (3): Waste generation. The three entities were typical resources required by the manufacturing processes and activities in a manufacturing premise. The second component is identification of sources of entities that contributed to the generation of CO_2 emission. Characterization of sources requires information on types of resources consumed in manufacturing processes and activities, types of wastes generated and location, types of processes and activities that consumed resources and generating wastes, quantity of resources consumed, quantity of waste generated as well as characteristics of waste generated. Further, the third component is the identification of components that will be evaluated in term of returns from the implementation. In general, the design of CPIM incorporates components of economic and environment as for the evaluation of returns. Finally, referring to the Research Question number 1 for Research Objective number 2, validation of the practicality of CPIM is demonstrated by using real case studies. Other than that, the use of three types of standard and simplified tools enables CP strategies to be implemented more easily and shorter time. Tools were comprehensively developed, where manufacturing premises are guided to complete required information related to their premise.

3.5.2 Design of Sub-Methodology I: Cleaner Production Audit

CP audit is the first step in the CPIM. Typically, CP audit is conducted to evaluate the status of performance for respective manufacturing premises, thus guiding towards improvement. CP audit is a process of collecting information to identify any inefficiency in material and energy consumption, as well as waste generation. CP audit is conducted in manufacturing premises to obtain a clear understanding on manufacturing processes and activities, quantifying material and energy consumption, quantifying waste generated, identifying issues, and subsequently generation possible options to overcome the issues (Mironeasa & Codină, 2013). CP audit is directly an important step in identifying key entities that contributed to the generation of CO_2 emission from manufacturing processes and activities. This section describes the methodology used in designing and developing tool for Sub-methodology I, which is CP Audit Tool.

3.5.2.1 Design of Cleaner Production Audit Tool

CP Audit Tool is developed to provide a structure during the process of gathering information and also analyzing audit findings for the preparation of audit report. The tool is designed to guide CP Auditor to identify relevant information to be gathered during the audit process, identifying issues and subsequently generates relevant improvement opportunities. The tool needs to be completed once the audit process is complete to ensure that relevant information is sufficient. The design of key components of CP Audit Tool is developed by answering Research Questions number 1 and 2 for Research Objective number 1.

Component 1: RQ 1: What are the key entities that contributed to the generation of CO_2 emission?

The methodology used to develop CP Audit Tool includes quantitative analysis of input and output stream, which is represented as material and energy flow for a manufacturing process (A. Özbay & Demirer, 2007). A typical flowchart illustrating the flow of input and output of materials and energy for a manufacturing process is shown in Figure 3.2. In this work, CP Audit Tool is developed by determining the boundary of audit to be the entire manufacturing process and activities in the premise (gate-to-gate), while the product is defined as the functional unit. Hence, the components included in the CP Audit Tool are the key entities that contributed to the generation of CO_2 emission. In details, the following are the classification of entities as shown in Figure 3.2:

(i) Raw material

Raw material profile consists of characteristics of raw materials consumed, including quantitative data related to raw material streams, which are main raw materials, additives and water. In the audit, raw material is defined as materials consumed in the manufacturing processes and finally becomes products. Chemicals, which consumed as the cleaning agents can also be considered as additives in the process, but not contribute in becoming the products. However, there are certain cases where chemicals can be considered as the main raw materials, such as chemicals that are used as additives in food and beverage manufacturing industries (Markakis, 1982). Further, water consumed in manufacturing processes can be divided into two main categories, which are process water and non-process water. Process water is defined as water consumed as raw material that contribute as product, such as filtered water used in food and beverage manufacturing industries. Whereas non-process water is defined as water used in the overall processes that not contribute as product, such as cooling water or hot water used in cleaning of equipment.

(ii) Energy

Energy profile consists of assessment of the energy used, including quantitative data related to fuel consumption streams in solid, liquid and gas phase, thermal energy and electricity used in the process. The use of electrical energy is divided into two categories, namely the energy used for manufacturing processes such as for machineries and other electrical appliances, while the non-process energy is the energy used to support the processes activities, such as lighting systems, air conditioning and administrative activities. Typical fuels used in manufacturing premises are diesel, petrol, liquefied petroleum gas, natural gas, firewood, and charcoal. Process fuel is defined as the fuel used to generate energy for the manufacturing processes, such as diesel used in boiler to produce steam, whereas gasoline used for forklifts are example of non-process fuel. In addition, fuel is divided into two categories since each fuel has different value of emission factor according to its usage, which are fuel for stationary combustion and fuel for mobile combustion (Wang et al., 2010).

(iii) Waste

Waste profile consists of characteristics of wastes generated from the manufacturing process and activities in manufacturing premises, including quantitative data related to waste stream in the phase of solid, wastewater and gas. Solid waste is divided into two categories: non-scheduled solid waste and scheduled solid waste. Scheduled wastes as listed in the Malaysian Environmental Quality Act 1974. The gas emissions include SOx, CO, NOx, CO_2 and hydrocarbons.

(iv) Product

The product profile includes an environmental assessment of products, including quantitative data related to environmental impacts attributed to the product flow through the manufacturing process. For example, products contents such as chemicals, which have a characteristics of explosive, flammable, oxidizing, toxic, carcinogenic, and irritation can contribute risk to the environment and human health. In addition, there are also products that can transform into harmful waste to the environment at the end of its useful life cycle, such as electronic products (Serranti et., 2015).

(v) Packaging

Packaging profile include environmental characteristics of packaging materials used in the manufacturing process, including quantitative data related to various types of packaging materials and size, other than considering the negative impact of these materials to the environment.

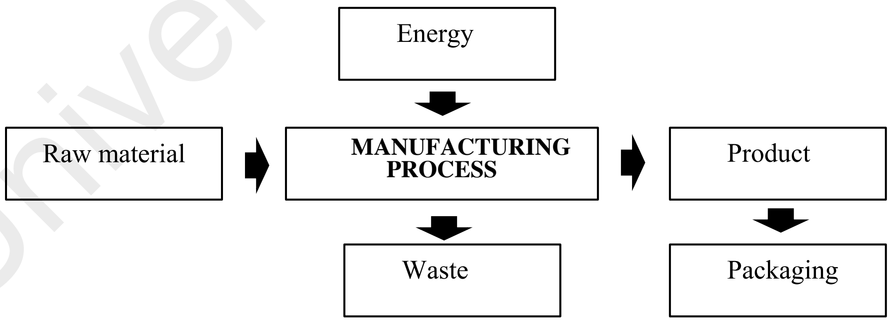

Figure 3.2: Material and energy flow in a manufacturing process (Fijał, 2007)

Based on the classification of key entities for a manufacturing premise, the features of CP Audit Tool is expanded to answer Research Question number 2 for Research Objective number 1.

RQ 2: What are the sources of entities that generate CO_2 emission?

During the CP audit, it is important to identify sources of entities that generate CO_2 emission in the premise. It is essential in order to identify key issues faced by the premise and subsequently generating improvement opportunities. In details, sources of entities that contributed to the generation of CO_2 emission in a manufacturing premise according to classification of entities are as follows:

(i) Raw material, product, packaging material

Typically the source of CO_2 emission generation from the raw materials, products and packaging materials can occur through material loss due to spillage during handling, off specification or expired raw materials and products, or materials that are not fully utilized such as left over of raw materials in the packaging containers (Duflou et al., 2012).

(ii) Energy: fuel used for transportation and for generation of energy, electricity

The source of CO_2 emission from energy consumption can be divided into two main categories, namely fuel consumption for transportation systems within the premise and fuel consumption to produce energy. Typically, fuels are consumed for forklifts and trucks. Fuels also used to produce energy such as direct heating for mixing process and fuel consumption to generate steam for boilers. Besides fuel, the source of energy consumption can also occur through the use of electricity for unit operations and other facilities such as electrical boilers, water pumps and wastewater treatment facilities. The use of electricity to support the overall operation of the premise such as lighting systems, air conditioning and administrative activities can also contribute as the sources of CO_2 emission generation.

(iii) Waste

The source of waste generation from manufacturing operations are typically through inefficiency during operation such as spills of raw materials, chemicals or products, expired or off specification materials or products, damaged packaging materials or raw materials or rejected products. In addition, wastewater can be generated generally through two main activities, namely processing activities, such as cleaning tools, floor and unit operation and the 'Clean In Place' process, and wastewater resulting from domestic use by the workers (Thevendiraraj et al., 2003). In addition, the emission gas can also be produced through the combustion of fossil fuels for energy production, especially for the use of the boiler.

Typically, CP audit process can be done through qualitative and quantitative methods (Mironeasa & Codină, 2013). Qualitative method can be done by observation and discussion with the representative of the audited premise, while quantitative method can be done by reviewing records of inventories, data sampling, installation of measuring equipment, estimations and material and energy balances. Both methods are discussed in Chapter 4: Result and Discussion. In continuation of the answers for Research Question number 1 and 2 for Research Objective number 1, the components that included in the CP audit tool are (1): Product; (2): Raw material; (3): Water; (4): Electricity; (5) Fuel; (6) Waste and (10): loss and wastage can be measured qualitative and quantitatively. However, component number (7): Housekeeping; (8); Risk and (9): Process flowchart can be evaluated qualitatively. Detailed description of the CP Audit Tool is discussed in Chapter 4: Result and Discussion.

3.5.3 Design of Sub-Methodology II: Cleaner Production Option Generation

CP option generation is the second steps in CPIM. Typically, it is the important step in improving performance of a manufacturing premise, where the implementation of suitable CP options able to provide returns is various aspects, specifically in economic and environment. CP option is defined as any activities, changes or improvements that can provide direct and indirect returns to the premise (Rao, 2004). The process of generating CP options focusing on identifying as many as possible of options that can reduce the generation of key entities that contributed to the generation of CO_2 emission from the manufacturing activities. This section describes methodology used in designing and developing tools for Sub-methodology II, which is CP Option Generation Tool.

3.5.3.1 Design of Cleaner Production Option Generation Tool

CP Option Generation Tool is developed to provide an appropriate framework and methods to generate options systematically. The tool is designed to help CP Auditor to generate as many as possible of CP options to overcome issues identified in the audited manufacturing premise. Subsequently, the tool can be used as soon as the process of analyzing CP audit findings is completed and main issues is identified. The design of main components of CP Option Generation Tool is developed based on main components in the CP Audit Tool. In overall, the development of CP Option Generation Tool is done in accordance with the steps illustrated in Figure 3.3.

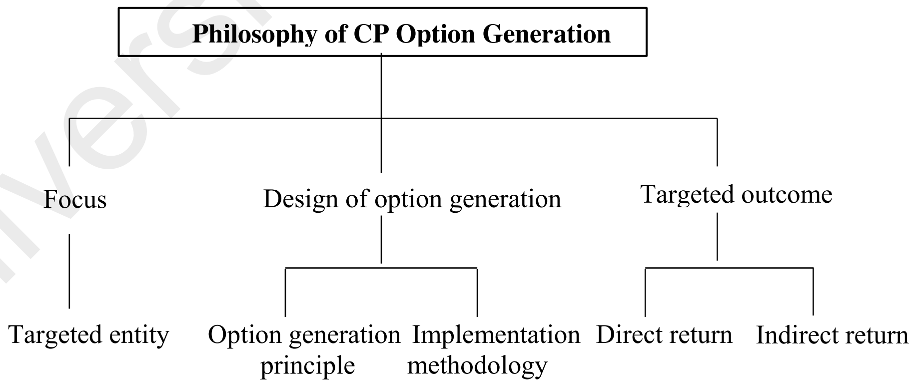

Figure 3.3: Methodology of developing Cleaner Production Option Generation Tool

CP Option Generation Tool is developed based on three components of philosophy, which are identifying focus, design of option generation, and targeted outcome. The first component is focus of key entities that contributed to the generation of CO_2 emission from manufacturing activities that have been identified in CP audit tool, which are materials, energy and risks. The second philosophy is designing option generation according to aspects of CP option generation principle and methodology of CP option implementation. The principles of CP option generation are developed according to fundamental principles of chemical engineering, which are changes in key process parameters, which are temperature (T), pressure (P) and time (t) (Murga, 2007). The methodology of CP option implementation are categorized into seven parts, which are (1): Design modification; (2) Operation modification; (3) Raw material substitution; (4) New technology; (5) Training; (6) Housekeeping; and (7) Reuse & Recycle. The third component is targeted outcome from the implementation of CP option. There are two types of outcomes, which are direct outcome and indirect outcome. In general, direct outcome is the return that can be evaluated immediately, which are returns in economical aspects and reduction in consumption of material and energy, while indirect outcome is the return that can be achieved in environmental aspect, which are reduction in effects of operation and products to the environment and reduction in CO_2 generation. The key components were then expanded in details to create a structured methodology for designing CP Option Generation Tool, which functioned as the basis in generating CP options.

Philosophy I: Focus of Cleaner Production Option

In general, CP options focusing on opportunities in material and energy saving, as well as improving safety aspects in workplace. Energy saving includes reduction and minimization of electrical energy wastage as well as energy for heating and cooling. Material saving includes reduction in raw material usage and other related materials such as packaging, chemicals, fuels, water and detergents. 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 (Fernández-Muñiz et al., 2009). Hence, prevention of incidents that related to the safety is also included as the opportunity in conserving materials and energy.

Philosophy II: Principles of CP Option Generation and Implementation Methodology

In theory, CP options can be generated unlimitedly for a manufacturing premise. However, the basic principles in generation CP options for each entity can be divided into the following basic principles:

(i) Reduction of Operation Time

The reduction of operating time, which involves heating or cooling processes can reduce energy consumption, since the energy consumption is proportionally to the operating time. Furthermore, by reducing time of usage such as electricity consumption, the value of kW.hr will also be reduced.

(ii) Increasing or Reducing Operating Temperature

Heating or cooling processes consumes energy for changing the temperature of input streams or product. Reducing or increasing the temperature setting can reduce energy requirement reduced due to shorter temperature gradient.

(iii) Reducing 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 maximum pressure that can be generated by the compressors. Reduction in pressure can provide savings in air compressor systems operation and reduction in amount of leakages, as well as prolong shelf life of equipment and air compressor.

Subsequently, there are various types of CP options, started from minor changes of certain processes, till the major modification of design or changes in technology. However, the options can be fundamentally characterized according to the implementation methodology. In most of manufacturing industry, the typical methodology of CP implementation is housekeeping, material substitution, design modification, operation modification, application of new technology, training and reuse & recycle (Kjaerheim, 2005). This methodology can further be expanded to identify specific options for selected entity to be evaluated. There are seven methodologies that can be used by the industries to generate CP options as follows:

(i) Housekeeping

The main focus is to prevent material and energy loss, minimizing waste generation and improving operating procedure. Housekeeping aspect is the most favorable method in generating CP options since the options generated are usually requires no or low investment costs with quick returns (Yusup et al., 2015).

(ii) Design Modification

Modification in design can starts from minor up to the major modification. For example, minor modification can be done by installing spillage trap system, which can reduce raw materials spillage from the conveyor to the storage tank. Meanwhile, major modification can be done by replacing new unit operations or increasing production line. Depending on the types of industries, some of the design modification may require technical expertise or detailed research studies before generating suitable CP options.

(iii) Operational Modification

Modification involves changes in process parameters such as time, temperature, pressure, sequence, and other relevant parameters (Duflou et al., 2012). For example, reduction in operating time can reduce energy consumption. Further, operational modification can also be done by combining two processes or activities together or eliminates one of the processes.

(iv) Raw Material Substitution

Raw materials substitution can help to achieve high yields, reduction in processing time, energy consumption and waste generation (Suopajärvi, 2011), together with ability in handling less toxic materials.

(v) New Technology

Adoption of new technology can be considered if productivity can be increased and reduction in material loss, waste generation and energy consumption can be achieved. New technology can be applied into existing system as additional system or as replacement of overall or partial systems.

(vi) Training

Untrained operators can cause high generation of waste, less productivity and increase in risk (Ferenhof et al., 2014). Implementation of proper training for operators in various aspects can be one of the main CP options. Training also required when standard operating procedures are developed or when design or operational modifications are implemented in the premise.

(vii) Reuse & 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 cheaper or requires more investment.

Philosophy III: Targeted Outcome

In general, CP options are generated to solve issues identified in the audited premises. However, CP options can also be generated to improve certain aspects in the premise. Implementation of CP options directly aiming in reducing wastes generation, reducing raw material and energy consumption, reducing loss of material and energy, reducing risks, increasing productivity, and indirectly reducing CO_2 emission generated in the premise. There are four key requirements of generation CP options for a manufacturing premise, which are saving in costs, prevention in pollution, and compliance to regulation as well as reduction in CO_2 emission.

(i) Cost Saving

Implementation of CP options can achieve either direct or indirect returns. Direct cost savings can be achieved through reduction in cost of raw materials, energy and waste treatment (Gale, 2006). Meanwhile, indirect cost savings can be achieved through increase in the productivity.

(ii) Pollution Prevention

CP options approach emphasizes on prevention as compared to traditional end-of-pipe method (Lei et al., 2002), where the waste generated is treated to comply with the standards.

(iii) Compliance in Regulation

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

(iv) Reduction in CO_2 emission

CP options generally reducing the generation of CO_2 emission through controls and reduction of the consumption of entities that contributes to the generation of CO_2 emission.

In further, the key components philosophy of CP Option Generation Tool is expanded to develop detailed steps in generating CP options. Thus, the design of CP Option Generation Tool is developed and consists of components as listed in Table 3.1. In general, CP Option Generation Tool consists of three key components, which are (1):

Mechanism; (2): Steps; and (3): Details. The details on methodology of generating CP options according to structure in Table 3.1 are discussed in Chapter 4: Result and Discussion.

Table 3.1: Key components of Cleaner Production Option Generation Tool

MECHANISM	Ask question	Determine the effects	Fix the target	Generate CP options according to implementation practice	List out the potential CP options
DETAILS	Key question	1. Raw material loss 2. Product loss 3. Electrical energy loss 4. Heat energy loss 5. Waste generation 6. Effect to productivity 7. Effect to safety and health 8. Effect to product quality	Reduction Prevention Improvement	1. Housekeeping 2. Design modification 3. Operational modification 4. Raw material substitution 5. New technology 6. Training 7. Reuse & recycle	CP options generated based on real scenario of the premise

3.5.4 Design of Sub-Methodology III: Cleaner Production Option Evaluation

CP options generated are evaluated to analyze the potential of the application and practicality of the options, for decision-making purposes. Feasibility evaluation aiming to identify opportunity of implementing CP options, advantages and implication of the implementation as well as identifying resources for the implementation. Subsequently, two main criteria are considered for the evaluation of CP options, which are economic and environmental aspects (Coelho & de Brito, 2013). This section describes methodology in designing and developing tool for Sub-methodology III, which is CP Option Evaluation Tool.

3.5.4.1 Design of Cleaner Production Option Evaluation Tool

CP Option Evaluation Tool is developed to provide important criteria for evaluating expected major returns from implementation of CP option. The tool must be completed as soon as the process of generating CP options is completed, in order to proceed with the prioritization of the options generated. Subsequently, the tool is designed to help the users to identify criteria that should be considered during the process of evaluating CP options in order to identify expected returns, thus makes prioritization and selection of the best options. The design of the main components of CP Option Evaluation Tool is developed based on answering Research Question number 3 for Research Objective number 1.

OBJ 1: Develop a new standard methodology in implementing cleaner production strategy for SMIs, proposed as Cleaner Production Implementation Methodology for SMIs.

RQ 3: What are the components that evaluated in term of returns?

Overall, the development of CP Option Evaluation Tool is in accordance with the steps illustrated in Figure 3.4.

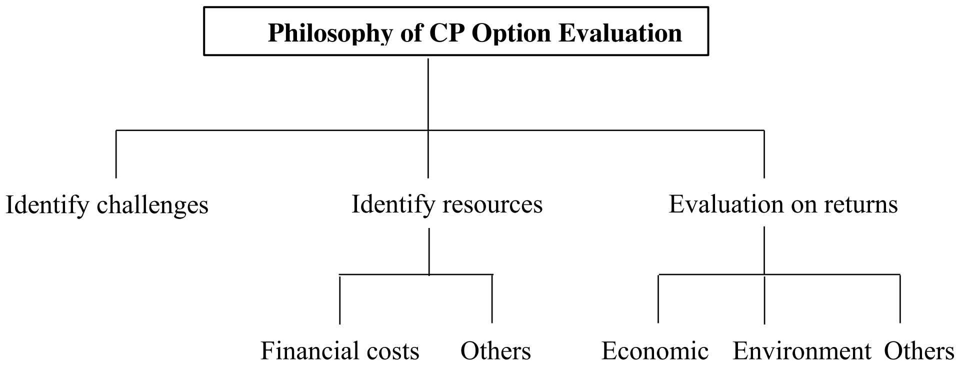

Figure 3.4: Methodology of developing Cleaner Production Option Evaluation Tool

CP Option Evaluation Tool is developed based on three main components, which are identifying challenges, identifying resources and evaluating returns. The first component is identifying challenges that may occur while implementing CP options. The main challenges may occur in terms of financial, human resources or negative effect to the product. Further, the second component is identifying resources required to implement CP options. Resources may also exist in terms of financial and human resources. Finally, the third component is the evaluation of expected returns from the implementation of CP options. Returns are evaluated in terms of economic and environmental aspects as well as other related aspects. Subsequently, these components are expanded in details to design the CP Option Evaluation Tool, which will be used as the basis in prioritizing CP options that will be implemented.

(j) ***Philosophy I: Identifying Challenges in Implementing Options***

Challenges in implementing CP options may occur in term of human resource, such as the absence of competent personnel to facilitate and monitor the implementation of CP options or the absence of positive supports and commitments from the top management (Lopes Silva et al., 2013). Further, CP options generated may also have risks to be implemented, as the production operation could not be stopped and may disturbs the production rate, or may give negative effects to the product quality.

(k) ***Philosophy II: Identifying Resources Required***

Implementation of CP options typically requires two main resources, which are financial and human resources. Financial costs is the main resources to be considered and evaluated by the manufacturing premises, such as purchases of new equipment, construction works, installation and electrical wiring, salary of workers, and loss of income during plant shut down. Sometimes, there are also additional cost incurred from the changes in process design, such as treatment cost, additional utilities, additional workers, and also cost of maintenance. In addition, options implementation may also involve implementation of new strategies such as changes in production operation, operational parameters, unit operation design and standard operating procedures. Hence, expert workers are needed to monitor overall process of CP options implementation in the company.

(l) ***Philosophy III: Evaluating Returns***

Generally, evaluation of returns is done in the economic, environment and other related aspects.

(i) Economic Evaluation

Economic evaluation is done to determine positive economic returns that expected to be obtained from the implementation of respective CP option. It includes identifying and quantifying all expected returns. The evaluation typically involves cost-benefit analysis. Evaluation on payback period is done to identify durations of obtaining the capital invested, where the shortest duration shows that the CP option is more feasible to be implemented.

(ii) Environmental Evaluation

Environmental evaluation focuses on the CP options that able to reduce the generation of CO_2 emission, based on monitoring the entities that contributed to the

CO_2 generation (Lin & Lei, 2015). Reduction in CO_2 can be estimated by comparing the amount of CO_2 generated before and after the option implemented. As for a premise that aiming in producing greener products, the highest reduction in quantity of CO_2 emission will be the priority of selecting CP options to be implemented.

(iii) Others

Other than returns that can be quantitatively evaluated, there are also other criteria that can be evaluated, such as improvement in product quality, improvement in company image, safer production operation and also improvement in working area that could enhance workers motivation and productivity.

A detailed description on the CP Option Evaluation Tool and applications will be described in Chapter 4: Result and Discussion.

3.6 Validation on the Practicality of Cleaner Production Implementation Methodology

The second objective of this work is to study the practicality of CPIM that have been developed. The feasibility study of CPIM is the final steps in this work, by answering to Research Question number 1 for Research Objective number 2 and is done through demonstration of case studies. The criteria used for selecting the premises is a very important element for this work, as the criteria will determine whether the CPIM is practical and can be applied to various types of SMIs manufacturing premises. Each case study will be characterized and modeled for references to researchers, who are developing similar methodology according to CPIM framework. In this work, five main criteria are used for selecting the premises, which are (1): Typical manufacturing industry; (2): Location; (3): Number of worker; (4): Good inventory and record keeping; and (5): Consistency in production rates. Table 3.2 shows the checklist of criteria that was used for selecting suitable case studied premises.

(i) Typical Manufacturing Industries

The manufacturing premises selected were beverage, plastic and printing premises. The premises were selected as for the most of the operational processes and activities, unit operations, and other facilities in the premises were typical and may also exists in other manufacturing premises. Typical operational processes and activities were also easier to be understood, thus the application of CPIM in the studied premises could be easier.

(ii) Location

Priorities were given to premises located in Klang Valley and Selangor, to facilitate visits, discussions, data gathering and other relevant activities.

(iii) Number of Worker

Premises with minimum number of 15 full-time workers were selected to ensure sufficient number of team members for CP implementation activities.

(iv) Good Inventory and Record Keeping

The application of CPIM could be easier as the premises have a systematic inventory and records keeping, such as utility bills, records on purchases and records on standard operating procedures. This is important to facilitate mass and energy balances and other relevant calculations.

(v) Consistency in Production Rates

The premises have a consistency in types of products as well as production rates, where daily production operations were done without depending on customers' demand. Thus, calculation on production rates can be done based on monthly or annual unit. Further, the consistency in production rates can also enables estimation of material and energy balances be done according to inventory records without any difficulties.

Table 3.2: Criteria of premise selection checklist

Name of company :			
Address :			
Name of representative :			
Criteria	Tick (✓)		Comments
	Yes	No	
Location			
Premise located in Klang Valley and Selangor			
Number of worker			
Premise has minimum number of 15 full-time workers			
Inventory and record keeping			
Premise has minimum of 1 year records on the following:			
Electricity bill			
Water bill			
Raw materials purchasing			
Waste generation			
Production			
Standard operating procedure			
Consistency in production rates			
Premise operates based on continuous production			

Each Sub-methodology of CPIM, which is CP Audit Tool, CP Option Generation Tool and CP Option Evaluation Tool will be evaluated in terms of its application and recorded. Detailed descriptions will be described in Chapter 4: Result and Discussion.

CHAPTER 4: APPLICATION AND FEASIBILITY OF CLEANER PRODUCTION IMPLEMENTATION METHODOLOGY

4.1 Introduction

The term "Standard Methodology" has been developed and being used since decades as one of the art term among professional evaluators (Vergé et al., 2013). It refers to the real working documents that can be used to evaluate current situation and status of performance for a premise. Thus, Cleaner Production Implementation Methodology consists of elements 'what' and 'how' to implement CP strategies. In overall, the detailed description of CPIM described in this section is illustrated in Figure 4.1.

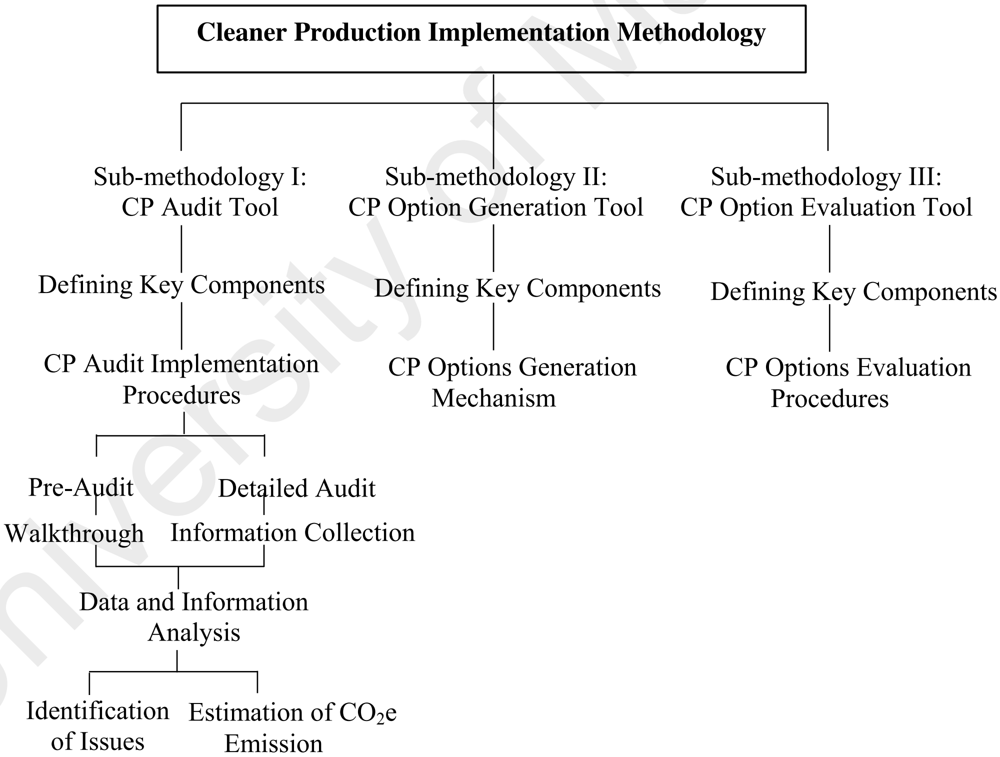

Figure 4.1: Cleaner Production Implementation Methodology Contents

4.2 Cleaner Production Implementation Standard Tools

Each Sub-methodology of CPIM has its own standard tool, which are (1); Cleaner Production Audit Tool; (2): Cleaner Production Option Generation Tool; and (3): Cleaner Production Option Evaluation Tool. The tools functioned to determine types of important components that need to be evaluated during the CP strategy implementation cycle. Indirectly, CPI tools can also provide guidance and direction that will assist in conducting assessment and evaluation activities. Generally, CP Audit Tool consists of instructions to identify and measures the quantity of key components that need to be evaluated during the CP audit. CP Option Generation Tool consists of instructions on the procedures to be followed to generate CP options, while CP Option Evaluation Tool consists of instructions on evaluating the feasibility of generated CP options, which focuses on the economic and environmental aspects. The contents and detailed description of each tool are discussed in the following sections.

4.3 Sub-Methodology I: Cleaner Production Audit Tool

Cleaner Production Audit Tool serves as a tool that assist CP Auditor to conduct CP auditing and subsequently analyzing data and information obtained. The tool describes relevant steps and systematic approach in detail, which aims to ensure that the auditing activities are conducted intensively and can assist in the process of analyzing data and information. CP Auditor needs to have a clear understanding of what they should be doing and how to complete the related activities.

4.3.1 Key components

CP Auditor should have basic understanding on important aspects of auditing before conducting CP audit in a manufacturing premise. It is to ensure that the overall auditing process can be conducted completely and systematically. The basic aspects of CP auditing are as follows:

(i) Comprehensive meaning of CP auditing in a manufacturing premise;

(ii) Justification on why CP audit need to be conducted;

(iii) Determination of objective and scope of audit;

(iv) Determination of resources required in conducting the audit; and

(v) Determination of key components that need to be assessed and evaluated.

4.3.1.1 Determination of the meaning of Cleaner Production Audit

Audit means examining or evaluating record or document with the aim to determine the validity of the information provided by the company (Nagy & Cenker, 2002). However, the definition of typical audit is different from the definition of CP audit. CP audit is defined as the process of collecting and analyzing information for a manufacturing premise with the aim to obtain sufficient knowledge on the current status of a premise's performance, whether in terms of operating efficiency or environmental management. The objectives of CP audit are also different from typical financial audit because audit is the process of searching for information, rather than the process of determining the validity of the information. In this study, CP audit was carried out with the main objective to identify the main entities that generate CO_2 emission in an SME manufacturing premise in order to generate improvement opportunities. In addition, the audit focuses on the safety and health aspects in a workplace, where evaluation on the operation and handling of the equipment is performed. For example, the raw materials characteristics and chemicals used, material handling and various types of personal protective equipment used are identified. Furthermore, CP audit also focuses on the aspects of quality management, where the generation of off-specification products is analyzed to identify the causes and opportunities to reduce wastes.

4.3.1.2 Justification on Cleaner Production Audit Requirement

CP audit is an initial step for managing, controlling and improving environmental performance of a premise. If a premise has never been concerned with the impact of its products on the environment, CP audit is the most suitable step to determine the status of the premise and the best approach for reducing generation of waste and emission. CP audit is conducted in a manufacturing premise as a process of investigating and gathering information to meet the following requirements:

(i) Obtain a clear understanding of the processes and operating activities in a manufacturing premise.
(ii) Quantify raw materials, products, waste and other resources that are consumed and generated.
(iii) Obtain a clear understanding of all the issues that exist in a manufacturing premise.

4.3.1.3 Determination of Objective and Scope of Cleaner Production Audit

Determination of objectives and scopes of audit is an important step in starting an audit process. CP Auditor needs to ensure that objectives and scopes of audit are defined clearly and specifically to ensure the audit process can be conducted with existing resources and within specified time schedule. Clear audit objectives provide a structure that can help CP Auditor to stay focused on the expected audit findings to avoid confusion. Furthermore, clear objectives also can ensure that the audit process can be conducted efficiently with the expected results. The objectives of the audit should clearly define the aims to be achieved from the audit process. Objectives of an audit can be general or specific. Examples of general audit objective include "conducting CP audit in premise A to identify the sources of wastewater generation" or "conducting CP audit in premise A to identify environmental issues that exist in the premise." Examples of specific audit objective include "conducting CP audit in premise A to identify opportunities on CP options that can reduce overall electricity consumption by 20%", or "conducting CP audit in premise A to quantify water consumption rate per ton of product produced".

Subsequently, the scope of CP audit defines the boundary to be focused during the audit process. Audit must not necessarily be conducted for the whole premise, but in a certain part or area, or the processes and activities of certain operations. Audit scope that is clearly defined can determine the depth of the audit. The scope of audit also specifies the range of data or records to be audited. For example, CP Auditor should determine the duration of electricity consumption that is to be reviewed, for example six months or a year, to determine the rate of electricity consumption as compared to the rate of production. Furthermore, a clearly defined scope also allows CP Auditor to avoid collecting unnecessary information, which may consume resources and time. The scope of an audit can be as simple as "to determine the total amount of water consumption for premise A" or "to determine the total amount of water consumption for floor cleaning and equipment for premise A".

4.3.1.4 Determination of Resources for Cleaner Production Audit

Objectives and scope of audit that are clearly defined can also help develop detailed plans for audit activities. It gives a clear idea to the CP Auditor on the resources required to conduct CP audit. Typically, the main resources required for CP audit are as follows:

(i) Cleaner Production Audit Implementation Schedule

The length of time required for the audit process depending on the depth of the audit and can be determined once the objectives and scopes of the audit are defined. An implementation schedule contains a detailed list of activities to be carried out during the audit process and a list of milestone to be achieved. However, a fully developed time schedule is not necessary, depending solely on the objectives and scopes of the audit. The schedule for the audit can still be modified according to the requirement from time to time. Table 4.1 shows example of audit implementation schedule.

Table 4.1: Example of Cleaner Production audit implementation schedule

Name of Audit	:	Cleaner Production Audit				
Company's name	:	Jadern Plastic Industries (M) Sdn. Bhd.				
Address	:	PLO 153, Balakong Jaya Industrial Park, 43300 Balakong, Selangor				
Team members						
Name of Auditor 1	:	Mr. Hani Hashim (HH)				
Name of Auditor 2	:	Mr. Rohaizad Sadie (RS)				
Name of Auditor 3	:	Mr. Eddy Sham (ES)				
Implementation Schedule						
No.	Activity		Week			
			1	2	3	4
1.	Formation of CP audit team at the premise		→			
2.	Walkthrough visit		→			
3.	Inventories and records reviews		→	→	→	
4.	Installation of measuring equipment		→	→	→	
5.	Mass and energy balance		→	→	→	
6.	Data analysis		→	→	→	
7.	Quantification of CO_2e emission				→	→
8.	Determination of key issues				→	→
9.	Progress meeting and presentation to the premise				→	→
10.	Report preparation					→

(ii) Cleaner Production Audit Team Members

In general, the audit process can be conducted individually or in teams. The number of team members depending on the depth of CP audit and the size of the premise to be audited. The number of team members who will conduct the audit is flexible as long as each member is aware of their role in the auditing process. However, there are cases in which measurement instruments are needed. In such cases, more audit team members are required. Table 4.2 shows example of audit team members with specific task.

Table 4.2: Example of specific task for Cleaner Production audit team members

Name of Audit	:	Cleaner Production Audit
Company's name	:	Jadern Plastic Industries (M) Sdn. Bhd.
Address	:	PLO 153, Balakong Jaya Industrial Park, 43300 Balakong, Selangor
Team members		
Name of Auditor 1	:	Mr. Hani Hashim (HH)
Name of Auditor 2	:	Mr. Rohaizad Sadie (RS)
Name of Auditor 3	:	Mr. Eddy Sham (ES)
Specific task for CP Auditor		

No.	Activity	Week				CP Auditor in charge
		1	2	3	4	
1.	Walkthrough visit	→				HH, RS, ES
2.	Inventories and records reviews	→				HH, RS, ES
3.	Process audit	→	→	→		HH
4.	Water audit	→	→	→		RS
5.	Energy audit	→	→	→		ES
6.	Waste audit	→	→	→		HH, RS
7.	Safety and health audit			→	→	ES
8.	Housekeeping, productivity			→	→	ES
9.	Progress meeting and presentation			→	→	HH, RS, ES
10.	Report preparation				→	HH, RS, ES

(iii) Information on Premise Background

CP Auditor should obtain the main background information of the premise, such as address and location of the premise, name of the representative, type of industry and product, operating time, safety measures and rules to be followed during the site visit. Background information should be provided and reviewed in advance to get an initial overview of the premise to be visited. Furthermore, information on type of product and industry also allows CP Auditor to obtain information on common issues related to the same industry, where the information can be used to determine the targeted area.

4.3.1.5 Determination of Main Components to be Evaluated and Analyzed

The proposed CP audit focuses on identifying entities that contribute to the generation of CO_2 emission, measuring the quantity and thus prioritizing targeted entities that generate the most emission. Hence, the main components that will be assessed and analyzed during the audit process are as follows:

(i) Consumption of main raw materials, additives, water

For example, consumption of materials in a plant that produces fruit juice includes liquid sugars, fruit puree, food additives, flavors, colors and filtered water.

(ii) Energy consumption (electricity and fuel)

For example, consumption of energy in a plant that produces fruit juice includes electricity for operation units and other facilities such as cold room and lightings. Whereas, liquefied petroleum gas are used as fuel for forklifts.

(iii) Solids, liquids, gases and wastewater generation

For example, waste generation in a plant that produces fruit juice mainly includes wastewater generated from activities such as cleaning of floor, and CIP process.

(iv) Loss of thermal energy

For example, loss of thermal energy in a plant that produces fruit juice includes energy loss during frequent opening of cold room that stores fruit puree.

(v) Waste materials

For example, waste material generation in a plant that produces fruit juice includes damaged packaging bottles and caps, spillage of fruit puree and additives, and used raw materials packaging containers.

Furthermore, CP audit also evaluate components that indirectly contribute to the generation of CO_2 emissions, namely:

(i) Safety risks in workplace

For example, safety issues in a plant that produces fruit juice mainly includes wet and slippery floor due to spillages of materials.

(ii) Housekeeping

For example, housekeeping issues in a plant that produces fruit juice mainly includes limited working space, high stacking of packaging bottles, long duration of raw material storing and not implementing First In First Out (FIFO).

4.3.2 Cleaner Production Audit Procedures

This section describes detailed step-by-step of conducting CP audit. In order to have easier understanding of the steps included in the CP audit process, the steps are simplified and illustrated as in Figure 4.3.

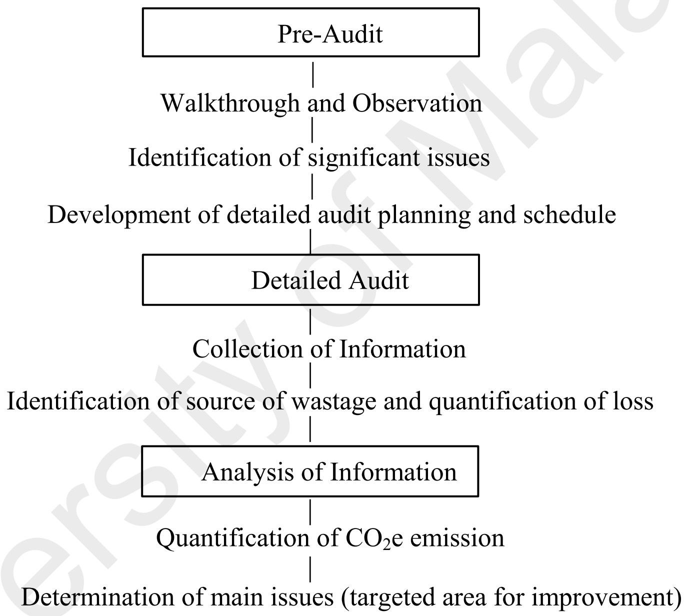

Figure 4.2: Detailed steps of Cleaner Production auditing

4.3.2.1 Pre-Cleaner Production Audit

Pre-audit is conducted with objective to get the initial overview or information on a manufacturing premise that will be evaluated. Specifically, the main objective of pre-audit is to observe the main manufacturing process and activities, as well as support activities, to determine the size of the premise and to observe the management and operation structure, as well as to identify significant issues that exist in the premise. The main information to be collected during the pre-audit process is company profile, detailed manufacturing process and activities and information on environmental aspects. The information obtained can be used as a guidance to determine the focus and depth of audit activities to be conducted. The information will also be used as a basis for detailed planning of audit activities.

a) Company Profile and Process Flow Chart

In general, the output of the pre audit activities should be able to answer the following questions:

(i) What are the products produced at the premise?

For example, a product of a plant that processes raw fish includes fish fillet, canned fish and fish oil.

(ii) Where the products are marketed?

For example, product’s market of a plant that processes raw fish includes fish crackers industry.

(iii) What are the main manufacturing processes and activities?

For example, main manufacturing processes and activities in a plant that processes raw fish includes fish deboning, washing, mixing of fish flesh with additives, and steaming.

(iv) What is the history of the company's environmental compliance?

For example, environmental compliance issues include untreated wastewater and odor.

(v) What are the main input and output streams?

For example, main input stream includes raw fish and additives. Whereas main output stream includes product (fish fillet), and by-products.

In order to answer the above questions, CP Auditor use review the existing record, which can be obtained from the premise profile, records on production and process flow chart. Table 4.3 shows example of checklist that can be used to obtain background information of the premise.

Table 4.3: Company background information checklist

Types of information	Tick (✓)			Personnel in charge
	Available	Not available	Not complete	
Process				
Process flow chart	✓			
Data on mass balance		✓		
Data on energy balance		✓		Production/ Maintenance/ Quality Control
Plant layout	✓			
Standard Operating Procedure	✓			
Equipment layout		✓		
List of equipment and specification			✓	
Product, raw material, operation				
Records on production	✓			
Records on by product	✓			Production
Records on raw material	✓			
Production operational schedule	✓			
Material safety data sheet	✓			
Financial				
Records on utilities	✓			
Operational and maintenance cost			✓	Human Resource
Raw material cost	✓			
Management and waste treatment cost		✓		
Compliance				
License on waste management		✓		Safety/ Environment
Records on environmental monitoring		✓		
Environmental audit reports		✓		

CP Auditor should develop the best plan to get the information that is not available in the record. The best method that can be used to collect information on the production process is by referring to the process flow chart, which contains the input and output streams including environmental components (products and waste) for each step of the process. A process flow chart can be used as the basis of material and energy balance during the evaluation process. An example of a simple process flow chart for an SME manufacturing premise is illustrated in Figure 4.3.

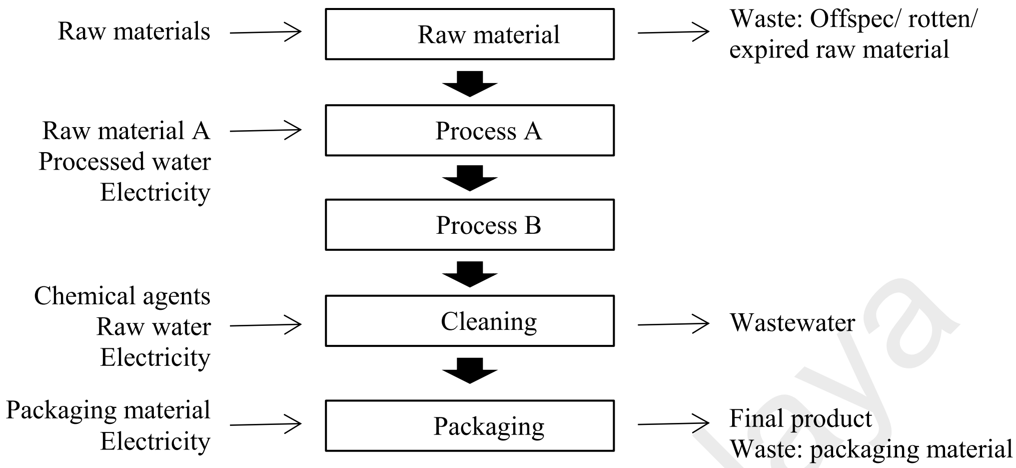

Figure 4.3: Typical process flow chart of a manufacturing premise

In addition, it should be noted that information collection based on process flowchart does not only refer to the main production process, but also activities that support the production process as follows:

(i) Cleaning

For example, cleaning of floor and operation units, such as blending tank.

(ii) Supporting operation

For example, cooling system, steam and compressed air.

(iii)Receiving and storage of main raw materials and additives

Activities of receiving raw material and additives can be done daily or monthly. Thus effects the duration of material storage requirement.

(iv) Waste storage, waste management and treatment systems

Waste storage is done according to waste characteristics and systematically labeled, whereas treatment system includes wastewater treatment facilities.

(v) Operation units and equipment maintenance

Maintenance can be done according to schedule or requirements.

(vi) Administration

Activities in administrative office include the use of facilities such as computers, printers, and utilities.

b) Walkthrough Observation

Pre-audit process can be conducted through walkthrough evaluation. This method can usually be completed within one day, depending on the size of the evaluated premise. The information in Table 4.3 can be gathered during walkthrough observation. This process leads the CP Auditor through each production process starting from the first process to the final process, including other activities that support the operation of the production, focusing on areas where the products, waste and emissions are generated. Walkthrough observation aims at identifying significant issues that exist in the premise, before any measurement is done. It is advisable that this process is conducted physically through site visits, where observations made during these visits can provide more tangible inputs, such as waste spillage on the floor and leaking of water pipes. In addition, site visit also allows CP Auditor to communicate with operators to get quick information. Specifically, walkthrough evaluation can be conducted with four easy steps as follows:

(1) Start the walkthrough evaluation by referring to a process flow chart to understand the production processes.

(2) Observe each step of the production process and activities related to all aspects of waste generation, resource utilization and efficiency.

(3) Identify issues from observation and opportunities for improvement.

(4) Determine main issue for generation of specific CP options.

The main objective of a walkthrough evaluation process is to identify significant issues that exist in the respective manufacturing premise for further evaluation in order to determine the main issue. Furthermore, opportunities for improvement, which could give a significant positive impact on the premise performance, can be identified. Each step of the production process needs to be fully evaluated and recorded as the information obtained can be used to develop plans for detailed evaluation process. Detailed information can provide a more systematic approach in achieving the targets for improvement. It should also be noted that if there are improvement opportunities that require no cost or low cost, the opportunities should be implemented immediately. The following questions can be used during interview with the premise representative in order to identify significant issues that exist in the premise and opportunities for improvement. The questions are categorized according to issues related to processes, waste generation, training for workers, and housekeeping.

(1) Issues on Process

(i) Is there any leakage? Is there any proof that can be observed such as effects of corrosion on floor, wall or pipeline?

(ii) Is there any spillage on the floor? Will it be reused or discarded?

(iii) Does the equipment operate at optimum capacity? Is there any proof that waste generation is caused by inefficient operation of equipment? For example, inefficient grinding process in chili paste manufacturing plant causes loss of raw materials.

(iv) Is there any wastage of energy? For example, non-insulated steam pipelines.

(v) Is there any odor issue? For example, odor issue from chicken slaughtering process.

(vi) Is there any noise issue? For example, noise issue from paper milling process.

(vii) How the plant layout affects the efficiency of the operation?

(viii) Is there any equipment that can improve the efficiency of existing equipment? For example, installation of inverter in existing motors.

(2) Issues on Waste Generation

(i) Is the waste generated is segregated according to types?

(ii) Are there opportunities for reuse or recycling of waste?

(iii) Is the waste treated onsite? Can the treated waste be recycled?

(iv) How is the waste disposal done?

(3) Issues on Training for Workers

(i) Do the existing standard operating procedures cause waste generation? Are there any opportunities to modify existing procedures?

(ii) Are the operating procedures completely followed? Are there any procedures that are difficult to follow?

(iii) Do workers have any suggestions for improving the existing procedures to increase the operation efficiency?

(iv) Do workers have any suggestions on how the waste generation can be reduced?

(4) Issues on Housekeeping

(i) Is there any sign of inefficient housekeeping practice? For example, not practicing Just In Time for raw material receiving activities.

(ii) Is the process water discharged without any monitoring? Are there any methods that can be used for the cleaning process? For example, the use of dry air.

(iii) Is there any storage tanks that are left opened, or stacked without proper arrangement, which could be evidence of an inefficient storage practices?

(iv) Are storage bins being labeled according to the contents?

(v) Is emergency equipment placed at a proper location?

(vi) Does the plant layout causing difficulties in cleaning and maintenance activities?

c) Determination of Focus

The final step during the pre-audit is to determine the focus for the preparation of detailed evaluation. For an ideal evaluation process, all production process and unit operation need to be completely evaluated. However, if there is a limitation in time and resources, selection of the most important processing areas need to be done. Typically, the assessment can be conducted by focusing on the following areas:

(i) Area or process that consumed the highest amount of raw materials and chemicals;
(ii) Area or process that generate the highest amount of waste and emissions;
(iii) Area or process that has the highest risk to workers;
(iv) Area or process that causes the highest loss financially; and
(v) Area or process that has highest potential for significant improvements.

All information obtained during the pre-audit process should be systematically managed updated for a detailed evaluation process.

4.3.2.2 Detailed Cleaner Production Audit

Data collected during CP audit can be used to measure the efficiency of the overall operations and determine targets to be monitored. Furthermore, the data can be used to evaluate the performance of a specific process, in which the causes of issues that exist in the premise can be identified, thus improvement opportunities can be generated. Audit activities involve data gathering to quantify resource consumption and generation of waste and emission. Typically, the auditing process is conducted through review of records, estimation and measurement. CP Auditor should be able to calculate the total loss of resources through collected data and measurement. For example, high water consumption indicates that there is a possibility of leakage in any pipelines in the premise. Other than that, the use of CP audit tool, which consists of information on input and output streams is very useful to determine the information that needs to be collected. Most of the necessary data might have already existed in the premise records, such as records on material purchase, production data and waste generated. However, if the data is not available, estimation needs to be done. Input-output balancing method is a measurement method that can be used for this purpose. The typical balancing method used is material and energy balance.

a) Quantification through Mass and Energy Balances

The main objective of conducting material balance is to quantify the total amount of raw materials consumed in producing a product and to determine material loss during the production process. The material balance is based on the principle of "quantity of input should be equal to quantity of output and consumed." Ideally, the input stream should be equal to the total output flow. However, the ideal situation is difficult to achieve due to various factors that cause materials loss that is not measurable such as loss through vaporization in food manufacturing premises. (Equation (4.1)) shows the formula of material balance.

$$\Sigma \text{ material}_{in} = \Sigma \text{ material}_{out} (\text{product + waste + emissions + accumulation}) \qquad (4.1)$$

For example:

In a concentration process of orange juice as in Figure 4.4, a fresh extracted juice containing 8.08% (w/w) solids is fed to a vacuum evaporator. In the evaporator, water is removed and the solids content increased to 60% (w/w) solids. If 1,000 kg/h of orange juice entering, the material balance is as follows:

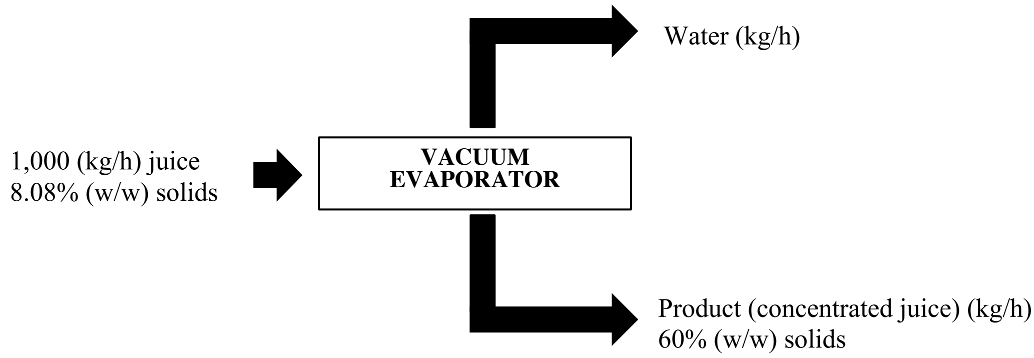

Figure 4.4: Mass balances of orange juice concentration process

Total material balance:

$$1{,}000\ \left(\frac{kg}{h}\right) = Water\left(\frac{kg}{h}\right) + Product(\frac{kg}{h})$$

Solid balance:

$$1{,}000\frac{kg}{h}\left(\frac{8.08}{100}\right) = Water\frac{kg}{h}(0) + Product\frac{kg}{h}(\frac{60}{100})$$

Thus,

$$Product = 136.7\frac{kg}{h}\ , Water = 863.3\frac{kg}{h}$$

Material balance allows CP Auditor to identify and calculate material loss and waste generation. It also provides an indication on the causes of material loss and waste generation. It is easy to conduct material balance for individual unit operation and provide accurate results. In addition, the material balance for individual unit operation or process can help in conducting overall material balance. Besides material balance, energy balance is also conducted to calculate the amount of energy consumed to produce the product and quantify energy loss from the production process as well as energy efficiency of the process. Energy balance can also be done for the entire process or for individual unit operation.

(Equation (4.2)) shows the formula of energy balance.

$$\Sigma\ energy_{in} = \Sigma\ (energy\ out + energy\ used\ or\ obtained\ during\ a\ process + energy\ loss) \quad (4.2)$$

For example,

If a non-insulated cooking tank has an area of 3 m^2, with surface temperature of 50°C, the heat loss to the surrounding can be quantified as follows:

$Q = hA\ (Ts - Ta)$

$= hA\ (Ts - Ta)$

$= \left(0.005 \frac{kW}{m^2 K}\right)(3\ m^2\ )(323 - 301)K$

$= 0.38\ kW$

Subsequently, the following steps can be used for conducting material or energy balance:

(1) Referring to the existing process flow chart given by the premise, develop process flow chart that consists of all input and output streams.

(2) Narrow down the entire process into individual unit operation and include all input and output streams.

Material and energy balances can also be improved by incorporating the cost components for each of the input and output streams. Findings that include cost components may help in the process of selecting suitable CP options to be implemented by the premise. The following methods can be used to determine the cost for each of the waste generated from operation or production process.

(1) Cost Estimation of Total Waste Stream

The quantification consists of costs of material purchase, production, cleaning and maintenance, monitoring, treatment and waste disposal. Material balance should provide detailed data for each of the material streams, which includes quantity of materials, quantity of materials converted into products and quantity of waste materials.

The ratio of input to output enables CP Auditor to quantify the cost breakdown of waste materials. Table 4.4 shows example of cost estimation of total waste materials.

Table 4.4: Example of cost estimation of total waste materials

Input materials/ month	Waste materials/ month	Cost of materials/ month	Cost of waste materials/ month
1,000 tons	10 tons	$ 100,000	$ 1,000

(2) Cost Estimation of Individual Waste Stream

Cost estimation of individual waste stream can be conducted by dividing the total cost of waste generation by the quantity of waste generated within a specific duration. For example, referring to Table 4.4, cost of individual waste material is $100/ton of waste generated.

(3) Cost Estimation of Waste in Unit Operation

Detailed material balance provides data on quantity of material loss in unit operations. The cost of individual waste can be used to quantify the total cost of waste in each unit operation. The information can be used to determine the process or unit operation that consumes the highest cost for treating the generated waste.

4.3.2.3 Cleaner Production Audit Tool

CP Audit Tool is developed to help CP Auditor to conduct auditing in a manufacturing premise with minimum time and resources. In general, CP Audit Tool consists of 17 components that have been comprehensively expanded from the key entities that contribute to the generation of CO_2 emission. The tool, which is presented as a form, needs to be completed during the auditing process. The components are listed as follows:

(1) Basic information of audit;

(2) Information on main product;

(3) Information on by products;

(4) Information on raw material consumption;

(5) Information on utilities consumption;

(6) Information on process flowchart;

(7) Information on unit operation and production activities;

(8) Information on support activities;

(9) Information on facilities;

(10) Information on quantification of wastewater, non scheduled waste and scheduled waste;

(11) Information on gaseous emission;

(12) Information on material loss;

(13) Information on heat energy loss;

(14) Information on risk and safety aspects;

(15) Information on complaint received;

(16) Information on housekeeping issue; and

(17) Other observation.

Component 1 is divided into two subsections. Subsection 1(a) is the general information of CP audit activities that will be conducted, which consists of objectives and scope of the audit, information of CP Auditor team members and information of the premise representatives. Whereas subsection 1(b) is the general information of the premise to be audited, where the information can be obtained during pre-CP audit activities.

Component 2 and 3 consists of information on types of main products and by-products produced by the audited premise. Rate of production can be calculated in monthly or annual basis, depending whether the productions are continuously or according to the customers' demand. Product information is the main component, where it functions as the functional unit for data analysis and is used to identify key issues faced by the premise. By-products are also considered as the production, which consumed material and energy. Moreover, if the by-product does not have any commercial values, it can contribute to the generation of waste. In addition, types of product packaging are also considered due to types of packaging materials or size of packaging, which can also contribute to the generation of waste.

Component 4 consists of the list of raw materials used in the manufacturing processes, which are converted into the product. The unit of raw materials can be in monthly or annual basis, according to the rate of production. Furthermore, additives such as food chemicals are also considered in contributing to the generation of waste.

Component 5 consists of information on type of utilities used in the manufacturing processes, mainly water, electricity and fuel. The unit used is according to the unit of rate of production. Utility used can be quantified in batch or individually. Unit operation and activities that required utilities are also identified and evaluated. Subsequently, detailed of water consumption can be measured by installing water flow meter in every individual water source. As for individual electricity consumption, it can be quantified by identifying capacity of equipment or unit operation with respective operating hour. Fuel consumption can be divided into two parts, which are consumption for transportation and consumption for manufacturing processes. Mass and energy balance methods can be used by comparing values obtained individually or in batch.

Component 6, 7, 8 and 9 consist of detailed information on manufacturing processes and activities in the audited premise, together with the description of each process or activity. Further, facilities in the premise are also considered to consume resources such as water and electricity.

Component 10, 11 and 12 consist of the information on type of waste generated in the premise, mainly solid waste and wastewater. The quantity of waste and source of waste generation are also recorded. Furthermore, wastewater contents need to be analyzed, mainly COD and BOD. By referring to the amount of COD and BOD obtained, total raw material loss discharged with wastewater can be quantified, thus source and cause of material loss can be identified to complete the information required in Component 12. Subsequently, raw material loss can also occur through inefficient handling, where spillages of materials could not be recovered. Waste can be quantified either in batch or in individual for each process. Information on gas emission also needs to be recorded. The information can be obtained from gas emission monitoring and control reports prepared by the premise.

Component 13 consists of information on energy loss, which is energy loss through hot material or cold material and hot surface. According to information on source of energy loss, flow rate and material temperature, total loss can be estimated by using formulas given in this tool.

Component 14 consists of information on safety and risk issues that exists in the premise. Information is related with type of risks, sources and effects to the workers. Further, risk identified need to be evaluated in terms of level of severity to identify targeted control measures.

Component 15 consists of information on complaints received by the premise, if any. Complaints can be exists in terms of noise, odor or emissions. Subsequently, information on complaints can helps CP Auditor to identify significant issues that exists in the premise. Further, implementation of CP strategies is also aimed to help premise to comply in environmental regulations.

Component 16 consists of information on housekeeping and plant layout issues that can be obtained through observations. Housekeeping issues need to be considered as inefficient housekeeping can contribute to the generation of waste and safety risks in the plants. Housekeeping issues can exists in terms of inefficient in labeling, handling or improper storage areas.

Component 17 consists of list of additional observations that do not contribute significantly to the main issues in the premise. Table 4.5 shows the CP Audit Tool in detail.

4.3.2.4 Analytical and Assessment Tools for Cleaner Production Audit

a) Quantification of material consumption

Quantity of raw materials consumed can be measured according to the product recipe or purchasing inventories (Bertrand & Rutten, 1999). Furthermore, the difference in quantity of raw material consumed and product produced are considered as raw material loss.

b) Quantification of energy consumption

The measurement of electrical consumption of unit operations can be done by using clamp on instrument such as power meter (Krarti, 2001) or multiplying power rating (kW) with the operating hour (h).

c) Quantification of water, wastewater and solid waste

Typically, it was very difficult to measure wastewater flow rate in SMI premises due to poor drainage system. Thus, the following methods was used to determine water and wastewater flow rate:

i) Use container and stopwatch to measure wastewater, such as from cleaning activities (Anh et al., 1996).

ii) Installation of individual water flow meter to measure wastewater from each section in manufacturing processes (Franklin et al., 1998).

Furthermore, quantity of solid waste generated can be measured by sorting according to types and weighing (kg) (Dowie, Mccartney, & Tamm, 1998).

d) Quantification of energy loss

Heat loss can occur through hot surface such as from non-insulated cooking tank and through release of hot material such as purged steam and condensate, while energy loss from cold material can occur through purged cooling water and cold air. The measurement of energy loss can be done by measuring the area of hot surfaces (m^2), temperature of hot surface, hot materials or cold materials, together with the surrounding temperature (°C). Hence, total loss can be determined by applying formula of energy loss as given in Component 13.

e) Physical aspects in working environment

(i) Noise

Digital sound level meter can be used to determine level of sound pressure (Foster et al., 2000. Sampling points for noise measurement can be done at various points such as grinding and cutting machine, steam boiler, etc.

(ii) Particulate Matter

Total dust concentration can be measured by using digital dust sampler and dust sampling filter (Viana et al., 2008).

Table 4.5: Cleaner Production Audit Tool

1a: GENERAL INFORMATION OF AUDIT			
NO.	**INFORMATION**		**DETAILS**
1.	Audit Objectives	:	
2.	Audit Scopes	:	
3.	Auditor's Name	:	
4.	Company's Representative	:	

1b: BASIC INFORMATION OF COMPANY			
NO.	**INFORMATION**		**DETAILS**
1.	Company Name	:	
2.	Company Address	:	
3.	Company Homepage	:	
4.	Category of Industry	:	
5.	Number of Employee	:	
6.	Operating Hours	:	
7.	Year of Operation	:	
8.	Other Branch Information	:	
9.	DOE Enforcement History	:	
10.	Recent Development	:	
11.	Factory/Company Ownership	:	
12.	Product Market	:	
13.	Certification (ISO/HACCP/etc.)	:	

Table 4.5: Continued

2: MAIN PRODUCT			
NO.	**PRODUCT**	**PRODUCTION RATE**	**PACKAGING TYPE**
1.			
2.			
3.			
3: BY PRODUCT			
NO.	**PRODUCT**	**PRODUCTION RATE**	**PACKAGING TYPE**
1.			
2.			
3.			
4: RAW MATERIAL CONSUMPTION			
NO.	**RAW MATERIAL**	**FUNCTION**	**CONSUMPTION RATE**
1.			
2.			
3.			

Table 4.5: Continued

5a: UTILITY		
NO.	**UTILITY**	**CONSUMPTION RATE**
1.	Water	
2.	Electricity	
3.	Diesel	
4.	Petrol	
5.	Liquefied Petroleum Gas	
6.	Natural Gas	
7.	Others (please specify)	

5b: DETAILED WATER CONSUMPTION		
NO.	**TYPE OF USAGE**	**CONSUMPTION RATE**
1.	Raw material	
2.	Washing of materials	
3.	Cleaning of floor/ equipment	
4.	Soaking	
5.	Others (please specify)	

Table 4.5: Continued

5c: DETAILED ELECTRICITY CONSUMPTION				
NO.	**TYPE OF USAGE**	**AVERAGE RATING (kW)**	**AVERAGE CONSUMPTION (h)**	**kWh**
1.	List of equipment			
2.	Lighting			
3.	Air conditioning			
4.	Computers, printers			
5.	Others (please specify)			

5d: DETAILED FUEL CONSUMPTION			
NO.	**TYPE OF FUEL**	**FUNCTION**	**CONSUMPTION RATE**
1.	Petrol		
2.	Liquefied Petroleum Gas		
3.	Natural Gas		
4.	Wood chips		
5.	Coal		
6.	Diesel		
7.	Others (please specify)		

Table 4.5: Continued

6: PROCESS FLOW DIAGRAM

Table 4.5: Continued

7: UNIT OPERATION		
NO.	**TYPE OF UNIT OPERATION**	**FUNCTION**
1.		
2.		
3.		
8: OTHER ACTIVITIES		
NO.	**TYPE OF ACTIVITY**	**FUNCTION**
1.		
2.		
3.		
9: FACILITY		
NO.	**TYPE OF FACILITY**	**FUNCTION**
1.		
2.		
3.		

Table 4.5: Continued

10: WASTE QUANTIFICATION				
10a: WASTEWATER				
NO.	**SOURCE**	**GENERATION RATE**	**WASTEWATER CHARACTERISTIC**	
			COD (mg/l)	**BOD (mg/l)**
1.	Washing of materials			
2.	Cleaning of floor/ equipment			
3.	Others (please specify)			
4.				

10b: SOLID WASTE (NON SCHEDULED)			
NO.	**TYPE OF WASTE**	**LOCATION**	**GENERATION RATE**
1.	Off-specification product		
2.	Off-specification raw material		
3.	Packaging material		
4.	Domestic		
5.	Others (please specify)		

Table 4.5: Continued

10c: SCHEDULED WASTE			
NO.	**TYPE OF WASTE**	**LOCATION**	**GENERATION RATE**
1.	Spent solvent		
2.	Lubricant oil		
3.	Packaging containers		
4.	Sludge		
5.	Others (please specify)		
11: GASEOUS EMISSIONS			
NO.	**TYPE OF EMISSION**	**LOCATION**	**RELEASED RATE**
1.	SO_2		
2.	SO_3		
3.	NO_2		
4.	CO_2		
5.	Others (please specify)		

Table 4.5: Continued

12: RAW MATERIAL LOSS/ DISCARDED PRODUCT /ETC			
NO.	**TYPE OF MATERIAL**	**POSSIBLE CAUSES**	**GENERATION RATE**
1.			
2.			
3.			
4.			
5.			

13a: ENERGY LOSS THROUGH HOT SURFACE				
NO.	**SOURCE**	**SURFACE AREA, A (m^2)**	**SURFACE TEMPERATURE, T_s (°C)**	**TOTAL HEAT LOSS (kW)** $Q = h A (T_s - 28°C) / 1000$
1.				
2.				
3.				
4.				
5.				

Table 4.5: Continued

13b: ENERGY LOSS THROUGH HOT MATERIAL				
NO.	**SOURCE**	**MASS FLOWRATE, m (kg/s)**	**MATERIAL TEMPERATURE, T_b (°C)**	**TOTAL HEAT LOSS (kW)** $Q = m\ Cp\ (T_b - 28°C)$
1.				
2.				
3.				
4.				
5.				

13c: ENERGY LOSS THROUGH COLD MATERIAL				
NO.	**SOURCE**	**MASS FLOWRATE, m (kg/s)**	**MATERIAL TEMPERATURE, T_b (°C)**	**TOTAL ENERGY LOSS (kW)** $Q = m\ Cp\ (28°C - T_b)$
1.				
2.				
3.				
4.				
5.				

Table 4.5: Continued

13d: ENERGY LOSS FROM LATENT HEAT (STEAM)			
NO.	**SOURCE**	**DISCHARGED RATE, m (kg/s)**	**ENERGY LOSS** Q = 2150 m (kW)
1.			
2.			
3.			
4.			

14: SAFETY AND HEALTH RISK			
NO.	**OBSERVATION**	**COMMENT**	**SEVERITY LEVEL (1/2/3/4)** **1 - low risk** **2 - medium risk** **3 - high risk** **4 - immediate attention**
1.			
2.			
3.			
4.			

Table 4.5: Continued

15: COMPLAINT RECEIVED			
NO.	**COMPLAINT**	**FREQUENCY**	**ACTION TAKEN**
1.			
2.			
3.			
16: HOUSEKEEPING ISSUES			
NO.	**ISSUES**	**LOCATION**	**EFFECT ON QUALITY/ PRODUCTIVITY/SAFETY**
1.			
2.			
3.			
17: OTHER OBSERVATIONS			
NO.	**ISSUES**	**LOCATION**	**EFFECT ON QUALITY/ PRODUCTIVITY/SAFETY**
1.			
2.			
3.			

4.3.3 Analysis of Cleaner Production Audit Findings

Main issues faced by a premise can be identified based on the analysis of audit findings. Identification of issues can be done through estimation of CO_2 emission generated from the manufacturing activities in the audited premise. The quantification of CO_2e emission for this study uses simplified formula by Intergovernmental Panel of Climate Change (IPCC) as of Equation (4.3).

$$\Sigma\ CO_2e = \Sigma\ (\text{consumption or generation}_{\ entity} \times \text{emission factor}_{\ entity}) \quad (4.3)$$

Furthermore, CO_2e emission generated in a manufacturing premise can be calculated according to the Malaysian emission factors, together with the default emission factors listed in IPCC Guidelines for National Greenhouse Gas Inventories and heat value of fuel. Therefore, the example of detailed emission factors is summarized in Table 4.6.

Table 4.6: Emission factors of input and output

Entities	Emission factor	Unit	Reference
Water	0.8	kg CO_2e/m^3	(Cornejo et al., 2014)
Electricity	0.67	kg CO_2e/kWh	Association of Water & Energy Research Malaysia, 2012)
Diesel	2.69	kg CO_2e/l	IPCC 2006
Liquefied Petroleum Gas	1.53	kg CO_2e/l	IPCC 2006
Solid waste	3.7	kg CO_2e/kg	(Murphy & McKeogh, 2004)
Wastewater	1	kg CO_2e/kg COD (removed)	(Keller & Hartley, 2003)

Subsequently, the boundary of the study only covers production processes and activities in manufacturing premises without considering the whole life cycle of the products. The system boundary used in this study, schematically represented in Figure 4.5, include the following subsystems.

(i) Production of main product;

(ii) Transportation within premise. For example, the use of forklift;

(iii) Consumption of utilities (water, electricity, fuel); and

(iv) Generation of waste (solid waste, wastewater).

However, excluded from the boundary are:

(i) Raw material extraction;

(ii) Product utilization phase;

(iii) Transportation of raw materials to the premise and transportation of product to customers; and

(iv) Final disposal (recycling, incineration, landfilling and composting)

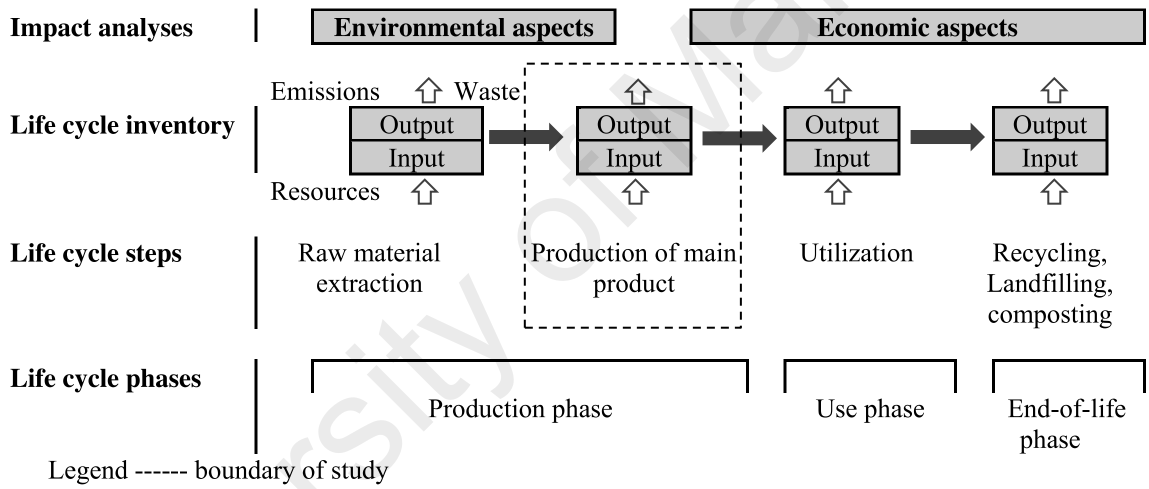

Figure 4.5: Life cycle system boundary of study (Brent & Visser, 2005)

The key issue can be determined by identifying entities with the highest value of CO_2 emission generated. This is known as benchmarking, where the method can evaluate the level of severity for the respective issues. The benchmark value can be compared among the premises with the similar types of industries to evaluate level of performance. The examples of benchmark value for entities that contributed to the generation of CO_2 emission are listed as follows:

(i)	Water consumption per unit of product produced	:	m^3 of water consumed/kg of product
(ii)	Fuel consumption per unit of product produced	:	m^3 of fuel consumed/kg of product
(iii)	Electricity consumption per unit product produced	:	kWh of electricity consumed/kg of product
(iv)	Wastewater generated per unit product produced	:	m^3 of wastewater generated/kg of product
(v)	Solid waste generated per unit product produced	:	m^3 of solid waste generated/kg of product

Hence, entity with the highest value of CO_2 emission is considered as the key issue for the audited premise. As for a respective premise, the entity that has the highest benchmark value compared to other premises is also considered as the key issue. Therefore, improvement opportunities will be generated based on the audit findings with the identified key issues. The strategy to generate improvement opportunities focuses on preventing and reducing the key entities that generate CO_2 emission.

4.4 Sub-Methodology II: Cleaner Production Option Generation Tool

CP option is defined as opportunities of improvements that can be implemented to overcome issues that exist in manufacturing premise or to improve company's performance. In this work, CP options generation focusing to overcome issues caused by entities that contributed to the generation of CO_2 emission. Various methods can be used to generate ideas in generating CP options. Ideas generation to produce CP options can be obtained through:

(i) Case studies. Various case studies are conducted by researchers on CP implementation strategies in manufacturing premises. Strategies implemented may focuses on reduction of resources and waste generation, minimizing risks, etc.

(ii) CP Auditor's knowledge and experiences gained during implementation of CP strategies in various types of manufacturing industry.

(iii) Discussion/ brainstorming with company's representatives. For example, discussions with production personnel can generate various ideas focusing on the possibility of improvements through modification of production processes and parameters, whereas safety personnel can contributes various ideas on minimizing safety issues in the premise.

Through the methods, it is important to ensure that:

(i) Contributions of various levels of company's representatives are encouraged.

(ii) Ideas generated should be recorded.

(iii) Ideas generated should be seriously considered.

(iv) Feedbacks should be given to each of idea generated.

Typically, the method that can be used to generate CP option is through brainstorming activities. It is proven that during this session, various management levels in a company, such as managers, engineers, and production operators, together with the CP Auditor able to generate a lot of CP options. Various methods can be used to conduct brainstorming activities. Following questions can be used during the brainstorming activities:

(i) Use keywords, such as elimination, minimization, reduce, prevent, improve.

(ii) Use CP methodologies, such as housekeeping, design modification, operation modification, change of raw materials, new/alternative technologies, training, reuse & recycle.

(iii) Identify cause through issues. For example, spillages on floor occur from inefficient handling or inefficient equipment. What are the causes of this issue and how it can be improved?

(iv) What are the cause of waste generation and how the wastes are disposed? Are there opportunities in reusing the waste?

(v) What are the options that can be implemented quickly? The best options may require longer time to be implemented. However, it doesn't mean that no options can be implemented quickly.

4.4.1 Cleaner Production Option Generation Tool

CP option generation is developed as a methodology in generating CP options. The use of probing questions that have been developed according to 17 components of CP Audit Tool enables the process of generating CP options to be conducted systematically, where the answers to the probing questions are the opportunities of the generation of CP options. Generally, the implementation of CP options can be classified into six categories, according to the evaluation of implementation costs. Through the categories, premises can prioritize the CP options generated according to the requirement or returns to be achieved.

4.4.1.1 Thinking Process for Cleaner Production Option Generation

The thinking process in generating CP options can be divided into four steps, which are entities targeted, principles of CP option generation, implementation methodology and eventual output. The methodology of generating CP options is illustrated in Figure 4.6.

Entities Targeted	Principles of CP Option Generation	Implementation Methodology	Intermediate Output	Eventual Output
Energy Material Safety	Modification in following parameters: Temperature Pressure Process time Number of process	Housekeeping Design Modification Operational Modification Change of Raw Material New Technologies Staff Training Recycle & Reuse	Direct Cost Reduction Improve Product Quality Reduce Waste Generation Reduce Energy Consumption Reduce Risk Improve Reputation Others	Carbon Emission Reduction Environmental Impact Reduction Others
FOCUS	**CP OPTION DESIGN**		**TARGETED OUTCOME**	

Figure 4.6: Methodology of generating CP options

The thinking process for generating CP options according to the respective four main steps is expanded to generate various CP option opportunities. The thinking process starts with referring to the investigative questions that have been developed for the 17 components of the CP audit tool. The response to the investigative questions need to be in term of Yes or No. According to the response, answers to the investigative questions need to be determined in term of effects to the entities that contributed to the generation of CO_2 emission. Furthermore, the target needs to be determined whether to reduce, prevent, or to improve. The CP options can be generated based on seven categories, which are Housekeeping, Design modification, Operation modification, Change of raw materials, New/ alternative technologies, Training, Reuse & recycle. Finally, general or specific CP options can be generated. The detailed CP option generation tool is given in Table 4.7.

Table 4.7: Cleaner Production Option Generation Tool

No.	Question	Response	Effects/ Issues	General aim	Methodologies	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.	Is the product environmental friendly?					
7.	Is it easy to handle the products/ packages?					
8.	Is the packaging size suitable?					
9.	Is the production generates high amount of by products?					
10.	Is the product eco-labeled?					
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?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
	Part 3: By-products					
1.	Is the by-product required?					
2.	Is the by-product needs to be minimized?					
3.	Is the products environmental friendly?					
4.	Is the packaging size suitable?					
5.	Is the by-product eco-labeled?					
6.	Is the rate of returned by-product high?					
7.	Is the packaging material easily damaged?					
8.	Is the packaging material recyclable?					
9.	Is the designated storage space optimum?					
10.	Is the by-product fully utilized?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
	Part 4: Raw Materials					
1.	Is there any better replacement for the materials?					
2.	Is the material usage to the optimum?					
3.	Is the material environmental friendly?					
4.	Does this material generate waste?					
5.	Does this material yielded to 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.	Does 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.	Does the purchase process yielded to excessive raw materials? (i.e. there is a need to store excessive raw materials)					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
	Part 5a: Utilities Required					
1.	Are the utilities environmental friendly? (i.e. the use of natural gas)					
2.	Do the utilities pose risk? (i.e. toxic)					
3.	Do the utilities generate waste? (i.e. ash generated from the use of wood chips as fuel)					
4.	Are there special needs for the handling/storage of the utilities? (i.e. cold room, compressor, training)					
5.	Is the consumption of the utilities acceptable (compared to the benchmark)?					
6.	Are the utilities generated at the company? (i.e. electricity)					
7.	Are the utilities suppliers far from the company? (i.e. supplier of LPG gas)					
	Part 5b: Detailed Usage of Water					
1.	Is water needed?					
2.	Is the water used in a way that will cause water wastage?					
3.	Is the water usage optimum?					
4.	Is the water used more frequently than needed?					
5.	How many times is the water used unnecessarily?					
6.	Is there too long a duration when water is used?					
7.	Is the water temperature optimum?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
8.	Does the water quality/ specification fit the usage purpose?					
9.	Is there too much of wastewater generated with the current ways of using water?					
10.	Is the generated wastewater highly polluting?					
11.	Is the used water reusable?					
	Part 5c: 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 the energy-saving type?					
11.	Is the equipment automated?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
	Part 5d: Detailed Usage of Fuel					
1.	Is the fuel environmental 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 the 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?					
	Part 6: Main Process Flow Chart					
1.	Can the process flow/steps/ activities be modified?					
2.	Are there too many processes/ steps/ activities?					
3.	Is the time consumption high for the processes/ steps/ activities?					
4.	Do the processes/ steps/activities run continuously or intermittently?					

Table 4.7: Continued

Part 7&8: 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.	Are the settings 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 properly labeled?					
19.	Is the energy usage of the process/ activity optimum?					
20.	Does hot/ cold surface exposed?					
21.	Does the unit operation produce noise?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
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 9: Facilities					
1.	Do the facilities generate waste?					
2.	Are there special requirements for the facilities?					
3.	Do the facilities produce scheduled/ hazardous/ clinical waste?					
4.	Is there usage policy?					
5.	Do the facilities require many resources? (i.e.: water)					
6.	Do the facilities require much electricity?					
7.	Are the facilities well maintained?					
	Part 10a: Wastewater Quantity					
1.	Can wastewater generation be avoided?					
2.	Is the wastewater generation rate high? (Compared to the benchmark)					
3.	Does the wastewater quality vary with the source?					
4.	Is the wastewater treated before being released to the environment?					
5.	Does wastewater of different quality mixed together?					
6.	Are there any factors that affect the generation/ quality of wastewater (i.e. leakage)					
7.	Is there a sharp increase in the quantity/ quality of wastewater?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
	Part 10b: Solid Waste Quantity (Non-Scheduled)					
1.	Can waste generation be avoided?					
2.	Is the waste generation rate high? (Compared to the benchmark)					
4.	Are all the wastes disposed off?					
5.	Is the waste treated before being released to the environment?					
6.	Does waste of different quality mixed together?					
7.	Are there any factors that affect the generation of waste (i.e. inefficient handling)					
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 any special requirements for storage/ handling of the waste?					
12.	Does the company have waste production/ handling policy?					
13.	Does the waste labeled in detail?					
14.	Is the storage space compatible with the waste generation rate?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
	Part 10c: Quantity of Scheduled Waste					
1.	Can the waste generation be avoided?					
2.	Can the toxicity be reduced?					
3.	Is the waste handled according to the rules and regulations?					
4.	Are workers exposed to safety and health risk?					
	Part 11: Gas Emission (Other than Steam)					
1.	Is the energy reclaimable?					
2.	Can the emission rate be reduced?					
3.	Is there any leakage at the sources of emission?					
	Part 12a: Loss of Heat Energy Through Hot Surface					
1.	Is the operating temperature optimum?					
2.	Are there exposed surfaces?					
	Part 12b: Loss of Heat Energy Through Hot Items					
1.	Is the operating temperature optimum?					
2.	Is the energy reclaimable?					
	Part 12c: Loss of Heat Energy Through Cold Items					
1.	Is the operating temperature optimum?					
2.	Is the energy reclaimable?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
Part 12d: 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 or steam or condensate? (i.e. Steam trap)					
4.	Is there any open heating process? (i.e. heating tank)					
Part 13: Safety and Health Risk						
1.	Can accidents be avoided?					
2.	Can accidents be reduced?					
3.	Does the plant have health and safety policy?					
4.	Is the workplace condition suitable? (i.e.: temperature, moisture, smell, lighting)					
5.	Is safety practiced at the plant? (i.e. display of speed limit, training)					
6.	Does the plant adequately equipped with safety equipment? (i.e. PPE, fire distinguisher, first aid kit)					
7.	Are the equipment/ facilities at the plant well maintained?					
8.	Do accidents generate waste?					
9.	Does the plant have additional control system?					
10.	Are there special requirement for some processes/ activities? (i.e. fume hood)					
11.	Do the safety equipment function well?					
12.	Does the plant have easy access/ exit route?					
13.	Does the plant layout pose risk?					
14.	Are there blind spots at the plant?					

Table 4.7: Continued

No.	Question	Response	Effects/ Issues	General aim	Methodologies	Options
	Part 14: Complain					
1.	Can complain be avoided?					
2.	Can complain be rectified?					
3.	Is there a good system to record complaint?					
	Part 15: Layout Issues					
1.	Is the labeling system adequate?					
2.	Does the layout of the plant obstruct the walkways?					
3.	Does the layout of the plant impair visibility?					
4.	Does the layout of the plant affect ventilation?					
5.	Is there adequate lighting at the plant?					
6.	Does the product arrangement complicate the transfer process of the products onto the forklift?					

4.5 Sub-Methodology III: Cleaner Production Option Evaluation Tool

The evaluation of CP options generated is conducted to evaluate the feasibility of the CP options in order to prioritize for implementation. Components to be evaluated are economic and environmental returns.

Economic Evaluation

Economic evaluation is conducted through estimations of main costs and benefits obtained. The following methods can be used to conduct economic evaluation:

(1) Identify cost of equipment, installation and other cost related to modifications.

(2) Identify continuous cost, which are operating cost, maintenance cost, material cost and labor cost.

(3) Identify expected returns in terms of savings in material, water, energy or waste treatment.

(4) Identify total investment cost and total savings for the evaluated CP option.

(5) Calculate net savings by deducting total investment cost and total savings.

(6) Calculate pay back period by using (Equation (4.4)).

$$\text{Payback period} = \Sigma\ \text{Investment} / \Sigma\ (\text{Investment} - \text{Savings}) \quad (4.4)$$

Payback period indicates estimated duration required to obtain capital that was invested to implement the CP option.

For example:

CP option : Installation of 100 unit of LED energy saving bulbs		
	Item	Amount (USD)
Investment Cost	Purchasing equipment	3,500.00
	Installation	500.00
	Electrical work	-
	Construction work	-
Additional operating cost due to modification (monthly rate)	Manpower	-
	Electricity	-
	Water	-
	Fuel	-
	Treatment	-
Savings (monthly rate)	Manpower	-
	Electricity	420.80
	Water	-
	Fuel	-
	Treatment	-
Payback Period	Investment / Net Savings	9.5 month

Environmental Evaluation

Environmental evaluation was conducted to identify positive or negative effects of the generated CP options. Typically, environmental returns are significant such as reduction in waste generation or reduction in the toxicity of waste. Following information is required to conduct environmental evaluation:

(i) Reduction in the quantity and toxicity level of waste.

(ii) Reduction in energy consumption.

(iii) Reduction in water and material consumption.

(iv) Increased in waste reusability.

(v) Reduction in environmental negative effect of the product.

For example:

CP option : Installation of 100 unit of LED energy saving bulbs		
	Item	Amount (monthly)
Environmental benefit	Reduction in carbon dioxide emission	2,562.7 kg CO_2e
	Reduction in electricity consumption	3,825 kWh
	Reduction in water consumption	-
	Reduction in fuel consumption	-
	Reduction in raw material consumption	-
	Reduction in wastewater generation	-
	Reduction in solid waste generation	-

4.5.1 Cleaner Production Option Evaluation Tool

CP Option Evaluation Tool is developed to assist in evaluation process, thus prioritizing the generated options. The tool is combining the evaluation of economic and environmental components, where the method of payback period calculation is included in the economic evaluation, while the reduction of quantity of CO_2 emission is focused for the environmental evaluation. The evaluation process starts with identifying issue that existed in the premise as well as the location of the issue. Further, identification of possible challenges that may occur in implementing the options are done, followed by identifying list of resources required, together with investment costs. Economic evaluation is done where payback period is determined. Expected returns in environmental and productivity aspects are also determined. Finally, evaluated CP options are given the implementation merit, according to lowest payback period and highest returns. In addition, CP options with highest contribution to the reduction of CO_2 emission are also prioritized for the implementation. The detailed CP Option Evaluation Tool is given in Table 4.8.

Table 4.8: Cleaner Production Option Evaluation Tool

Issues	:		
Area	:		
Source &/or reason	:		
Option	:		
Category of option	:		
Possible challenges		**Type of challenges**	**Tick √**
	:	No expertise	
	:	Top management's commitment	
	:	Production cannot be stopped	
	:	Too risky	
	:	May have effect on product quality	
Input required			
		Input required	**Tick √**
	:	Technology	
	:	Manpower	
	:	Training	
	:	Awareness	
	:	Process change	
	:	Operation parameters change	
	:	Material change	
	:	Design change	
	:	Standard operating procedure	
	:	Monitoring	
	:	Additional control	
	:	Research & Development	
	:	Approval from authorities	
Investment Cost			
		Item	**Amount Required (RM)**
	:	Electrical work	
	:	Purchasing equipment	
	:	Construction work	
	:	Shut Down loss	
	:	Man power cost	
	:	Financing cost	
	:	Others	
	:	**Total Cost (A)**	
Additional operational cost due change/Modification (Monthly rate)			
		Item	**Amount Required (RM)**
	:	Manpower	
	:	Electricity	
	:	Steam	
	:	Fuel	
	:	Maintenance	
	:	Treatment	
	:	Others	
	:	**Total Cost (B)**	

Table 4.8: Continued

		Item	Saving (RM)
Saving (Monthly rate)	:	Man power	
	:	Electricity	
	:	Steam	
	:	Fuel	
	:	Maintenance	
	:	Treatment	
	:	Others	
	:	**Total Saving (C)**	
Payback period	:	**A/(C-B) month**	
Other possible benefits		**Benefit Type**	**Tick √**
	:	Improved quality	
	:	Improved images	
	:	Safer operation	
	:	Less riskier operation	
	:	Better motivation	
	:	Better working environment	
	:	Lesser environmental issues	
	:	Reduction in carbon footprint	
	:	Others	
Merit of implementation		**Merit**	**Tick √**
	:	Implement immediately	
	:	Implement within six months	
	:	Keep it as future plan	
Documentation required if implemented		**Type of documentation**	**Tick √**
	:	Paper documentation	
	:	Video documentation	
Monitoring plan (Describe)	:		
Prepared by	:		
Confirmed by	:		

4.6 Practicality Validation of Cleaner Production Implementation Methodology

The validation on the practicality of Cleaner Production Implementation Methodology was demonstrated in case studied premises of different types of industries. Based on criteria of premise selection, three SMEs manufacturing premises were selected of which beverage, plastic and printing.

4.6.1 Case Study I: Fruit Juice Manufacturing

4.6.1.1 Company's Background Information

The case study is a fruit juice-processing premise located in Kuala Lumpur, Malaysia. The premise was established in 1991 with 45 full time workers. It produced an average of 3,456 m^3 of 16 types of flavors concentrated and cordial juice annually. The premise engaged batch production with a daily operation of 8 hours and 4 batches of productions. The company held Hazard Analysis and Critical Control Points (HACCP) and Malaysian Islamic Dietary (HALAL) certificates.

4.6.1.2 Process Description

The production processes involved a 7-step processes: raw material thawing, dispensing and batching, dissolving, mixing, filling and capping, packaging, and storage as illustrated in Figure 4.7. The main raw materials were assorted types of fruit puree imported mainly from India and the frozen ingredients were stored at 10°C in a cold room up to three months. The frozen ingredients were thawed at room temperature before being mixed with dry ingredients, which were then dispensed and batched according to the recipe. The formulated ingredients were dissolved separately in small-capacity mixing tanks before being pumped into a 3000-litre electrical mixing tank. The materials were then mixed homogenously with filtered water and liquid syrup for 1 and 1/2 hours for each batch. The total amount of filtered water used as a raw material for the production was 108 m^3 monthly. After the mixing, the produced juices were filled into 1-litre or 2-litre plastic packaging bottles, depending on the customers' requirement. They were then labeled, capped and packed accordingly. During the filling process, it was estimated that 2 L of products remained inside the filling hose, which was considered as a product loss. In addition, the production processes took place in a clean and hygienic fully air-conditioned rooms at 16°C, which required significant electricity consumption. The finished products were stored at room temperature before delivery.

All the manufacturing equipment, especially process tanks, were cleaned and rinsed by hot and cold water daily after production. It was also observed that wastewater from the cleaning activities was discharged without any pre-treatment.

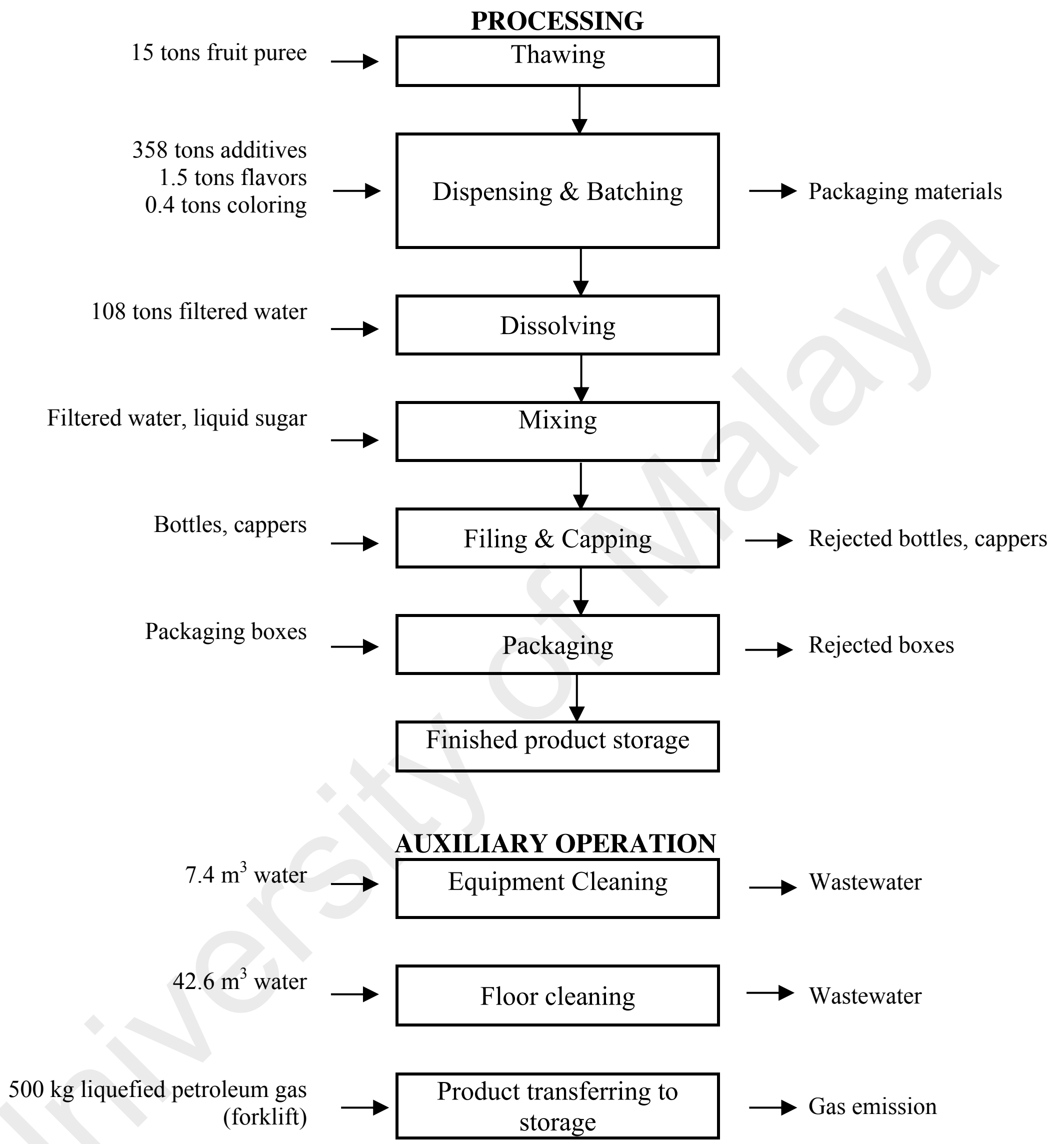

Figure 4.7: Process flow diagram of fruit juice production

4.6.1.3 Analysis of Cleaner Production Audit Findings

Analysis of audit findings shows that a total of 158 m^3 of water was used monthly for overall production activities in the premise, where approximately 7.4 m^3 of water was used for the cleaning activities. City water was purchased at 0.63 USD/m^3 of water, resulted in 99.5 USD/month. In addition to water, electricity and fuel were also used in the production process. Electricity was purchased at 0.11 USD/kWh, with operation consumption of approximately 26,628 kWh/month, which translated into 2,929 USD/month. Liquefied petroleum gas (LPG F14) was used as the source of fuel for forklift trucks in the premise. The fuel was consumed at a rate of 500 kg/month, or 310 USD/month. Table 4.9 summarizes the consumption of the above-mentioned resources.

Table 4.9: Resource consumption on monthly basis

Resource	Water (m^3)	Electricity (kWh)	Fuel (kg)
Consumption	158	26,628	500
Unit price (USD)	0.63	0.11	0.62
Cost (USD)	99.50	2,929.00	310.00

Table 4.10 illustrates the input-output analysis of water usage for specific process and wastewater generated from the production process. The discharged wastewater, mainly generated from cleaning activities, had a COD value of 50 mg/L.

Table 4.10: Water flow in the different production process unit on monthly basis

Process	Input flow (m^3)	Output flow (m^3)
Process water - raw material	108	
Non process water - CIP	7.4	7.4
Non process water - Domestic	42.6	42.6

It was found that 230 kg/month of solid waste was generated. Electrical consumption of the main unit operations is presented in Table 4.11 together with the energy rating in kW and daily operating hours.

Table 4.11: Energy consumption of different unit operation

Type	Operating (hours/month)	Monthly consumption (kWh)
10 kW motors for mixing stirrer	64	640
1.7 kW heater	64	109
19.5 kW air compressor	60	1,170
34.5 kW air conditioning	160	5,520
26.5 kW cold room	720	19,080
Others (lighting, computers)		109

The detail of Cleaner Production audit findings is attached in Appendix A.

4.6.1.4 Quantification of Carbon Dioxide Emission

The total CO_2e emission generated from the premise was approximately 20.2 tons on a monthly basis, which was equal to 242.4 tons per annum or 0.07 kg CO_2e/liter juice produced as summarized in Table 4.12. Figure 4.8 illustrates the sources of CO_2e emission and their respective emission percentage. Electricity consumption was identified as the major contributor of CO_2e emission in the production premise, contributing to 88% of the total percentage, with a quantitative value of 17,841 kg CO_2e on a monthly basis or 0.06 kg CO_2e/liter juice produced. Therefore, electricity consumption was considered as the critical entity that needs to be addressed to reduce the CO_2e emission of the premise.

Table 4.12: Quantification of carbon dioxide emission

Entities	CO_2e emission (kg/month)	kg CO_2e/liter juice produced
158 m^3 of water	126	0.00043
26,628 kWh of electricity	17, 841	0.062
500 kg of LPG	1, 457	0.0051
230 kg of solid waste	851	0.0029
50 m^3 of wastewater	2.5	0.00001
Total	20,277.5	0.07

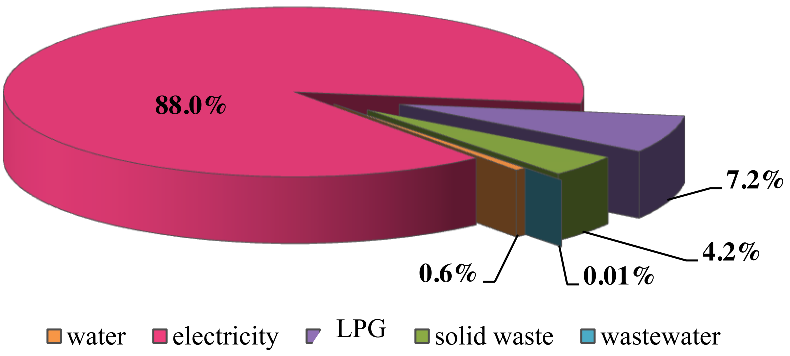

Figure 4.8: Breakdown of CO_2e emission according to sources

4.6.1.5 Evaluation of Cleaner Production Options

Cleaner Production options suggested in this study focused on efficient operation of the refrigeration systems of the respective premise, which are air conditioning and cold room. It was recommended that the premise should increase the air conditioning temperature from 16°C to 20°C which would result in 40% electricity savings without any investment cost. Furthermore, air conditioning systems at unoccupied areas should be turned off and used only when necessary.

It was also recommended that the daily production operation should not exceed eight hours without unnecessary requirements. The air conditioners should be turned off one hour before the production operation ends. In addition to efficient use of air conditioning system, the premise should also consider investing in monitoring equipment and maintenance, targeting at identifying and eliminating sources of unnecessary openings especially in the areas that require cooling.

On the other hand, it was identified that the cold room used for storing the frozen raw materials, was the main contributor to electricity consumption in the premise. The cold room consisted mainly of a compressor, evaporator and condenser. In this study, the installation of an inverter unit into the compressors could reduce the energy consumption by 10%, which could be translated into 1,908 kWh monthly. It was also found that frequent operation of cold room at full rated load was more energy efficient compared to its operation at partial.

Besides, it is important that loading and unloading tasks should be carefully organized, where the cold room doors should only be opened if required and with immediate transfer of materials into the cold room. It was also advised that the frequency of opening the doors should be minimized to prevent energy loss as this no-cost practice could achieve 2% of electricity saving based on the estimation. The electricity savings achieved by implementation of the suggested CP options can be further interpreted in terms of CO_2e emission reduction.

Generally, implementation of the six focal CP opportunities can lead to electricity saving up to 68,496 kWh a year. It was equivalent to CO_2e emission reduction of 46 tons or 7,535 USD annually. Table 4.13 summarizes the CP options with their corresponding outcomes on electricity saving, CO_2e emission reduction and payback period.

Table 4.13: Summary of economic and environmental evaluation of recommended cleaner production options

Area	CP options	Estimated investment costs (USD)	Annual savings		Estimated CO_2e emission reduction (kg)	Payback period (Year)
			kWh	Value (USD)		
Air conditioning	1. Increase temperature from 16°C to 20°C.	0	26,496	2,913.60	17,752.8	Immediate
	2. Eliminate unnecessary openings in the room.	2,325.00	3312	364.80	2,218.8	6.3
	3. Complete daily operation within 8 hours instead of 10 hours.	0	6,624	728.40	4,437.6	Immediate
Cold room	1. Quick entry into cold room immediately after the processing.	0	4,584	504.00	3,070.8	Immediate
	2. Minimize frequency of opening.	0	4,584	504.00	3,070.8	Immediate
	3. Installation of inverter for the compressors.	7,130.00	22,896	2,517.60	15,340.8	3

4.6.1.6 Summary of Case Study I

It is estimated that the studied premise in the present study should be able to reduce CO_2e emission from 0.06 kg to 0.048 kg CO_2e/liter juice produced with simple and logical CP options implementation. Such reduction is equivalent to almost 46 tons of CO_2e a year. However, implementation of some of the suggested options such as repairing leakages at all sources and purchasing inverters for cold room compressors require an investment of 9,455 USD. The cost involved in the implementation would be recovered within 6 years based on the calculation. Compared to the previously reported CO_2e emission values, it was found that the value obtained in this study was slightly lower. This was because this study considered only the gate-to-gate production processes. The respective values can be used as the basis for benchmarking purposes by other similar production premise. However, although the comprehensive energy consumption was expected to reduce through the implementation of CP strategies, there are other CP opportunities to further reduce CO_2e emission. As such, a detailed study on electrical power consumption of each unit operation per unit of juice produced is recommended. Based on the results of this study, CP strategy is found to be a feasible CO_2e emission reduction strategy for the beverage industry.

4.6.2 Case Study II: Recycled Plastic Resin Manufacturing

4.6.2.1 Company's Background Information

The case study is a plastic resin-producing premise located in Selangor, Malaysia. The premise was established in 1995 with 20 full time workers. It produces plastic resins for industrial purposes from recycled plastic wastes with annual full capacity of 1,800 tons of plastic resins. The premise operated 24 hours with two batches of production daily.

4.6.2.2 Process Description

Polypropylene (PP) and oriented polypropylene (OPP) wastes such as packaging plastics, plastic wrappers, and rejected plastic were used as the raw materials. Pigments were added as the coloring agents for the product. Subsequently, 2,520 tons of raw materials were used annually for the production of plastic resins. Initially, the plastic wastes received were inspected and sorted out manually according to quality and color to eliminate undesirable materials such as metal, wood, sand and other contaminants. The sorted plastics were then directly put into the shredder and cut into small pieces, followed by a preliminary washing process using river water to remove dirt, sand and other contaminants that stick on the plastic surface. There was a series of moving plates and rotators used in the washing process. The final washing process was done using city water (SYABAS). After the washing process, the plastic flakes were directed to the compacter, which serves as the drying unit. Subsequently, compacted plastics were produced. The compacted plastic was then collected and fed manually to the extruder that was powered by an electrical heater. The plastics were melted and molded to a wire tube size shape. The molded plastic was then directly cooled by cooling water and subsequently passed above brushes to remove dirt and sticky materials. The product was then cut into small pellets and packed according to customer requirement. Finally, the finished products were stored at room temperature before delivery. In the case where plastic resins failed to meet color or moisture specifications, the resins would be put under homogenization process. The overall process flow chart of the plastic resins processing is presented in Figure 4.9.

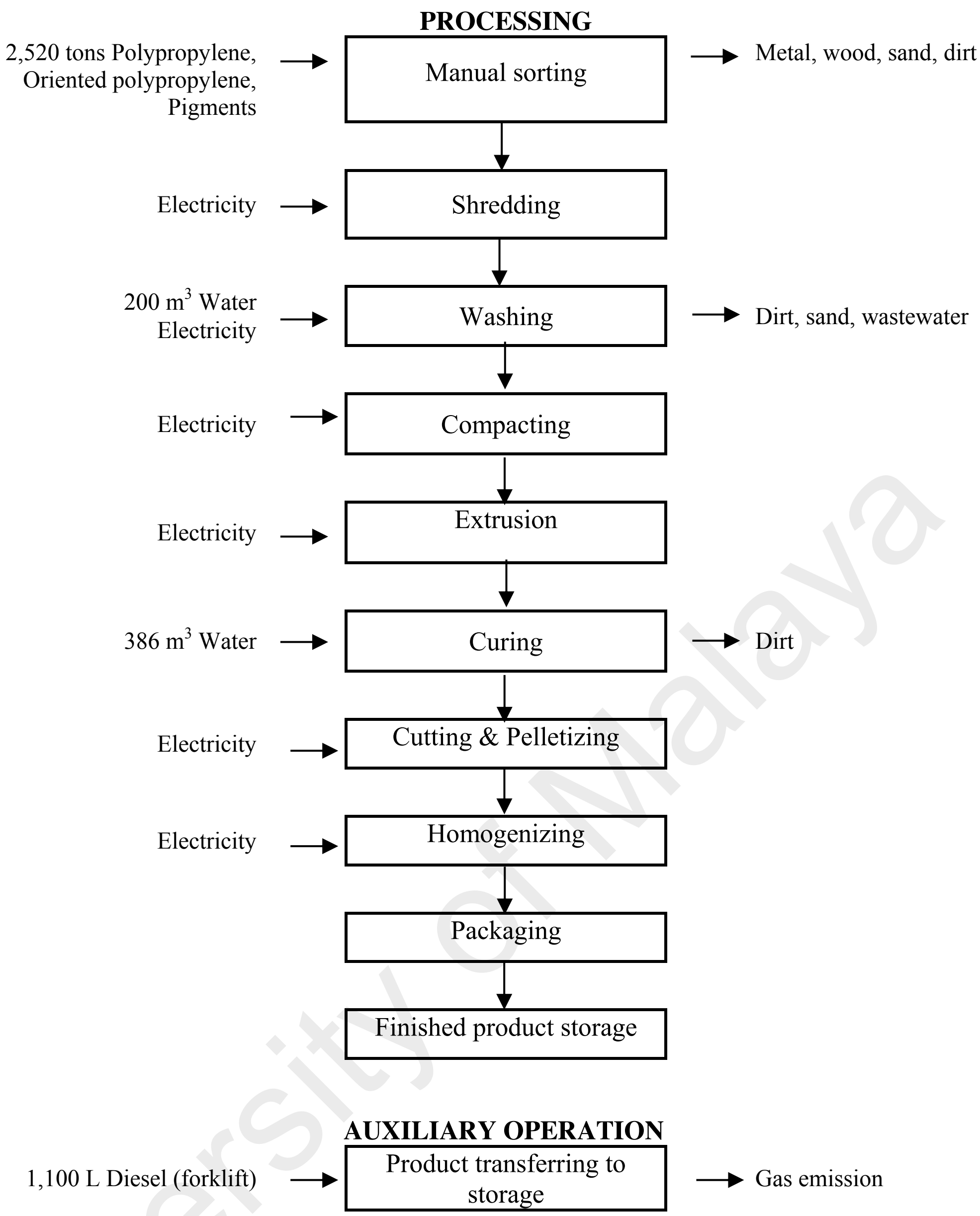

Figure 4.9: Process flow diagram of plastic resin production

4.6.2.3 Analysis of Cleaner Production Audit Findings

A total of 650 m^3 of water was used monthly for the overall production activities in the premise, where approximately 450 m^3 of city water is used for final cleaning, cooling process and domestic use. Water was purchased at 0.63 USD/m^3 of water, resulting in 283.5 USD/month. As for preliminary cleaning process of raw material, 200 m^3 of river water was used and it is estimated that the pumping cost is about 0.49 USD/liter. Apart from water, electricity and fuel were also used in the production processes. Electricity was purchased at 0.11 USD/kWh, with a consumption of approximately 140,000 kWh/month, which translated into 15,400 USD/month. The premise owns two forklift trucks for transportation purpose within the premise, with a monthly diesel fuel consumption of 1,100 liters or 594 USD/month. It is estimated that the distance travelled is 1,375 km based on usage of 0.8 liter/km. Table 4.14 summarizes the consumption of the above-mentioned resources.

Table 4.14: Resource consumption on monthly basis

Resource	Water (m^3)		Electricity (kWh)	Fuel (L)
	River	City		
Consumption	200	450	140,000	1,100
Unit price (USD)	0.49	0.63	0.11	0.54
Cost (USD)	98.00	283.50	15,400.00	594.00

Table 4.15 illustrates the input-output analysis of water usage for specific process and wastewater generated from the production processes. The discharged wastewater, mainly generated from cleaning activities, had an average chemical oxygen demand (COD) value of 300 mg/L.

Table 4.15: Water flow in the different production process unit on monthly basis

Process	River	City	
	Preliminary washing	Final washing and Cooling water	Domestic
Input flow (m^3)	200	386	64
Output flow (m^3)	200	450	

It was quantified that 8 tons/month of solid waste were generated from the foreign materials in the raw materials. Solid wastes were stored in specific areas before being collected by waste contractors. Electricity consumption of the main unit operations is presented in Table 4.16 together with the energy rating in kW and daily operating hours.

Table 4.16: Energy consumption of different unit operation

Type	Operating (hours/month)	Monthly Consumption (kWh)
2 units of 50 kW heater for extruder	600	60,000
2 units of 25 kW extruder drive	600	30,000
15 kW shredder	200	3,000
18 kW compactor	600	10,800
17 kW water pump	600	10,200
10 kW agitator washer	600	6,000
2 units of 6 kW motor for shredder conveyor	300	3,600
3 units of 4 kW pellet cutter	600	7,200
2 units of 1 kW plastic cutter	200	400
3 units of 1 kW pellet blower	600	1,800
3 unit of 1 kW air conditioning	208	624
Others (lighting, etc.)		6,375

The detail of Cleaner Production audit findings is attached in Appendix B.

4.6.2.4 Quantification of Carbon Dioxide Emission

The total CO_2e emission generated from the premise was approximately 127 tons on a monthly basis, which was equal to 1,524 tons per annum or 0.84 kg CO_2e/kg plastic resins produced as summarized in Table 4.17. Figure 4.10 illustrates the sources of CO_2e emission and their respective emission percentage. Electricity consumption was identified as the main source of CO_2e in the premise, contributing to 73.8% of the total emission percentage, with a quantitative value of 93.8 tons CO_2e on a monthly basis or 0.63 kg CO_2e/kg plastic resin produced.

Table 4.17: Quantification of carbon dioxide emission

Entities	CO_2e emission (kg/month)	kg CO_2e/kg resin produced
650 m^3 of water	520	0.0035
140,000 kWh of electricity	93,800	0.63
1,100 L of diesel	2,959	0.02
8,000 kg of solid waste	29,600	0.19
650 m^3 of wastewater	195	0.0013
Total	127,074	0.84

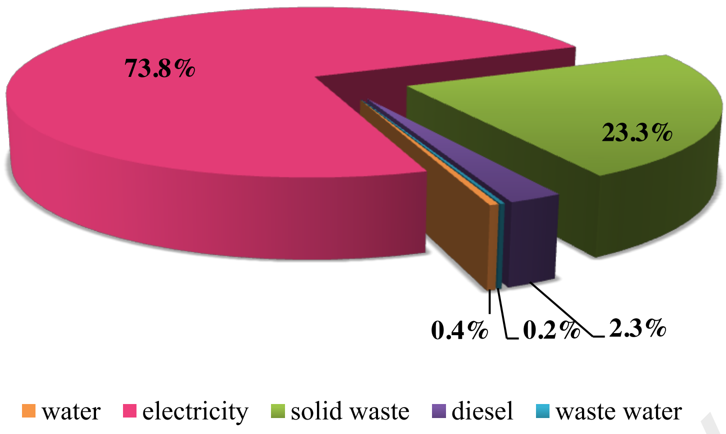

Figure 4.10: Breakdown of CO_2e emission according to sources

4.6.2.5 Evaluation of Cleaner Production Options

Cleaner Production options suggested in this study focused on efficient operation of the heating process, which is the extruder. It could be beneficial to identify the heating requirements for extruder in order to monitor heat energy loss. It was recommended that the premise should run the extrusion process at possible optimum melting temperature, which potentially would result in 25% of electricity savings without any investment cost.

It was also recommended to insulate hot surface of the extruder with blanket insulator made by ceramic fiber-fabric. For operating temperature below 454°C, hot surface covered by thermal shield blanket insulation is estimated to obtain heat loss reduction of 85%, which equates to payback period of less than 6 months.

On the other hand, it was identified that auxiliary system for the whole premise including administration office such as lightings, air conditioning and office equipment such as computers was the main contributor to electricity consumption in the premise. In this study, it was recommended to install energy saving LED bulbs to replace existing conventional fluorescent bulbs. The use of LED bulb in the lighting system would potentially bring savings in energy consumption of about 60%. It is also recommended that the integration of motion or infrared sensors to the lighting system in the premise could further bring significant economic benefits.

Further, it is recommended that the premise should increase the air conditioning temperature from 16°C to 20°C, which expected to result in 40% of electricity saving. Implementation of good practices, as simple as turning off air conditioning and lighting systems at unoccupied areas and used only when necessary would also potentially bring returns in term of electricity saving. In order to achieve efficient use of air conditioning and lighting system, the premise should also consider investing in installing automatic turn on/ off switch with timer, together with routine maintenance to monitor equipment efficiency. The electricity savings achieved by implementation of the recommended CP options can be further evaluated in terms of CO_2e emission reduction.

Generally, implementation of the four options can lead to electricity saving up to 300,895 kWh a year. It was equivalent to CO_2e emission reduction of 201.6 tons or 33,098 USD annually. Table 4.18 summarizes the CP options with their corresponding outcomes on electricity saving, CO_2e emission reduction and payback period.

Table 4.18: Summary of economic and environmental evaluation of recommended cleaner production options

CP options	Estimated investment costs (USD)	Monthly savings		Estimated CO_2e emission reduction (kg)	Payback period (Month)
		kWh	Value (USD)		
1. Optimize temperature in heating and extrusion process.	0	15,000	1,650.00	10,050	Immediate
2. Increase air conditioning temperature from 16°C to 20°C.	0	249.6	27.50	167.2	Immediate
3. Insulate hot surface of extruder with ceramic-fiber fabric blanket.	4,650.00	6,000	5,610.00	4,020	10
4. Install LED energy saving bulbs for lighting system. (100 unit)	3,500.00	3,825	420.80	2,562.8	9.5

4.6.2.6 Summary of Case Study II

The results indicated that the largest source of CO_2e in the plastic resin production premise is electricity consumption (73.8%), followed by solid waste generation (23.3%), and fuel usage (2.3%). The total CO_2e emission reduced is 16.8 tons monthly. With implementation of simple CP options focusing on reducing energy consumption, it is estimated that the premise could potentially reduce its CO_2e emission by 0.11 kg CO_2e/kg of resin produced though implementation of some suggested CP options required an investment of 8,150 USD. However, it is estimated that the cost involved could be recovered within 10 months. The feasibility studies of the CP options proved that implementation of zero or low cost CP options could potentially reduce electricity consumption and CO_2e emission. The results of this study appeared as a good indicator of the main sources of CO_2e in the plastic resin production premise in Malaysia. Implementation of CP strategies can be recommended to other plastic production premise.

4.6.3 Case Study III: Printing

4.6.3.1 Company's Background Information

The premise is located in Kuala Lumpur, Malaysia, which occupies a land area of 83,000 square feet. The premise has been in operation since 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.

4.6.3.2 Process Description

The printing process, which is presented in Figure 4.11, 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 colors 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. In addition, 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 schedule waste contractors. Remaining wastewater is discharged into public drains without any pre treatment.

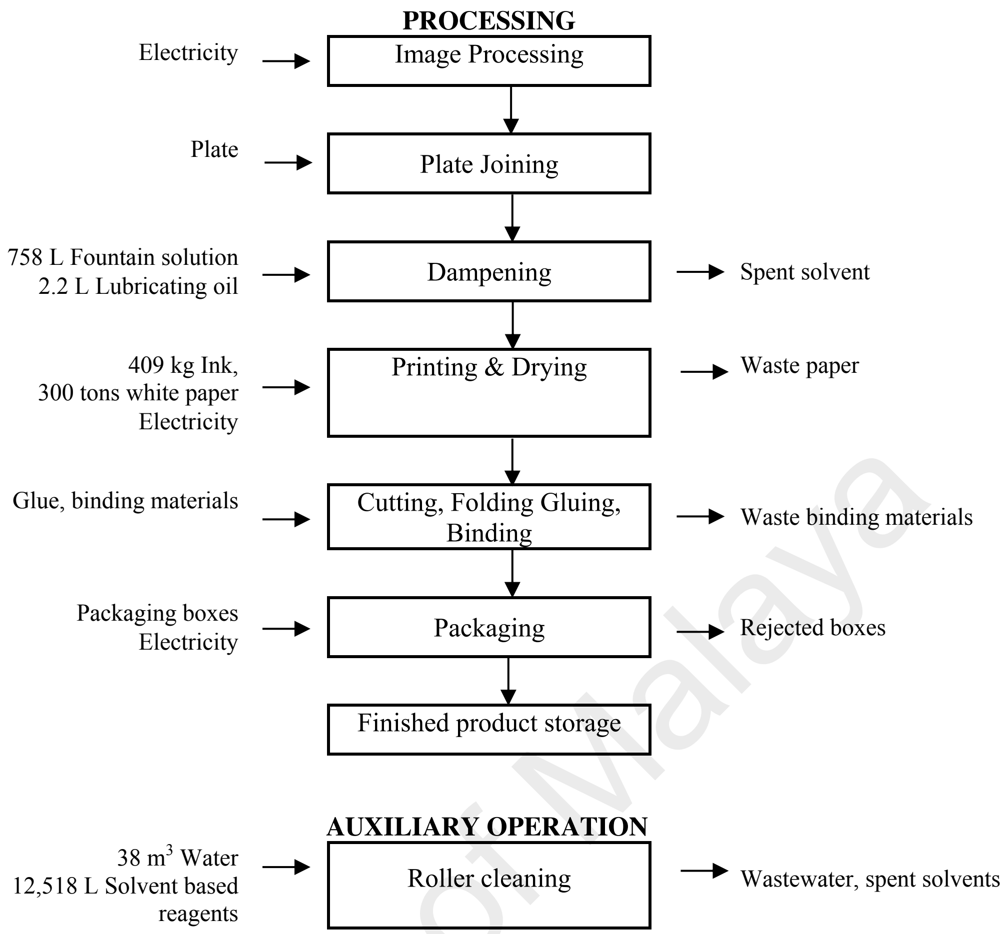

Figure 4.11: Process flow diagram of the printing process

4.6.3.3 Analysis of Cleaner Production Audit Findings

Analysis of audit findings shows that a total of 2886 m^3 of water is used monthly. City water was purchased at 0.63 USD/ m^3 of water, resulted in 1,818 USD/month. In addition to water, electricity is also used in the production processes with hourly operation consumption is approximately 312,226 kWh/month. Electricity was purchased at 0.11 USD/kWh, resulting in an annual cost of about 412,138 USD. Table 4.19 summarizes the consumption of the above-mentioned resources.

Table 4.19: Resource consumption on monthly basis

Resource	Water (m^3)	Electricity (MWh)	Paper (tons)	Ink (kg)	Fountain Solution (l)	Lubricating Oil (l)	Cleaning agents (l)
Consumption	2,886	312	300	409	758	2.2	12,518

Approximately 38 m^3 of wastewater are generated from the roller cleaning activities, while 2,092 m^3 are generated from overall washing activities, with a COD value of 96 mg/L. Table 4.20 illustrates the input-output analysis of water usage for specific process and wastewater generated from the production process.

Table 4.20: Water flow in the different production process unit on monthly basis

Process	Roller cleaning	Washing	Domestic
Input flow (m^3)	38	2,092	756
Output flow (m^3)		2,886	

In addition, solid waste generated from overall production activities was identified to be the waste papers, includes trimmed papers and off spec 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 are estimated to be 3,116 kg/month. The detail of Cleaner Production audit findings is attached in Appendix C.

4.6.3.4 Quantification of Carbon Dioxide Emission

Total CO_2e emission is approximately 245 tons on a monthly basis, resulting in 2,940 tons per annum or can be presented as 0.8 kg CO_2e/kg of paper processed as summarized in Table 4.21. Figure 4.12 illustrates the sources of CO_2e emission and their respective emission percentage. Electricity consumption is the major contributor of CO_2e emission, which constituting about 85% of total percentage, with quantitative values of 209 tons CO_2e/kWh in a monthly basis or 0.7 kg CO_2e/kg of paper processed.

Table 4.21: Quantification of carbon dioxide emission

Entities	CO_2e emission (kg/month)	kg CO_2e/kg of paper processed
2,886 m^3 of water	2.3	0.007
312,226 kWh of electricity	209	0.7
6,000 kg of solid waste	22	0.07
3,000 kg of schedule waste	11	0.04
2,886 m^3 of waste water	0.3	0.001
Total	244.6	0.8

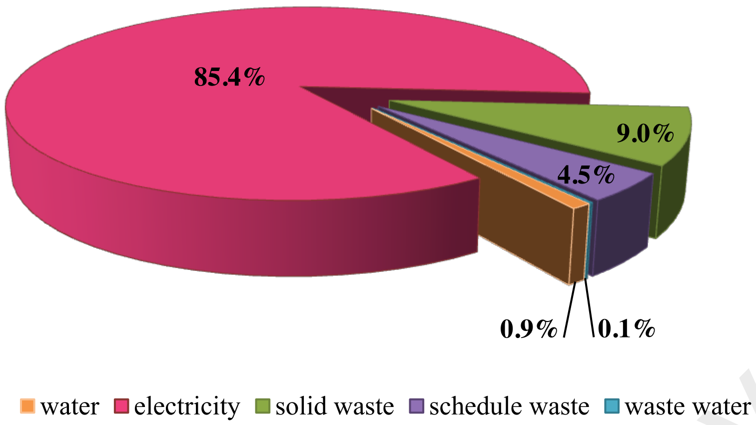

Figure 4.12: Breakdown of CO_2e emission according to sources

4.6.3.5 Evaluation of Cleaner Production Options

Cleaner Production options suggested focuses on the 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_2e emission a month, which is equivalent to a cost reduction of 244 USD/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 8000 kWh/month and CO_2e emission by 5 tons. The premise can potentially save 880 USD a month by implementing the option.

In addition, the company should install 22 watt-T5 fluorescent lamp, where a unit of T5 consumes only 9300 kWh of electricity a month, thus reducing 42% of electricity consumption as compared to the existing lighting system. CO_2e emission can be reduced by 4.6 tons and cost reduction of 755 USD a month.

As for the ventilation requirements, it is recommended that the company should ensure correct 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 20°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 16,571 USD as well as reductions of 101 tons of CO_2e 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 7,397 USD. Thus, reduction in CO_2e emission can be achieved by 45 tons/month.

Furthermore, installation of an inverter unit of the motorized equipment could reduce the energy consumed by 70%, or can be translated into 58,366 kWh monthly, resulting in the monthly estimated reduction of CO_2e emission of 39 tons. In addition to cleaner production 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_2e emitted, with the monetary savings of 3,209 USD. 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.

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 9,300 USD a month for a 50% reduction of waste paper. Hence, CO_2e 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. Table 4.22 summarizes the CP options with their corresponding outcomes on CO_2e emission reduction and monthly savings.

Table 4.22: Summary of economic and environmental evaluation of recommended cleaner production options

Area	CP options	Estimated investment costs (USD)	Estimated monthly savings (USD)	Estimated CO_2e emission reduction (ton)	Payback period (Month)
Air conditioning	1. Increase temperature from 16°C to 20°C.	0	16,571.00	101	Immediate
	2. Installation of energy saving air conditioner (15 unit).	9,166.00	7,397.00	45	1.2
Machineries	1. Installation of inverter unit of motorized equipment.	4,167.00	6,420.00	39	1
	2. Turn off air compressor during one-hour rest time.	0	3,209.00	20	Immediate
Lightings	1. Turn off lights during one-hour rest time.	0	244.00	1.5	Immediate
	2. Installation of clear glass window at the operation areas (20 unit).	5,250	880.00	5	6
	3. Installation of 22 watt-T5 fluorescent lamp.	3,500.00	755.00	4.6	4.5
Solid waste	1. Optimizing the size of papers for printed media.	0	9,300.00	13	Immediate

4.6.3.6 Summary of Case Study III

From the study conducted on the premise, it shows that the premise is faced with the issue of high electricity consumption. The total CO_2e emission of the premise is estimated at 245 tons of CO_2e/month, which produced 0.8 kg CO_2e/kg of paper processed. It is found that energy consumption, which contribute to the high percentage of CO_2e emission consist 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 35,476 USD and reduction in the generation of CO_2e emission by 216 tons of CO_2e a month. Meanwhile, even though the premise generated 6 tons of paper waste as a result of its printing activities, the amount of waste paper 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 9,300 USD a month could be achieved by implementing suggested option. Implementation of proposed CP options is expected to reduce 229 tons/month of CO_2e emission, with cost savings of 44,776 USD. Based on the findings, it shows that CP concept can be applied in the printing industry to identify the options that can be implemented to reduce the CO_2e emission as a result of the printing activities.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objectives defined in this work are successfully achieved as follows:

<u>Objective 1:</u>

The objective is to develop a new standard methodology in implementing cleaner production strategy for SMIs, proposed as Cleaner Production Implementation Methodology for SMIs (CPIM).

The methodology consisted of three main tools, which are Cleaner Production Audit, Cleaner Production Option Generation and Cleaner Production Option Evaluation. The Cleaner Production Audit tool consisted a checklist that will assist CP Auditor to quantify seventeen components of carbon dioxide emission contributors, which are water, electricity and fuel consumption, together with solid waste and wastewater generation. The components were then analyzed and key contributors for carbon dioxide emission generation were identified. Subsequently, the Cleaner Production Option Generation tool consisted a methodology that will assist CP Auditor to generate CP options with the guidance of investigative questions, which was developed based on seventeen CP audit components. CP options were then generated based on the modification of process and design, substitution of materials, adoption of new technology, housekeeping, training to workers, and reuse & recycling. Finally the third tool, Cleaner Production Option Evaluation tool consisted of a checklist that will assist CP Auditor to evaluate CP options in term of economic and environmental returns. Economic evaluation consisted list of components used to estimate payback period, which are items of investment costs, additional costs and expected savings. Whereas, environmental evaluation estimated carbon dioxide emission quantitatively.

Objective 2

The methods developed in objective 1 was then validated using three case studies, namely printing, beverage and plastic resin manufacturing premises.

For printing premise, the findings from CP audit tool reveals that the major sources of carbon emission is the electricity usage, mainly from the use of air conditioning, machineries and lightings. Subsequently, eight main CP options were generated, which resulted in 90% reduction in carbon emission, with a maximum payback period of 8 months. Similarly for beverage and plastic resin production premise, the issues identified are high electricity usage. Six and four CP options are generated for beverage and plastic resin production premise, respectively, with reduction of 19% and 13% and payback period of 6 years and 8 months.

In summary, with the assistance of CP audit tool, the overall audit processes were implemented with less resources and time. Furthermore, carbon dioxide emission generated from production activities in the premises were estimated by using IPCC simplified formula with defined boundary. Thus, key issues for each premise were identified. Subsequently, high electricity consumption was the key issue for the three case studied premises. CP options are generated by answering to the investigative questions listed in the CP options generation tool. Options generated were focusing on the strategies to overcome key issues in the premises. CP options generated vary from simple options such as housekeeping, to the modification of design and process.

5.2 Recommendation for future work

Based on the findings of this work, there are a few recommendations for future work to enrich the pool of knowledge for this area. First of all, more case studies are recommended for the use of proposed protocol to evaluate the effectiveness and further improvement.

1. Detailed life cycle assessment can be conducted to estimate total carbon emission generated from the overall manufacturing processes and activities.
2. New methodology for cleaner production implementation strategy can be developed for other sectors, including service sector such as hotels and medical centres.
3. An industry specific of CP audit tool can be designed and developed to investigate the impact of the tool to the implementation of CP audit activities in specific premise.
4. As for manufacturing industry, more study can also be conducted in the future, which focuses on other types of footprint such as water footprint and material footprint.
5. Finally, there should also be more other method of evaluating economic return in CP option evaluation tool, such as return on investment. Furthermore, environmental evaluation can also be enhanced by adopting methods to quantitatively estimates reduction in waste toxicity and risk to workers.

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LIST OF PUBLICATIONS AND PAPER PRESENTED

Published articles

1. Rahim, R., & Raman, A. A. A. (2015). Cleaner production implementation in a fruit juice production plant. *Journal of Cleaner Production*, *101*, 215–221 (IF: 4.959)
2. Rahim, R., & Raman, A. A. A. (2017). Carbon dioxide emission reduction through cleaner production strategies in a recycled plastic resins producing plant. *Journal of Cleaner Production*, *141*, 1067–1073 (IF: 4.959)

Published books

1. Abdul Raman, A. A., Raja Ehsan Shah, R. S. S., Rahim, R., & Kai Shing, C. (2014). *Guidelines For Green Industry Auditor*. (R. Abdul Rahman, C. R. Ngah, & N. Baharom, Eds.) (1^{st}). Department of Environment Malaysia.
2. Abdul Raman, A. A., Raja Ehsan Shah, R. S. S., & Rahim, R. (2014). *Guidelines For Green Industry Implementation: Juice Manufacturing*. (R. Abdul Rahman, A. A. Chik, & K. N. Samsuri, Eds.) (1^{st}). Department of Environment Malaysia.
3. Abdul Raman, A. A., Raja Ehsan Shah, R. S. S., & Rahim, R. (2014). *Guidelines For Green Industry Implementation: Printing Industry*. (R. Abdul Rahman, A. A. Chik, & K. N. Samsuri, Eds.) (1^{st}). Department of Environment Malaysia.
4. Abdul Latif, S., Abdul Raman, A. A., Raja Ehsan Shah, R. S. S., & Rahim, R. (2011). *Cleaner Production Tips For Small and Medium Industries*. (A. A. Abdul Aziz, Eds.) (1^{st}). Department of Environment Malaysia.

Submitted articles (under review)

1. Rahim, R., & Raman, A. A. A. A practical methodology of cleaner production auditing for Malaysian small and medium-sized manufacturing premises. *Journal of Cleaner Production*. (IF: 4.959) Submitted on 16th June 2016
2. Rahim, R., & Raman, A. A. A. Cleaner production options generation methodology for Malaysian small and medium-sized manufacturing premises. *Journal of Cleaner Production*. (IF: 4.959) Submitted on 5th October 2016
3. Raman, A. A. A., Rahim, R., Ramasamy, V. Implementation of cleaner production strategies in a palm oil processing plant. *Journal of Cleaner Production*. (IF: 4.959) Submitted on 30th January 2016
4. Rahman, R. A., Raman, A. A. A., Rahim, R., et al. Greening print media through cleaner production strategy: a case study. *Sains Malaysiana*. (IF: 0.446) Submitted on 21st June 2016