CLEANER PRODUCTION ASSESSMENT AND IMPROVEMENT STRATEGIES IN A TEXTILE INDUSTRY

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RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SAFETY, HEALTH AND ENVIRONMENTAL ENGINEERING

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ABSTRACT

This study was conducted in a textile manufacturing factory in order to evaluate the environmental and economic feasibility of Cleaner Production (CP) strategies. The aim of this study is to reduce the carbon footprint in the textile manufacturing processes. The quantification of the total resource consumption, energy consumption and waste generation and disposal was obtained through CP audit. The audit showed that the main contributors of CO_2 emission of the factory were electricity, water, fuel, chemical and raw material consumption as well as solid waste, scheduled waste and wastewater generation. The result from the audit showed that the CO_2 emission in this factory was 3,700 kgCO_2 per ton of fabric whereby it constitutes mainly of fuel and electricity with 57% and 41% respectively. From 24 CP options identified, 11 CP options were recommended based on their feasibility. Therefore, the CO_2 emission is expected to be reduced to 3,400 kgCO_2 per ton of fabric which is equivalent to 8% in reduction of CO_2 emission. The estimated investment cost required for the carbon footprint reduction was RM43,815 with a return on investment of 1.1 years. Thus, this shows that the CP strategies recommended is possible of reducing CO_2 emission in a textile manufacturing factory.

Keyword: Cleaner Production, Carbon dioxide emission, textile.

ABSTRAK

Kajian ini dijalankan di kilang pembuatan tekstil untuk menilai kebolehlaksanaan dari aspek alam sekitar dan ekonomi bagi strategi Pengeluaran Bersih (CP). Tujuan kajian ini adalah untuk mengurangkan jejak karbon dalam proses pembuatan tekstil. Kuantifikasi jumlah penggunaan sumber, penggunaan tenaga dan penjanaan dan pelupusan sisa diperoleh melalui audit CP. Pengauditan itu menunjukkan bahawa penyumbang utama pelepasan CO_2 di kilang adalah penggunaan elektrik, air, bahan api, bahan kimia dan bahan mentah serta sisa pepejal, sisa terjadual dan penjanaan air buangan. Hasil daripada audit menunjukkan bahawa pelepasan CO_2 di kilang ini adalah sebanyak 3,700 kgCO_2 per tan fabrik dimana ia terdiri daripada bahan api dan elektrik masing-masing sebanyak 57% dan 41%. Daripada 24 pilihan CP yang dikenal pasti, 11 pilihan CP dicadangkan berdasarkan kebolehlaksanaan mereka. Oleh itu, pelepasan CO_2 dijangka dapat dikurangkan kepada 3,400 kgCO_2 per tan fabrik yang sama dengan mana sama dengan 8% dalam pengurangan pelepasan CO_2. Anggaran kos pelaburan yang diperlukan untuk pengurangan jejak karbon adalah sebanyak RM43,815 dengan pulangan pelaburan sebanyak 1.1 tahun. Oleh sebab itu, ini menunjukkan bahawa strategi CP yang disyorkan dapat mengurangkan pelepasan CO_2 di dalam kilang pembuatan tekstil.

Kata kunci: Pengeluaran Bersih, Pelepasan karbon dioksida, tekstil.

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LIST OF SYMBOLS AND ABBREVIATIONS

e	:	Emission
ASEAN	:	Association of South East Asian Nations
BOD	:	Biological Oxygen Demand
Btu	:	British thermal unit
CEF	:	Carbon emission factor
CMOS	:	Complementary metal oxide semiconductor
COD	:	Chemical Oxygen Demand
CO_2	:	Carbon Dioxide
CP	:	Cleaner Production
CPVCM	:	Cleaner Production Virtual Centre Malaysia
CTES	:	Cleaner Technology Extension Services
CTIS	:	Cleaner Technology Information Service
DANCED	:	Danish Cooperation for Environment and Development
DOE	:	Department of Environment
e.g.	:	Exempli Gratia (For Example)
EoCM	:	Environmental Oriented Cost Management
GHG	:	Greenhouse Gases
H_2O_2	:	Hydrogen Peroxide
IPI	:	Industrial Production Index
IPCC	:	Intergovernmental Panel on Climate Change
ISO	:	International Standards Organization
Kg	:	Kilogram
kWh	:	Kilowatt Hour
L	:	Liter

LC_{50}	:	Lethal Concentration 50
M	:	Meter
m^3	:	Cubic meter
Mmbtu	:	One Million British Thermal Units
MATRADE	:	Malaysia External Trade Development Corporation
MJ	:	Mega Joule
MKMA	:	Malaysian Knitting Manufacturers Association
MIDA	:	Malaysian Investment Development Authority
MOSTI	:	Ministry of Science, Technology and Innovation
MP	:	Malaysia Plan
NaClO	:	Sodium Hypochlorite
$NaClO_2$	:	Sodium Chlorite
NaOH	:	Sodium Hydroxide
NO_x	:	Nitrogen oxide
OECD	:	Organisation for Economic Co-operation and Development
PM	:	particulate matter
ROI	:	Return on Investment
SIRIM	:	Standards and Industrial Research Institute of Malaysia
SMEs	:	Small and medium-sized enterprises
SO_2	:	Sulphur dioxide
TAPC	:	Textile and Apparel Production Chain
TNB	:	Tenaga Nasional Berhad
TSS	:	Total suspended solid
UNEP	:	United Nation Environment Programme
UNIDO	:	United Nations Industrial Development Organization
UNWATER	:	United Nations-Water

US	:	United States
US EIA	:	United States Energy Information Administration
W	:	Watt
WTO	:	World Trade Organisation
WWTP	:	Wastewater Treatment Plant

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Research Background

The rapid industrialization as well as the increasing number of global population each year has affected the availability of the natural resources in the world these days. Textile industry is known as one of the field sectors for the economic development of countries worldwide (de Souza, Melo, Pessoa, & Ulson, 2010) and it is estimated that over 150 countries are supplying textiles (World Trade Organization (WTO), 2007). The manufacturing activities of the textile industry in a Malaysian textile and apparel production chain (TAPC) include fiber manufacturing, wet processing, spinning, weaving, knitting and garment manufacturing. The textile industry involves various complex production processes that demands high consumption of resources such as water, energy and etc. (A Merve Kocabas, Yukseler, Dilek, & Yetis, 2009).

Among the resources used, one of the most important components of textile production processes is water (GilPavas, Dobrosz-Gómez, & Gómez-García, 2017). Textile industry is identified as one of the trades which have high water consumption and pollution internationally. This is because, large quantities of water are consumed and also large volumes of effluents are discharged by the processes (i.e. scouring, washing, dyeing, bleaching, sizing and finishing) that consist of intense colour, with high organic compound concentration and different composition (Takahashi & Kumagai, 2006). Furthermore, textile industry has caused a high tension on the global water resource (Saxena, Raja, & Arputharaj, 2017).

Malaysia's textile industry has been continuously growing despite the competition with other larger textile producing countries such as China and India. In 2017, the industry was ranked 11th Malaysia's largest export earner and makes up approximately RM15.3 billion or 1.6% share of export of manufactured goods (Malaysian Investment

Development Authority (MIDA), 2018). This shows that Malaysia's textile industry is growing its market not only domestically but also internationally. The global production of textile would cause an increment in electricity consumption. This is due to the usage of the modernized machineries and continuous equipment usage in uneconomical operating practices (Wang, Li, & He, 2017). The energy cost is estimated around 15%-20% greater than the production cost (Khude, 2017).

In order to find a healthy balance between the economic and environmental aspects of the textile production, pollution prevention needs to be implemented which is known as cleaner production. It is a technique intended for resources conservation, environmental risk mitigation, and to encourage greater overall efficiency through improved production techniques (Guha, 2018). It is also a well-known technique that embraces the 'cradle-to-grave' concept. Cleaner production (CP) is of a great relevance nowadays especially due to threatening industrial pollution levels, global natural resources shortage and the requirements of standardization of corporate environmental performance being more stringent (Matos et al., 2018).

1.2 Problem Statement

The textile industry was chosen as it represents one of the largest industrial water consuming sectors. An average sized textile factory that produces 8,000 kg of fabric/day has a daily water consumption of 1.6 million liters (Kant, 2012). The environmental issues caused by textile industry have worsened. This is proven as the global textiles and clothing industry was accountable for the consumption of 779 billion m^3 of water, 1,715 million tons of CO_2 emission and 92 million tons of waste (Kerr & Landry, 2017). Changes need to be implemented to help reduce the pollution that is happening.

The textile industry comprises of various sub-sectors in its operations. However, the most concerning processes are in the textile wet processing mills as over 80% of the industrial wastewater is being discharged (Lu, Liu, Liu, & Chen, 2010). Major environmental consequences are expected in the receiving waters if the textile effluents are poorly treated (Reddy, Chen, Zhang, & Yang, 2014). This will cause adverse effects to the human health as well as the aquatic and terrestrial ecosystem (Chequer et al., 2013).

High water consumption does not cause adverse effects to the water resources alone. For example dyeing and finishing requires extra energy in order to heat up larger water volumes to the dyeing temperature which leads to the higher energy cost needed (Hasanbeigi, 2010). It was also added that other factors of textile mills' pollution comes from the production processes that has high thermal energy requirement and demanding chemical usage that generate gaseous emissions and also solid wastes (Hasanbeigi, Hasanabadi, & Abdorrazaghi, 2012).

Increasing costs affects the business as well as the environment causing the industries to search for eco-friendly alternative in order to sustain their businesses. This is because the pollution control approach that is implemented in the industries involves high operational and investment costs which is inadequate in preventing environmental pollution (Toprak & Anis, 2017). Therefore, shifting toward pollution prevention technique in the textile industry which implies the cradle-to-grave concept is the preferred alternative. It is able to help to reduce conservation cost and environmental care, allowing the resource usage to be more efficient, encourage environmental friendly practices and lessen the material wastage (Yusup, Mahmood, Salleh, & Muhamad, 2014).

1.3 Research Questions

Research questions that arise from this problem statement are as follow:

1) What are the sources of CO_2 emission sources present in the factory?
2) What is the estimated carbon footprint generation per ton of fabric?

3) What are the CP strategies available to reduce carbon dioxide emission in the factory?
4) Are the suggested CP strategies environmentally and economically feasible?

1.4 Aim of the Research

This study aims to determine the most feasible CP options to reduce the carbon footprint at the selected textile manufacturing factory.

1.5 Research Objectives

To achieve the aim of the research, the following objectives are defined:

1. To determine the current state of the textile manufacturing factory through CP audit.
2. To estimate the carbon footprint generated per ton of fabric in the textile factory.
3. To generate and evaluate CP options for the industry.

1.6 Scope of the Study

The overall research covers the CP assessment conducted at a selected textile mill factory which is Powernet Industries Sdn. Bhd., located in Bentong, Pahang. The entire processes from receiving raw materials to dispatching the finished product were covered in this assessment. All resource flows of chemical, water, raw materials and energy consumption are studied in this assessment in order to make recommendations for optimization. The research boundary was set within the premise whereby the textile manufacturing processes and production is carried out.

1.7 Report Framework

The main features of the report are outlined below:

Chapter 1 covers the introduction and background of the research and contains the research problems, aim, objectives and scope of the research.

Chapter 2 describes the literature review of the textile industry issues in contribution towards water scarcity and pollution as well as the greenhouse gases (GHG) emission which leads to global warming. The implementation of cleaner production in Malaysia and other countries is also reviewed. Besides that, CP as a technique to overcome the worsening condition of the environment and improves the business sector is discussed and the involvement of the textile mill factory in cleaner production is also highlighted in this chapter.

Chapter 3 explains the methodologies in this research that ruminates about the CP strategies to reduce waste generation and CO_2 emission. The methods consist of data collection from the company's inventory, interviews and observation, conduct a detailed audit, problem source identification, analysis of data, generation of waste and CO_2 emission and lastly present the most feasible option based on financial analysis consideration.

Chapter 4 discusses the results and findings from the detailed audit before and after implementing the CP strategies. The potential good practices with minimal cost implications are suggested.

Chapter 5 concludes the research findings and recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Textile Industry

Textile industry has been well known for so long. Textile industry is widely recognized as one of the longest and most complex industries among the entire manufacturing industries (European Commission, 2005). Furthermore, textile is a dominant industry which fulfills the demand of consumers focusing on three main end-uses: garments, furniture and commercial use whereby the process chain and types differ based on the sought after final product.

The textile industry involves the manufacturing of natural and man-made fibers and fiber-based textile products whereby their production and consumption have increased in the latter years due to the emerging markets' population growth, increasing life standards, textile-based products increment as well as amount of their consumption and the age structure in the developing countries (Sema Palamutcu & Goren, 2015).

It was reported that there was an increase in percentage of the current dollar value of the world textiles exports for the year 2017 by 4.2% which sums up to $296.1 billion (World Trade Organisation, 2018). China dominates the chart of being No. 1 of the world's textile exporters in 2017, followed by the European Union and India respectively. These three powerhouses constitute 66.3% of the world textile exports in 2017 with an increment by 0.4% compared to 2016. It can be seen from the literature above that textile industry continues to be a relevant industry due to the increasing demand in the production of textile with continuous increment of world textile export each year.

2.2 Textile Industry in Malaysia

The history of the textile and apparel industry in Malaysia began in the early 1970's, after Malaysia embarked on export oriented industrialisation which has led to the growth of the industry (Malaysia External Trade Development Corporation (MATRADE), 2013).

It was reported that currently over 68,000 workers are employed across more than 970 registered garment and textile factories in the country whereby over 400 encompasses the manufacture of made-up garments, and the remaining are operating in major sub-sectors including polymerisation, spinning, weaving, knitting and wet processing, and textile accessories (Bizvibe, 2019).

As of 2015, it was reported that Turkey, Japan, China and Unites States are the top four destinations for Malaysian Export of Textiles and Apparel to the World (Malaysian Knitting Manufacturers Association (MKMA), 2019). US remains as the largest export market for Malaysian textiles products, accounting for over 17% of the industry's total textile and apparel exports every year. Malaysia's industrial production index has increased by 3.2% in January 2019, whereby in the textile, wearing apparel, leather and footwear sector the production has increased to 5.4% as compared to 4.2% in December 2018 (Department of Statistics Malaysia, 2019),. This has shown that the textile industry is currently on a steady rise and continuing to grow at a consistent pace.

It was reported that investments worth a total of RM428.8 million were approved in 2017 for 12 projects related to textiles and textile products industry, whereby it was led by foreign investors securing RM322.3 million (75.2%) (MIDA, 2018). Domestic investments, on the other hand, constituted the remaining 24.8% with RM106.5 million as seen in Figure 2.1. This shows that the Malaysian Textiles and Apparel Industry continue to expand and grow over the years. Approved investments were mainly concentrated in the production of primary textiles with eight projects worth RM389.9 million, while three projects approved (RM33.8 million) were for the production of ready-to-wear garments and lastly, one project valued at RM5.1 million was approved in the textile accessories sub-sector. Figure 2.2 below shows the Malaysian textile and apparel exports from 2008-2018. In conclusion, statistics from different agencies have shown that there is a positive relationship between the production of textile in Malaysia with the current economic status, both domestically and internationally.

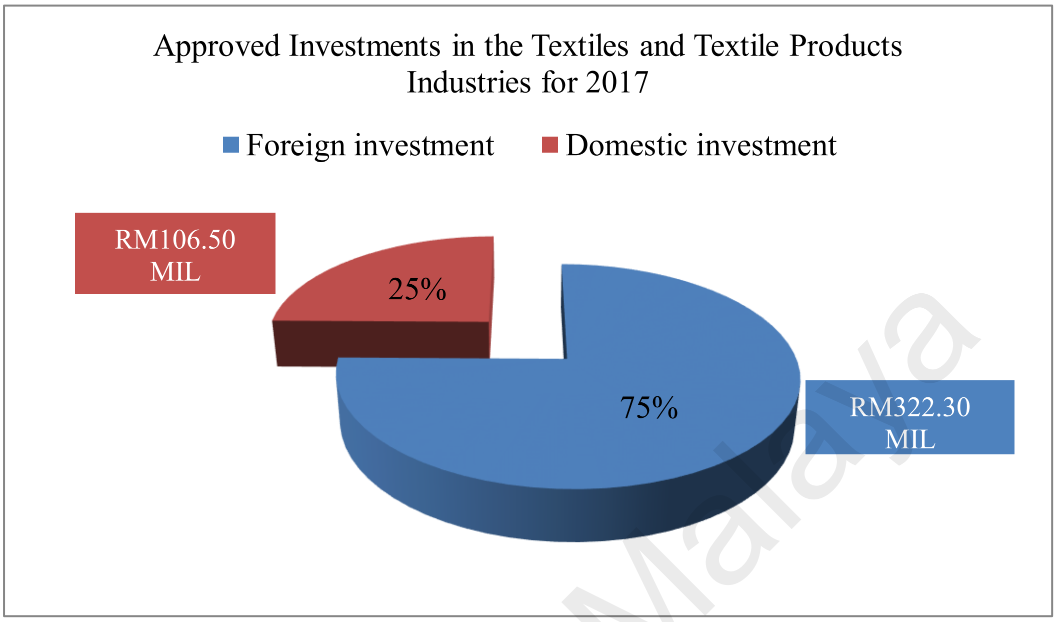
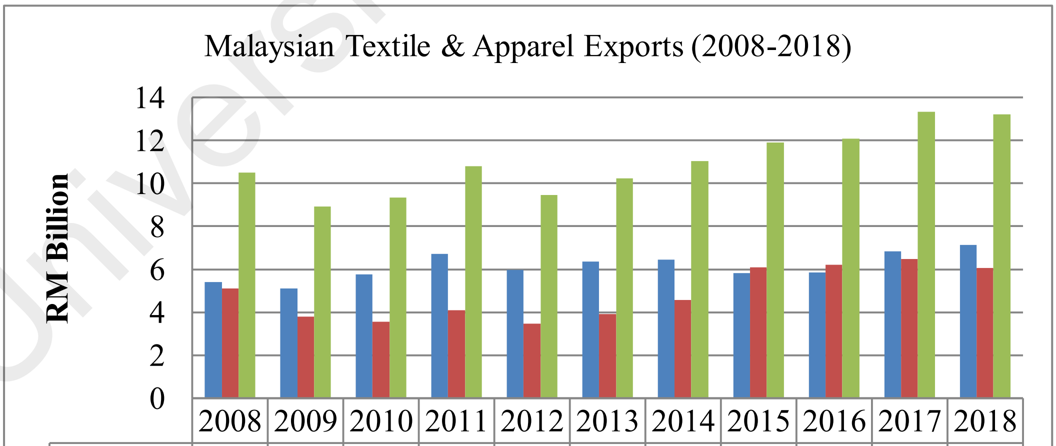


Figure 2.1: Approved Investments in the Textiles and Textile Products Industries for 2017

(Department of Statistics, 2018)



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Textile	5.4	5.1	5.76	6.72	5.98	6.35	6.46	5.82	5.85	6.85	7.14
Apparel	5.1	3.8	3.57	4.09	3.48	3.91	4.57	6.08	6.22	6.48	6.07
Total	10.5	8.93	9.33	10.81	9.46	10.25	11.03	11.9	12.07	13.33	13.21

Figure 2.2: Malaysian textile and apparel exports from 2008-2018.

(Department of Statistics, 2018)

2.3 Textile Manufacturing Processes

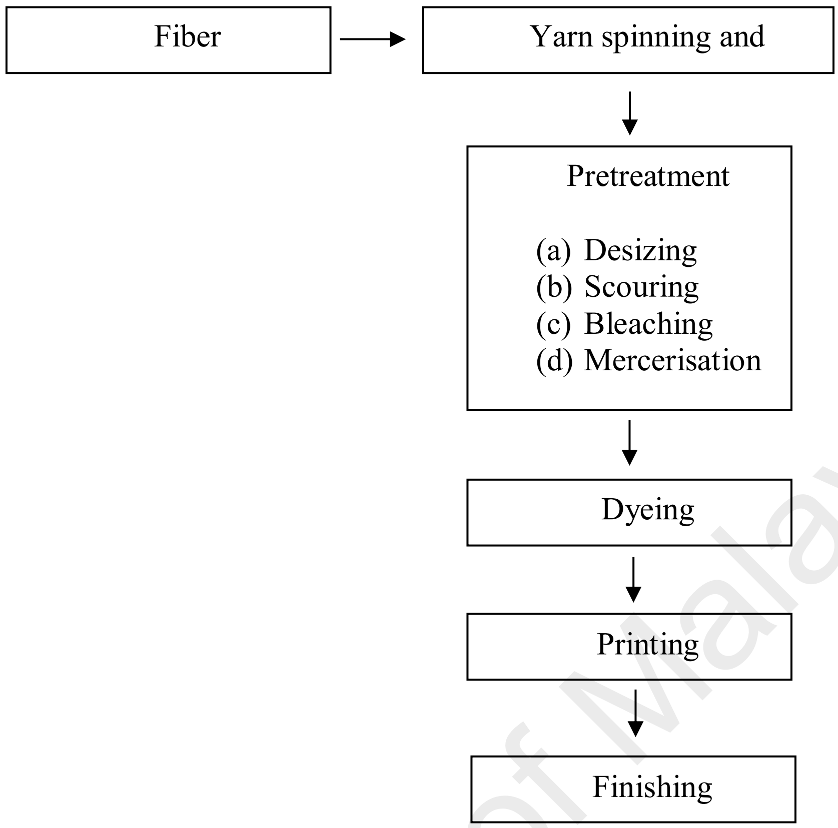


Figure 2.3: General production path line of a textile manufacturing industry

The textile manufacturing process is divided into several main substages which comprise of fiber manufacturing, spinning, weaving, and wet processing of clothing or any other consumer-oriented and product-associated textile manufacturing stages. Figure 2.3 above shows the main processes in the textile industry. Natural fibers and man-made fibers are the two main categories of textile fiber types in which natural fibers mostly cotton consumes high water volume, pesticides, insecticides and artificial fertilizers throughout the cultivation process. Man-made fibers on the hand, consume relatively higher amount of energy and also release toxic by-products in certain stages of manufacturing (Pang & Abdullah, 2013).

These are the description of each stage of the textile manufacturing processes involved (Table 2.1).

Table 2.1: Stages of a typical textile manufacturing process

Process	Function
Fiber manufacturing	Fibers that have been harvested and processed are analyzed to determine whether they are suitable for yarn manufacturing, which are then separated.
Yarn spinning	Converts raw fiber into yarn or thread. The fibers are prepared and then drawn out and twisted to form the yarn. Afterwards, it is wind onto a bobbin or cone.
Weaving	The process is carried out on a loom (of varieties) which interlaces lengthwise yarns (warp yarns) with width wise ones either weft or filling yarns.
Desizing	To remove the sizing materials with the help of enzymes.
Scouring	To remove the impurities, both natural such as waxes, pectin and fat and acquired such as size, dirt and oil picked up during processing that does not adsorb water onto the fibers. This would result in difficulty during the wet processing operations. Thus, it is carried to make the textile material more hydrophilic or water absorbent. It's done with or without chemicals, at room temperature or at suitable higher temperatures, with the addition of correct wetting agents, alkali and etc.
Bleaching	Process of removing undesired color on the fabric using oxidizing agents such as hydrogen peroxide (H_2O_2), sodium chlorite ($NaClO_2$) and sodium hypochlorite ($NaClO$) in the bleach bath.
Mercerization	Process that treats cotton yarn or fabric with caustic soda (sodium hydroxide [NaOH]) to improve lustre, strength and affinity for dye as well as removing immature fibers.
Dyeing	It is a textile material colouring technique whereby the dye is applied onto the substrate in a standardized order to get a constant shade.
Printing	Process used to apply colour to a fabric. It is typically done on prepared fabric where it is applied to specific areas to achieve a planned design whereby the colour is applied to the fabric and then treated with steam, heat or chemicals to fix the colour on the fabric.

Table 2.1, continued

Finishing	Done to gain the final and demanded aesthetic, chemical and mechanical properties to the fabric as per the end use requirements through finishing processes such as: 1. Wrinkle Resistant/Crease Retentive 2. Water/Oil Repellent 3. Flame Retardant 4. Mildew Resistance

(Kocabas, 2008; Lebanese Cleaner Production Centre, 2010)

2.4 Environmental Issues in Textile Industries

China, India, Pakistan, Turkey, Egypt and Bangladesh are amongst the top countries of the textile industries which are contributing towards the global cloth production. With the mass production of textile every day worldwide, it may result in various environmental impacts. One of the main environmental impacts of the textile industry is the high amounts of chemical loads that are discharged into the receiving environment (Guha, 2018). Other important issues are high chemical and water use, consumption of energy, air emissions, solid wastes and odour formation, which may be a significant disturbance in certain processes (AYSE MERVE Kocabas, 2008)

Approximately 90% of the textile industry's total dyes end up in the fabrics as a result of the excess total dye utilization of 10^7 kg/year. As a result, 10^6 kg/year of dyes are released into the waste streams (Choy, McKay, & Porter, 1999). In addition, 280,000 tons of textile dyes is estimated to be discharged as industrial effluents each year throughout the globe (Maas & Chaudhari, 2005). This leads to wastage of the resources used in the textile industry which can actually be minimized.

It was reported that, annually, an estimated 700,000-1,000,000 tons of dyes are produced worldwide as there are more than 100,000 types of commercial dyes in the market (Gupta, 2009). The vast quantity of textile fibers produced by Malaysian textile industry may pose adverse effects to the environmental quality mainly involving the liquid effluent discharged. In Malaysia, 22% from the total volume of industrial wastewater is contributed by the textile finishing wastewater (Rakmi, 1993). All of the findings from these studies confirms that there is a high possibility of environmental issues occurring in textile industries due to the nature of processes involved.

2.4.1 Water Consumption in Textile Industry

In the textile industry, the textile wet processes use the highest water volume. European Commission stated that intensive amounts of water are required in various types of wet processes involved in each sub-sector of the textile industry which mainly involves the manufacturing of yarn, dyeing, printing, scouring and finishing processes (European Commission, 2005). This is because, in the textile wet processes detergents, dyes, auxiliaries and finishing agents are applied in order to create the finished product (Alkaya, Böğürcü, Ulutaş, & Demirer, 2011). In fact, Organization for Economic Co-operation and Development (OECD) added that the process complexity, type of machinery, product weight, dyestuff, washing and rinsing procedures also influence the water consumption. Hence, water plays a fundamental role at nearly every manufacturing operation despite the form of the textiles' final use.

It was found that primary water consumption was textile industry's major impact on the environment with 80-100 m^3 per ton of completed textile used and wastewater discharge with 115-175 kg of COD per tons of completed textile (Rosi, Casarci, Mattioli, & De Florio, 2007). This is also supported with the findings by other researchers regarding the high water consumption in textile industry as the total water consumption can reach up to 3000 m^3/day (Arslan-Alaton & Alaton, 2007). On the other hand, it was reported that the water consumptions based on the textile processing categories in California are relatively high which varies significantly between the minimum and maximum consumption as seen on Table 2.2 (Gleick et al., 2003). The results from the researches done has shown that high water consumption is used, mainly in the textile wet processes in order to produce a completed textile.

Table 2.2: Specific water consumption by processing category in textile industry in California

Processing category	Minimum (L/kg)	Max (L/kg)
Wool	110.8	657.5
Woven	5	507.5
Knit	20	376.7
Carpet	8.3	162.5
Stock/yarn	3.3	557.5
Non-woven	3.3	82.5
Felted fabrics	33.3	931.2

(Gleick et al., 2003)

2.4.2 Energy consumption in Textile Industry

Energy plays a dominant role as one of the cost factors in the textile industry, particularly during high energy price volatility. However, generally it is not considered as an energy-intensive industry in comparison to other industries. But, a research stated that textile industry consumes a significant amount of energy as it comprises multiple number of plants altogether (Hasanbeigi & Price, 2012).

Textile industry consumes a significant amount of electric energy as well as fuel-based heat energy. Types of energy used and its intensity vary in each process. To be more specific, the structure of the textile industry in a certain country influences the share of electricity and fuels within the total final energy use of the textile sector of that country (Hasanbeigi, 2010). In addition, it was also found that the total electric and thermal energy requirements are 18.8-23 MJ and 0.45-0.55 kWh per meter of fabric (Clark, 2007).

The electric energy-intensive production processes are twisting, knitting, spinning, texturing, weaving and clothing processes whereas the processes that consume high fuel-based heat energy are man-made fiber production and dyeing (wet processing) stages

(Sharma, 2005). Figure 2.4 shows the energy types and their consumption in textile processing stages.

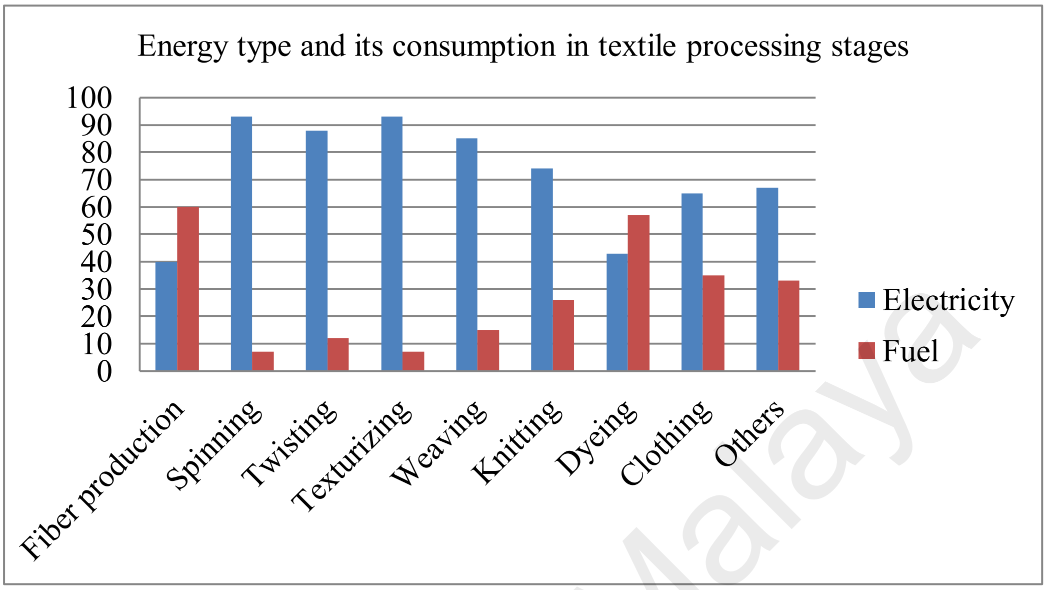


Figure 2.4: Energy type and its consumption in textile processing stages

(Sharma, 2005)

Several studies below highlighted the issue of energy consumption inefficiency in the textile industry. A study conducted by a researcher found out that there is inefficient energy consumption happening in Turkey which is contributed by various reasons (Ozturk, 2005). Among the causes is the high requirement for hot water and steam in their manufacturing processes, improper installations of the pipelines and equipments which results in steam and hot water lost through leakages and energy loss from the pipelines and machinery due to lack of insulation. He further added that there is a swift energy consumption increase in the industries and the severity of the effects it may cause on the Turkish economy. One of the major sources of waste of end-use energy waster is contributed by the high usage of motor driven systems in the textile industry (United States Department of Energy (U.S. DOE), 2005).

The cost of energy consumption is consistently rising. Research findings found that energy cost is often ranked third or fourth highest share of total product cost, following raw material, capital and waste (Koç & Kaplan, 2007). Table 2.3 below shows the energy cost factors for 20 Tex[3] combed cotton yarn in several countries for 2003 (Koç & Kaplan, 2007). The result shown is quite consistent with another researcher as he stated that the energy costs of both electricity and heat contributes 8-10% of total production cost (S Palamutcu, 2010). It can be concluded from the literature above that electric energy and heat energy both are extensively used in different processes required in the textile industry and with energy consumption inefficiency in the operations, it further increases the consumption and eventually the cost spent on energy.

Table 2.3: Energy cost factors for 20 Tex[3] combed cotton yarn in several countries

Cost factor	China	India	USA	Turkey	Korea	Brazil	Italy
Energy	8%	12%	6%	9%	6%	5%	10%

(Koç & Kaplan, 2007)

2.4.3 Chemical Usage in the Textile Industry

Various chemicals are predominantly used in the manufacturing processes of the textile industry. It is estimated that around 2,000 types of chemicals are used consisting of dyes, acids, alkalis, detergents and others (Shenai, 2001). This is highly concerned as it is approximated that 90% of the textile industry's total dyes end up in the fabrics as a result of the excess total dye utilization of 10^7 kg/year. As a result, 10^6 kg/year of dyes are then released into the waste streams (Choy et al., 1999). Globally, 280,000 tons of textile dyes is estimated to be discharged as industrial effluents each year to make matters worse (Maas & Chaudhari, 2005).

In Malaysia, 22% from the total volume of industrial wastewater is contributed by the textile finishing wastewater (Rakmi, 1993). If the textile effluent is incompletely treated, the presence of azo- and nitro-compounds in the structure of organic dyes has the possibility to generate aromatic amines (Haroun & Idris, 2009). This is dreadful as aromatic amines are capable of inducing cancer and tumors in the human body.

Another study in the textile industry was done where they investigated the toxicity of textile effluents at different stages of fiber processing of five companies in Puebla, Mexico (Villegas-Navarro, Ramírez-M, Salvador-SB, & Gallardo, 2001). The toxicity of the textile effluents was measured using Daphnia magna neonates for 24-48 hours exposure time. The results showed that all the wastewater samples were toxic in lethal concentration (LC_{50}) and have very high toxicity with acute toxicity unit level between 2.2 and 960. Contaminants that are present in the wastewater may cause adverse and synergetic toxicological effects to the marine life and human health (Verma, 2008). The results of these studies done shows that various types of chemicals are widely used in the production of textile and they usually end up in the surrounding waters as the textile effluents are poorly treated. In the end, this toxic chemical accumulation may lead to harmful effects to human, animals as well as to the environment.

2.5 Cleaner Production

CP was defined by United Nation Environment Programme (UNEP) in 1990 as *"The continuous application of an integrated environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment"*.. CP deals more with the source of problems rather than analysing the effects and consequences (Adrianto, 2011). It is an integral and highly necessary component in order to achieve sustainable development. The term CP can be exchangeable with the terms Cleaner Technology, Waste Minimization and Pollution Prevention (Cleaner Production Virtual Centre Malaysia (CPVCM), 2018). The effective implementation of CP practices is attainable either through any single or combination of these five general principles which are material substitution, good housekeeping and operating procedures, technology changes and optimization, on-site recycling and redesign of product or service (Nilsson, 2007; United Nations Industrial Development Organization (UNIDO), 2002).

It is best to adopt pollution prevention whereby the pollution and risks to human health and safety are reduced at source, rather than pollution control or “end-of-pipe” which is implemented at the end of the production process. UNIDO (2002) stated that the key focus in successfully implementing CP are elimination and reduction of waste, non-polluting and energy efficient production, a safe and healthy work environment and also environmentally sound products.

An optimal economic growth is achievable by the company by reducing the environmental impacts as well as the consumption of resources and optimizing their management particularly in a sustainable manufacturing environment (Huang, Luo, & Xia, 2013). Furthermore, CP is known as one of the most cost effective approaches as crucial consideration in improving the efficiency of energy utilization is taken into consideration in evaluating the link between economic growth and environmental degradation (UNIDO, 2014). (Bunse, Vodicka, Schönsleben, Brülhart, & Ernst, 2011) also added that other factors influencing manufacturers to attempt to be energy efficient is because of global warming, energy price increment and customers’ rising ecological awareness over time. Overall, CP has gradually received acceptance by companies because of the positive impacts it brings not only to the productivity of the companies, but also the economic and environmental impacts CP brings.

2.6 Cleaner Production Strategy Implementation in Malaysia

Cleaner Technology in Malaysia was first introduced back in January 1996 through projects under the Danish Cooperation for Environment and Development (DANCED) which involved a technical cooperation programme between the Malaysian and Danish government (CPVCM, 2018). The projects were implemented by the Standards and

Industrial Research Institute of Malaysia (SIRIM) under the Ministry of Science, Technology and Innovation (MOSTI) whereby its' purpose was to promote Cleaner Technology various activities such as environmental and energy audits, demonstration sites and the dissemination of information through two types of services which are Cleaner Technology Extension Services (CTES) and the Cleaner Technology Information Service (CTIS).

Rapid industrialization happening in Malaysia requires a National Cleaner Production Blueprint to be introduced to ensure its sustainability. Therefore, a Cleaner Production blueprint for Malaysia was published in 2007 by the Department of Environment (DOE) with the rationale that it acts as an effective management tool for environmental conservation, improvement of productivity enhancement and as well as profitability. In order to further strengthen the implementation of CP in the Malaysian industries, several other guidelines were published which are the Cleaner Production Audit Guidelines in 2007 and Guidelines for Green Industry Auditors in 2014.

Manufacturing industry is one of the most important contributors towards the Malaysian economy. This is proven as Malaysia's manufacturing sales grew 7.0% in January 2019 which contributed RM72.5 billion (Department of Statistics Malaysia, 2019). Textile, wearing apparel, leather and footwear sector has increased its sales value to 5.6% for January 2019 as compared to the previous month with 2.6%. Malaysia is the third largest energy consumer in the ASEAN region after Singapore and Brunei and its final energy consumption per capita is 1.701 MTOE/Millions for 2015 (International Energy Agency (IEA), 2017).

Previously, the Tenth Malaysia Plan (10th MP) 2011-2015 highlighted on green technology that is in the National Green Technology Policy and new renewable energy act and feed-in tariff mechanism. Malaysia is currently planning to develop and formulate an Energy Policy for Malaysia (2013 - 2050) that covers all relevant sectors and also including current issues and future challenges related to energy (Tasrip, Husin, & Alrazi, 2016). With the rapid industrialization happening in the industrial sector, the government has introduced CP through the programmes done as well as blueprints and guidelines published by respective departments. Industries in Malaysia need to start realizing the importance and benefits of CP implementation to further improve on their sustainability.

2.7 Case Studies of Cleaner Production Practices in Textile Industries

Other countries also show strong interest in cleaner production and the implementation has brought great improvement to the companies involved. The case studies below show the success of participating in CP that has created a more sustainable manufacturing process and products in the textile industry.

2.7.1 Case Study in Romania

A study conducted by Dumitrescu, Mocioiu, and Visileanu (2008) reported that Novatextile Pitesti, Romania adopted clean technology methods in their cotton fibre pre-treating-dyeing operation which resulted in reduction of the chemical auxiliaries used (73%), effluent costs (50%), carbon dioxide emission by 2500 times/year, saving clean water (50%), electric energy (35.6%) and thermal energy (45.8%) consumption. In addition, CP has also led them to be in compliance with current Romanian national legal requirements in environmental respects (Dumitrescu, Mocioiu, & Visileanu, 2008). CP has helped in reducing the resource consumption, GHG emission, electricity and water consumption as well as cost.

2.7.2 Case Study in Austria

Positive results were also obtained from the study done by a researcher in an interlining fabric manufacturing industry in Austria (Fresner, 1998). It was accomplished within the Austrian PREPARE-project, intended to produce case studies in Austria in order to reveal the potential that cleaner production approach has to solve company's current environmental problems. The result obtained have proven that through cleaner production in reduction of water use by 30%, dye emission by 50%, wastewater COD by 30%, and 15% of the gas consumption of the dryers would be saved.

The company also saved money by reusing the reprocessed hydraulic oil and reusing the adhesive paste in their respective processes. In the end, it shows that CP does not only improve the environmental performance, but it has also brought positive result to the financial performance of the company.

2.7.3 Case Study in Kenya

Another type of cleaner production study was conducted in composite textile industries in Uasingishu county, Kenya was to assess the effect of manager supports and employees' skills on adoption of CP in the industry studied (Kipkoech, 2016). Strong commitment given by the senior management in practicing CP in the organization increases the chances of CP technology to be adopted. Another factor which may enhance the implementation of CP is if the management shows strong interest and also stresses on CP technologies. It can be concluded from this study that the adoption of CP technologies is more likely to happen with the aid of manager's support.

2.7.4 Case Study in Indonesia

Next study done shows that in order to improve the environmental performance in the production of batik industry in Malang, East Java-Indonesia, suitable CP techniques were applied (Sirait, 2018). Batik production of the Celaket batik industry produces wastewater that has high concentration of BOD, COD, total suspended solid (TSS) and pH level which surpasses the water quality standard threshold set by the Malang government. This is mainly due to the usage of chemical substance during the dyeing process which constitute 95%.

Suitable CP options was implemented which was the material input substitution by replacing the chemical dyes such as indigosol or nafthol with natural dyes like indigofero or tintoria. This has led to a significant reduction in the concentration of BOD by 85%, COD with 89% and TSS with 98%. Therefore, this study shows that implementation of CP is able to significantly reduce the negative impact to the environment.

2.8 Benefits of implementing cleaner production

There are various benefits of implementing cleaner production. The most generalized benefits would be the reduction of pollution, waste and GHG emissions as well as the improvements of the process, productivity, and product efficiency in terms of energy, water, materials, and use and reuse of productive resources (Matos et al., 2018). A study conducted by Hicks and Dietmar in their analysis on the environmental oriented cost management (EoCM) has resulted in a reduction at an average of 15.3% of wastewater, which includes high-concentration organic liquid, waste gas by an average of 21.2% and solid waste, including waste catalysts, was reduced by an average of 25% in electroplating, dyeing, chemicals and pharmaceuticals industry (Hicks & Dietmar, 2007). CP has brought positive changes in comparison to the period prior to EoCM implementation.

Changes are also observed in a Cuban brewery where new procedures and operational changes in the production processes where the three main components of the beer wort which are malt extract, sugar and water were processed separately and used properly in a different sequence (Rivera, González, Carrillo, & Martínez, 2009). This has resulted in reduction of energy consumption by 49%, sugar by 4%, water by 7% and caustic soda by 3%; and reduction of excess hot water by 74%, waste generation by 11% and GHG by 21%. In addition, the beer production capacity has also increase nearly three times higher.

Next benefit of CP is occupational, human and environmental risk reduction. A study was conducted in the poultry slaughterhouse and found major issue with the management of wastewater that lead to major environmental concerns such as unpleasant odours, heat, noise and particulate matter (PM) emissions, accident risks and worker-related health problems, contamination of receiving body, wastewater cost increment and loss of local fauna (Kist, El Moutaqi, & Machado, 2009). CP measures that were implemented are adopting dry cleaning procedures, bleeding trough and tunnel enlargement to maximize amount of blood collected, environmental management policy adoption, cleaning procedures standardization, water system automation, use of an anaerobic reactor and a sequential oxic/anoxic system to reduce the eutrophication effect of the final wastewater product. These measures have helped reduce the negative impacts of the issues.

CP is known to bring in profit to the organization. It is economically beneficial for manufacturing companies to implement CP, mainly in the manufacturing operations management systems (Hicks & Dietmar, 2007). An estimated profit of US$ 162 thousand per year was generated due to the reduction of the manufacturing water consumption of 810 m^3 per year as well as the elimination of 55 tons of hazardous wastes annually through CP measures (Taylor, 2006). This is similar with another study in which it was found that 51% of the small and medium manufacturers in Victoria, Australia reported financial benefit from CP practices (Andrews, Stearne, & Orbell, 2002). Several studies done over the years in different industries has shown positive results after the implementation of CP in their companies by reducing waste, energy, resource, water consumption and GHG emissions. Not only that, the companies will be more highly participative as CP implementation often leads to increase in profit gain.

2.9 Summary of Literature Review

The review had discussed about textile industry related to the current demand in textiles and also the products that are produced for the consumers' demands and needs. Textile is often associated with clothing, home furnishing and even for industrial use. The expansion of Malaysian Textiles and Apparel Industry has led to many investment opportunities which have resulted in an increment in the country's industrial production index. Besides that, environmental impacts that textile production may cause is highlighted which focuses on the release of high chemical loads into the environment, water consumption, energy consumption as well as the chemical usage in the industry. The textile's wastewater discharged contains high COD value with 115-175 kg of COD per tonne of finished textile. Another study found that high water consumption is used in textile industry and can reach up to 3000m^3 per day. The energy consumption in the textile industry is worrying as the processes are electric energy-intensive and also consume high fuel-based heat energy. In the dyeing process, a large amount of dyes are used which in the end the excess dye utilization leads them to be discharged as industrial effluents which is a waste. These issues are of concern due to its potential negative effects possible of occurring. To further understand the field of study better, textile manufacturing processes involved in a typical textile industry is also discussed. The processes involved in a textile industry vary depending on the type of products being produced and technologies adopted. CP is a better option than "end-of-pipe" as the pollution and risks to human health and safety are reduced at source. Besides that, CP is known as a cost effective approach. In addition, textile sector in Malaysia further discussed in order to know the progress of the industry nowadays. One of the most important contributors towards the Malaysian economy nowadays is the manufacturing industry. The implementation of CP can lead to a cleaner and greener operation for the Malaysian industrial sector. The implementation of CP in textile industry of other countries is importantly taken into account to know the benefits it has resulted in reduction of the chemical auxiliaries used, effluent costs, carbon dioxide emission reduction, saving clean water, electric energy and thermal energy consumption. Apart from that, the literature reviews also underlined the benefits of implementing CP which includes reduction of pollution, waste and GHG emissions as well as the improvements of the process, productivity, and product efficiency in terms of energy, water, materials, and use and reuse of productive resources. Besides that, it also reduces occupational, human and environmental risk and gives profit to the organization.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the processes involved in the manufacturing of textile and CP methodology applied to achieve the carbon footprint reduction in the textile mill factory by using data collection technique and feasibility studies.

3.2 Company Background

Powernet Industries Sdn. Bhd. was established back in 1984 and is located in Bentong, Pahang. Inititially Powernet started manufacturing warp-knitted fabrics made from synthetic yarns such as polyester, nylon and spandex fibers for the lingerie industry. Besides that, the company has extended its production in other warp-knitted and woven fabrics that are used in the product applications such as apparel, automotive, household, shoe and industrial products.

Powernet has fully integrated manufacturing facilities and all processes are done in-house. Powernet is the leading manufacturer of warp-knitted fabrics and elastomeric fabric for the lingerie industry in Malaysia. It supplies 80% of its materials to the export market, such as the Philippines, Canada, Australia, Hong Kong, Indonesia, Singapore, Iran, Sri Lanka, South Korea, Pakistan, Thailand and South Africa, and the rest to the local market.

In addition, the company was awarded the ISO 9001:2000 Quality Management System Standard Certification by Lloyd's Register Quality Assurance for the manufacture of warp-knitted fabrics. Based on the verbal communication done with the manager of the company, it was stated that Oeko-Tex 100 standards was also implemented in the company.

3.3 Overall Research Methodology

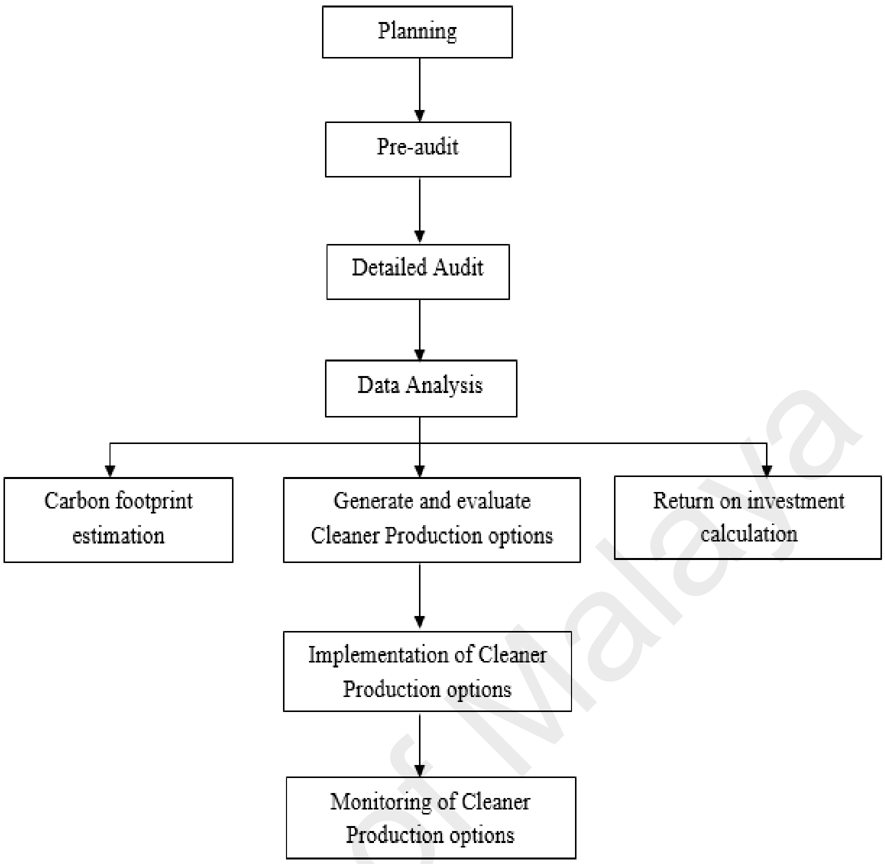


Figure 3.1: Overall methodology of the research

3.4 Planning

The first step in the CP audit is the planning. It is vital to plan the overall audit in total whereby in this stage it includes seeking permission from the company's management team, defining the objectives, scope and requirements clearly, allocating the resources required as well as planning the work details.

A CP audit requires a CP team to be formed comprising individuals of various backgrounds in the company which comprise those from production, engineering, safety, maintenance, accounting, and also facilities. They were selected as they are experts in their fields and the operations at the factory and would be able to assist in giving inputs on data implementation of CP strategy. To ensure that the audit is carried out according to plan, an audit schedule was developed as shown in Table 3.1 below.

Table 3.1: Audit plan schedule

No.	Activity	Date
1.	Preliminary visit a) To gather basic information of the factory. b) To identify the units of operations and facilities in the factory. c) To identify the process involved in the operations.	29th January 2019
2.	On-site Audit through walkthrough assessment and interviews. a) To observe production process and gather informations. i. Electricity consumption ii. Water consumption iii. Raw material consumption iv. Fuel consumption v. Wastes (Solid waste, hazardous waste and wastewater generated) vi. Safety and health b) To identify the input and output of resources at each production stage and summarized in the process flow chart.	27th February 2019
3.	CP option generation a) To conduct environmental, feasibility, technical studies to identify feasible options.	26th April 2019

3.5 Pre-Audit

Pre-audit is a preliminary assessment done whereby it is conducted to gather basic background information of the factory consisting of the type of processes involved in the entire production (Figure 3.3), number of employees, types and total number of product being manufactured, and unit operations involved. The factory's site layout (Figure 3.2) was obtained from the management and facilities team which shows the location of various operations, mainly the areas that requires to be examined such as the raw material storage area, warehouse, production, administration, waste storage area and wastewater treatment plant.

Figure 3.2: Factory layout plan

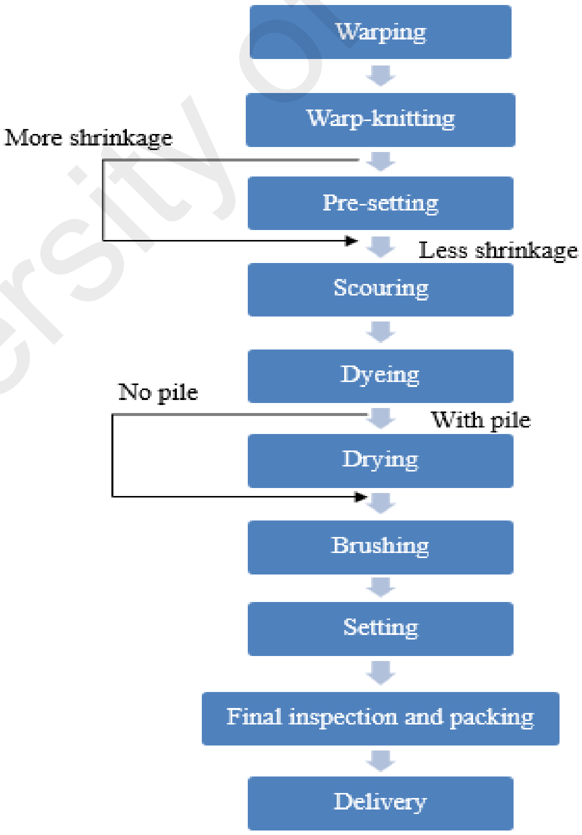


Figure 3.3: Fabric Manufacturing Process Flow Chart

3.6 Detailed Audit

For detailed CP audit, the primary purpose is to gather the necessary data needed by reviewing documents maintained in the factory (i.e. inventories on material and utility records, work flow in each process), observations and interviewing the supervisors, operators, maintenance and facilities team. This is done to understand every operation conducted as well as the process flow clearly. A detailed process flow diagram was also constructed. The process flow chart of the textile manufacturing processes obtained is presented in Figure 3.4. The audit is done to gain the quantitative and qualitative information of resource consumption, operation processes, waste generation, emissions and CO_2 emission. The information gathered consist of electricity consumption, water consumption, fuel consumption, chemical and raw material consumption and also the waste generated. This information will serve as a basis to generate CP options. The audit form used during the factory audit is attached in Appendix A.

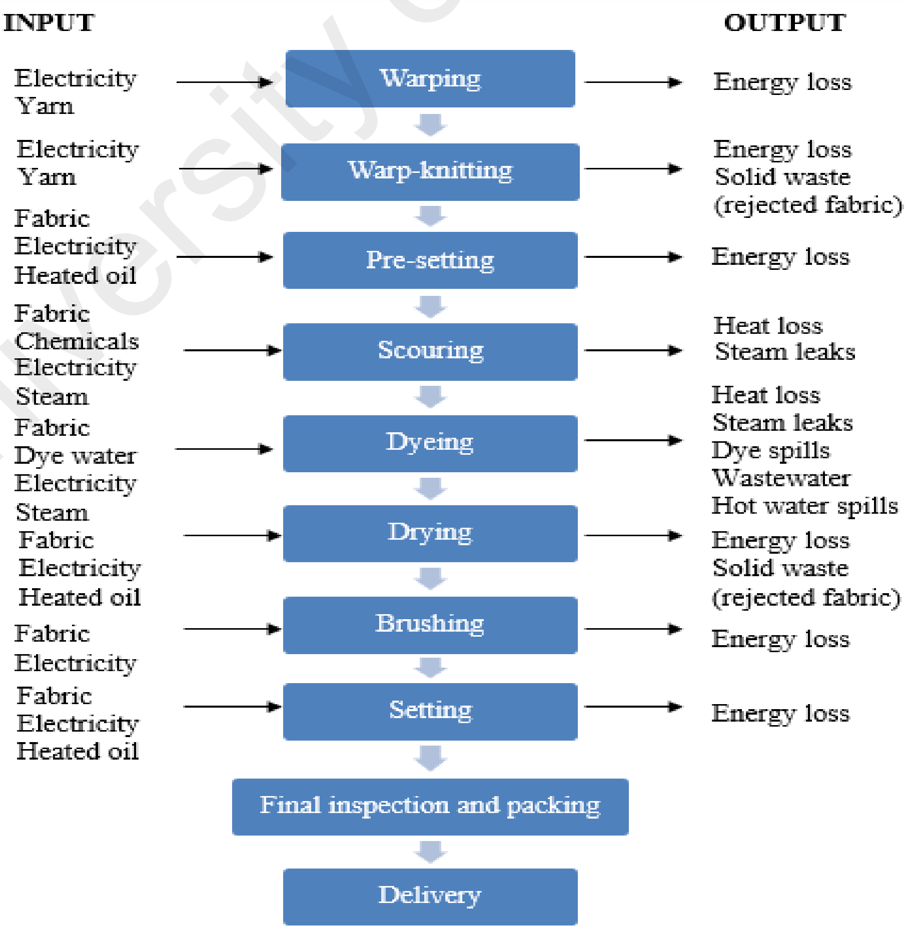


Figure 3.4: Textile manufacturing process flow diagram

3.7 Data Analysis

The data obtained such as raw material, fuels, electricity, water, waste generated and other entities that consume and generate the processes are identified and analyzed to generate the CP options. Data analysis is done in order to identify the CP options, to calculate the CO_2 emission and the return of investment.

3.8 Estimation of Carbon Footprint

Based on the Intergovernmental Panel on Climate Change (IPCC) method, an entity's CO_2 emission is calculated using factor-based approach by multiplying the component data (consumption or generation rate) with the component of Malaysian emission factors (Rahim & Raman, 2015) as shown in the equation below (Intergovernmental Panel on Climate Change, 2006). Carbon footprint (CFP) calculation is used to evaluate the GHG emission for various key economic sectors (Vergé et al., 2013). This allows companies to assess the processes and identifies those that cause the greatest impact to the environment as well as giving them the opportunity to improve on the inefficient processes which result in cost and resource reduction through the implementation of CP (Vasan, Sood, & Pecht, 2014).

CO_2e emission (kg CO_2) = Carbon Emission Factor (CEF) x Entity utilization ….Eq. 3.1

Table 3.2: Carbon emission factor

Resource and waste	CEF Value	Unit
Light fuel oil	10.21	Kg CO_2/gal
Electricity	0.70	Kg CO_2/kWh
Water	0.32	Kg CO_2/m^3
Raw material	21	Kg CO_2e/ton
Solid waste	3.7	Kg CO_2/kg
Wastewater	1	Kg CO_2/kg COD removed
Scheduled waste	21	Kg CO_2e/ton

(EPA, 2016; IPCC, 2006; Rahim & Raman, 2015)

3.9 Potential Cleaner Production Generation and Feasibility Study

The generation of CP options is based on the data analysed previously. The CP team members were required to conduct a brainstorming session to determine the improvement necessary throughout the process flow of the operation. The improvement may include the safety operating procedure of the operation, inventories, waste management, handling of equipments, training, house-keeping and also time management. Then, prioritization of the CP options to be implemented needs to be done based on the feasibility studies conducted in terms of economic, environmental and technical feasibility.

3.10 Return on Investment Calculation

Return on investment (ROI), otherwise known as payback period, is the estimated period to obtain profit from the investment made. Shorter payback period is preferred as it will generate greater results to the company as the investment cost will be recovered at a faster rate. ROI is one of the elements that need to be considered in selecting a suitable CP option which will be economically feasible for the company and also agreed by the management. ROI is calculated as follow (Department of Environment (DOE), 2010):

$$\text{Return on Investment} = \frac{\text{Total investment}}{\text{Total saving}} \quad \text{.................Eq. 3.2}$$

3.11 Safety Aspects during the Audit

Safety aspects are of great concern and shall not be neglected when conducting the CP audit. There are several important steps that need to be prioritized during the audit which is shown below:

1. Firstly, wearing proper and suitable safety attire is very important before entering the factory area. Personal protective equipments (PPE) such as safety shoes and safety helmets need to be worn at all times. Ear plugs as well as face mask should be worn when entering the designated areas.

2. The operators of the work process should be informed a few days in advance prior the audit being done. This is important to ensure safety aspects can be taken into considerations in which they need to ensure the machines are not operating during the interview. It will enable them to schedule their operations smoothly and not have any interruptions at work.

3. The interview session with the operators need to be carried out at a suitable and appropriate time as they are not busy with the operation process. This is important as to prevent any accidents from happening due to distractions.

4. It is important to schedule the audit visit with the factory' auditee team for them to ensure that there is no maintenance and repair work done in the operation area during the visit.

Compliance to all these safety aspects is important to ensure a smooth audit process can be carried out.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

A detailed on-site cleaner production audit was carried out in the factory. In this chapter, specific inputs-outputs values, distributions, analysis results, observations and evaluations based on the production processes of the mill were gathered. Subsequently, from the results obtained, the CFP calculation is discussed.

4.2 Cleaner production assessments

Cleaner production audit was carried out in the textile mill on the February 2019 as scheduled. It is categorized as a small and medium-sized enterprises (SMEs). The factory has a total of 50 workers which consist of the management employees as well as the operators which covers the manufacturing operations of one shift per day. The factory operated 8 hours daily. The factory operates from 8am-5pm for the operation processes which is from Monday-Friday and 7am-3pm for housekeeping and maintenance duties on Saturday. For the month of January 2019, 14 tons of fabric was produced. The factory produced 150 tons of finished fabric packed in the year 2018.

The company mainly produces finished fabrics from the polyester, nylon and mono yarn in this mill. Therefore, the production process includes dry processing as well as wet processing. The processes involved in the manufacturing are shown in Figure 4.

In the factory, the manufacture of yarn, dyeing and finishing processes are fully incorporated. The factory is established on a 23,550 m^2 area. In the mill, over 45 different types of chemicals, dyestuffs and auxiliaries are stored in the chemical storage room and used in the processes.

The factory has its' own wastewater treatment plant whereby the wastewater undergoes advanced processes before being discharged into the drainage system. The necessary energy, in terms of electricity and steam, to be used in the processes are provided by Tenaga Nasional Berhad (TNB) and boiler units in the factory.

Generally, in the mill, there are several types of synthetic fibers used to make various types of fabrics which consist mainly of polyester, nylon and mono. The steps in the processes are already fixed, however, there are some steps of the sub-processes that may change depending on the products requested by the customer

Although, the sequence of the major processes is stable during production line, sequence of sub-processes may differ according to the desired end use of the final product.

4.3 Analysis for Electricity Consumption

The quantification of the electricity consumption in the textile factory was calculated on a monthly basis based on the bill received from TNB. The tariff category for this factory falls under tariff D (low voltage industrial tariff) whereby the rate for the first 200 kWh is RM0.38/kWh per month whereas for the next kWh which is 201 kWh and above, the rate is RM0.441/kWh per month. The electricity consumption of the factory amounted to 3.0×10^4 kWh per month. Electricity consumption per ton of fabric obtained is 2.1×10^3 kWh/ton of fabric.

The total amount of the electricity paid was RM13,378 per month. Based on the audit findings, the electricity is mainly used by these main operational units which were the lighting as well as for the usage in operating the machineries, air compressor, air conditioner, motor pump, computer, boiler and others.

Table 4.1: Electricity consumption of various units

Type	Operating hours/month	Monthly consumption (kWh)	Percentage (%)
4.7kW Lighting	130	6.1×10^2	2
32kW Air conditioner	130	4.2×10^3	14
68.5kW Machine	126	8.6×10^3	29
134.8kW Air compressor	98	1.3×10^4	44
20.5kW Motor pump	126	2.6×10^3	9
3kW Computer	161	4.8×10^2	2
	Total:	**2.9×10^4 kWh**	**100%**

Figure 4.1 illustrates the electricity consumption of six main operational units and their percentage. The operation hours per month was estimated based on operational processes conducted in that month. Air compressor was identified having the highest electricity usage with 44%, followed by machines and air conditioner with 29% and 14% respectively. Due to compressed air's poor efficiency, it is known as the most expensive form of energy used in industries (Maarten Neelis, 2008). Thus, air compressor consumption is the main issue that needs to be addressed in order to reduce the electricity consumption in the textile factory.

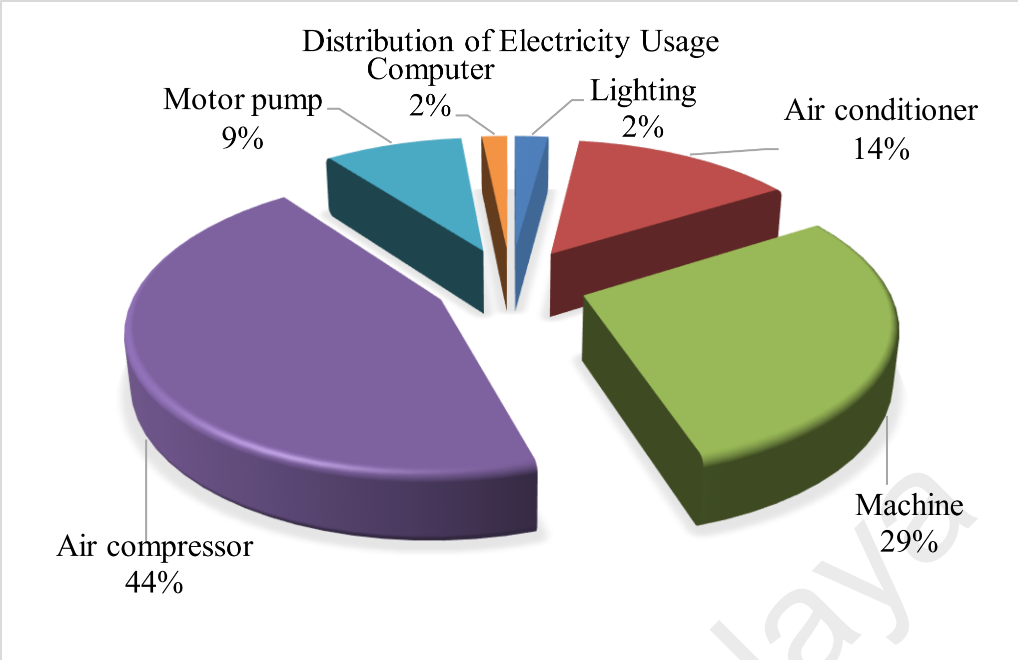


Figure 4.1: Distribution of electricity usage

4.4 Analysis for Water Consumption

Water is vital to ensure the manufacturing process can be done smoothly. Water is an important element which is used in the wet processes, cleaning of machineries and equipments as well as for domestic usage. The quantification of the water consumption in the textile factory was calculated on a monthly basis based on the bill received from Pengurusan Air Pahang Berhad, which is divided into two which are process water and non-process water.

Process water is purchased at a rate of RM1.95/m^3 which totals up to RM1,539 per month while the non-process water on the other hand, has a rate of RM0.92/m^3 for the first 250 m^3 and the remaining 167 m^3 has a rate of RM0.84/m^3 which cost RM370 per month for non-process (domestic) and a total of RM196 per month for non-process water (CIP). Water consumption per ton of fabric calculated was 1.0 x 10^2 m^3/ton of fabric. The water consumption in this particularly month is quite low since there are fewer textiles being manufactured. This is because Powernet is an intermittent textile producer whereby they produce textiles based on customers' orders and demand.

The process water's rate is higher compared to the non-process water because it is obtained from a different source which is the hydrant. This is because the water from the domestic use has lower water pressure which is insufficient to be used in the wet processes. Therefore, the hydrant is sought after in order to ensure the consumption of water for the processes is not disrupted. Non-process water is divided into two which are used for cleaning activities (cleaning-in-place) of the machineries and equipment and also for domestic purpose. Non-process water is not only used for domestic purposes, but it is also used for the operation of the steam boiler as make up water where three gallons of water is required each day. For the non-process water, it ends up to the drainage straight away without any treatments.

Table 4.2: Water flow in the different production process unit

Component	Water consumption/month (m^3)	RM	%
Process water	789	1,539	56
Non-process water (Domestic)	417	370	29
Non-process water [cleaning-in-place (CIP)]	213	196	15
Total	**1,419 m^3**	**RM2,105**	**100**

Figure 4.2 illustrates the water consumption of three categories of water used in the textile factory and their percentage where process water was identified having the highest consumption with 56%, followed by non-process (domestic) and non-process (CIP) with 29% and 15% respectively. This is consistent with the findings of another researcher whereby the process water usage is amongst the highest with 28.3% over four other usage purpose of water measured in the textile industry findings (Shaikh, 2009).

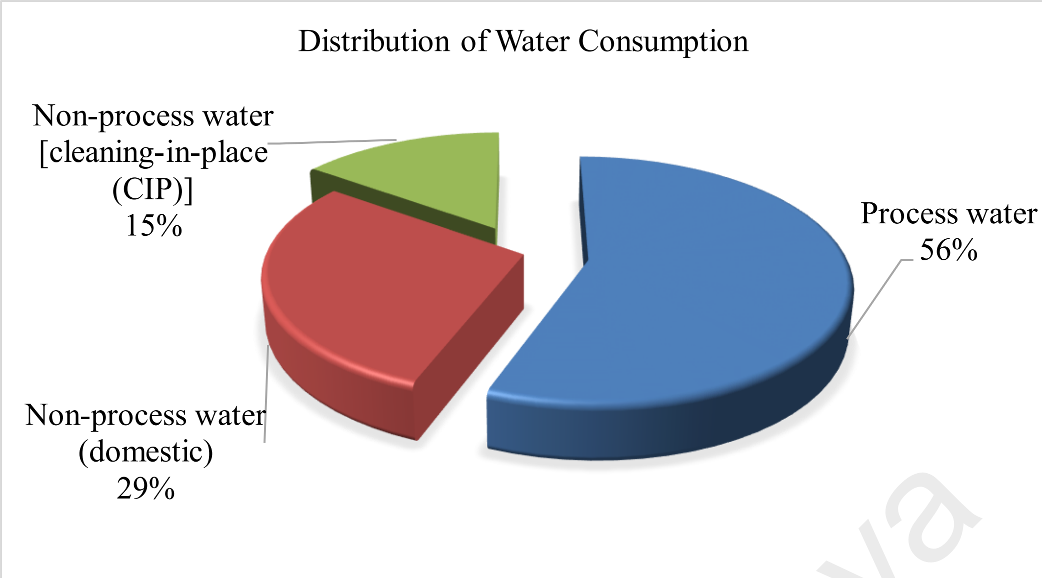


Figure 4.2: Distribution of water consumption

4.5 Analysis for Raw Material Consumption

The main raw material used in the manufacturing process of textile consists of chemicals and yarn. These two components' consumptions will be addressed further. It is widely known that in the textile industry, chemical consumption is intensive and a wide variety of chemicals of different quantities are required in wet processes such as scouring, dyeing, pre-setting, and setting as well as used in the boiler and WWTP. Total chemical consumption in the processes was 0.8 ton per month. This amount is inclusive of all the chemicals, dyestuff, auxiliaries used throughout the processes mentioned prior. Another important raw material used in the manufacturing of textile is yarn. Nylon, polyester and mono yarn consumption contributed to a total weight of 3.13 tons per month. Raw material consumption per ton of fabric calculated was 0.3 ton/ton of fabric.

Table 4.3: Raw Material consumption for product manufacturing

Components	Monthly consumption (ton)
Chemicals	0.88
Yarn	3.13
Total	**4.01 ton**

Table 4.4 shows the list of chemicals which are used in the textile manufacturing factory. Based on the verbal communication had with the plant manager, the factory has been accredited with OEKO-TEX 100 certification. OEKO-TEX 100 is a unified testing certification system tests various harmful substances such as heavy metals, formaldehyde, dyes, pesticides, pentachlorophenol and etc. This means that there are no harmful substances used in this factory.

Table 4.4: List of Chemicals used in the Process

No.	Process		
	Dyeing	**Stenter**	
1.	Antifoam FS New	25.	Prepreat WT
2.	Caustic soda flake	26.	Stiffener BN
3.	Determol RL conc	27.	Suprabond EP 080
4.	Hydrosulphite Conc	28.	Supraraise N
5.	Leveling DLP liquid	29.	Suprasoft NW
6.	Level AC	30.	Suprasoft T150
7.	Opticid VS liquid	31.	Antistatic P8
8.	Neowhite NY	32.	Ultrastretch NW
9.	Neowhite B-38 conc	33.	Acetic acid
10.	Supraclear HC powder	**Boiler**	
11.	Supraquest B liq	34.	Boil treat (RDC-230)
12.	Suprapol PE liq	35.	Boil treat (RDP-103)
13.	Supralex OB conc	36.	Boil treat (RDS-108)
14.	Suprafix MC liquid	37.	Boil treat (SD-118)
15.	Supralevel E142 liq	38.	Dasic Kleenfuel A.S (per liter)
16.	Supralevel E1200	39.	Pure dry vacuum salt
17.	Suprawash ET 200	40.	OC 13 online cleaning
18.	Supracid PS conc	41.	Flameproof HD710
19.	Supraretard KS	**Wastewater treatment plant**	
20.	Supradisp CD liq	42.	Coagulant RD 13(RD91)
21.	Supralevel CO-28	43.	Hydrogen peroxide
22.	Suprabid MIP liq	44.	Magnafloc X 25LA
23.	Suprasoft OD liquid	45.	Sodium sulphate
24.	Soda ash dense		

The waste chemicals generated from the processes involved are categorized as scheduled waste. This will be further explained in topic 4.7 related to the waste generation.

4.6 Analysis for Fuel Consumption

Light fuel oil was used as the fuel source for the operation in the factory. It is used in the operational process of the thermal oil boiler and steam boiler. Thermal energy produced was mainly consumed in the dyeing-finishing bath and stenter units. The purchasing rate of the light fuel oil was RM2.04 per liter. The monthly consumption of the light fuel oil was 10,725 L which accumulated to a total cost of RM21,879 per month. Fuel consumption per ton of fabric calculated was 7.7×10^2 L/ton of fabric. The factory opted for LFO instead of natural gas even though it is known to be highly efficient and clean.

Natural gas is much more efficient because it emits lesser harmful pollutants than oil (Liang, Ryvak, Sayeed, & Zhao, 2012). A comparison done by researchers show that natural gas emits 47,000 fewer pounds of CO_2 per billion British thermal units (Btu) than oil. It was further added that the nitrogen oxide (NO_x), sulphur dioxide (SO_2) and particulate for natural gas are 356, 1,121 and 77 fewer pounds of CO_2 per billion Btu than oil respectively (United States Energy Information Administration (US EIA), 1998). Furthermore, it is very unlikely to be done since the factory has limited access to natural gas due to the factory's geographic location. There is unavailability of the national gas pipeline infrastructure for gas-fired boiler to be installed.

4.7 Analysis for Waste Generation

The wastes generated from the textile manufacturing premise can be divided into three different categories which are solid waste, scheduled waste and wastewater. The quantification of waste produced is shown in Table 4.5 below.

From the audit done, the findings show that the total solid waste generated per month is 0.18 ton. Solid waste generated per ton of fabric calculated was 0.01 ton/ton of fabric. The solid waste consists mainly of the rags, yarns, waste fibers, cloth scraps and rejected textile end product that do not meet with the specifications which are nylon textile wastage of 0.13 ton and polyester textile wastage of 0.06 ton.

These textile wastes, however are not sent to the landfill sites of municipality, but are kept in the storage room and are available to be purchased by individuals or organizational institutions at a cheaper price. The remaining solid waste only constitute a small of fraction of the waste generated consisting of paper, yarn cones and bobbins (broken or discarded), plastic and paper packaging waste and others which are not gathered nor counted for and are sent straight away to the landfill for disposal.

The scheduled waste of the processes was collected and stored up to three months before they were disposed of by a licensed organization responsible of managing these wastes known as Kualiti Alam Sdn. Bhd. Therefore, the generated scheduled wastes of the factory up until January 2019 was 1.19 ton in which the factory was charged RM1,890/ton. Thus, the total amount paid for the disposal of the waste was RM2,250.

Assume that the estimated average of generated scheduled waste was equal for each month, therefore the scheduled waste per month was 0.4 ton which costed RM756 for disposal purposes. Scheduled waste generation per ton of fabric calculated was 0.03 ton/ton of fabric.

Table 4.5: Quantity of waste generated in the textile factory

Waste type	Unit	Quantity/month
Solid waste	Ton	0.18
Scheduled waste	Ton	0.4

4.8 Evaluation of wastewater generation

Great amount of wastewater is generated in the textile factory as a result of intensive water consumption and high chemical usage. Pre-setting, dyeing and setting processes are those which involve the usage of chemicals, dyes and auxiliaries and mainly resulted in the wastewater discharged. Besides that, the pollutant loads of the wastewater have also increased due to the presence of the chemical residues and fiber impurities. The manufacturing operation has resulted in the generation of wastewater of 428 m^3 per month in the month of January 2019. The wastewater generation per ton of fabric calculated was 3.1 x 10 m^3/ton of fabric.

Besides that, the cleaning operations of the machineries and equipments usually carried out using water, detergents and cleaning products. Cleaning wastewater contains remains of dyes, pastes, fibers, lint, detergents and cleaning solvents which also end up in the wastewater treatment plant (WWTP). The generated wastewaters were treated by biological, physical and chemical treatment processes before discharged to water bodies.

It involves filtration, chemical coagulation and adsorption column packed with activated carbon. The list of chemicals used to treat the wastewater can be seen in Appendix A. The quality of the effluents in the wastewater discharged followed the standard set by the Environmental Quality Act (EQA) 1974. The effluent that is discharged upstream of a water supply intake has met Standard A regulated as per Schedule 5 of the Environmental Quality (Industrial Effluent) Regulations 2009.

The detailed information on the industrial effluent of the WWTP can be viewed on Appendix B. The parameters measured in the discharged wastewater consist of BOD, COD, suspended solids, oil and grease, phenol, sulphide, chromium, copper and etc. According to Standard A requirement, the BOD value is set at 20 mg/L whereas for COD value, it is 80 mg/L. The results of the water sampling of the industrial effluent done by the environmental consultant in the month of January 2019 was obtained from the factory record. The values of BOD and COD in the discharged effluent are 3 mg/L and 21 mg/L respectively. Therefore, both BOD and COD value of the discharged effluent meet with the required standard.

4.9 Carbon footprint Analysis

From the data that has been collected, the CFP calculation has been done in order to estimate the emission of CO_2 from the manufacturing processes in the textile industry. The CFP components to be measured comprise of electricity consumption, water consumption, raw material consumption, fuel consumption, solid waste generation, scheduled waste generation and also wastewater. The total CO_2 emission is 5.1 x 10^4 $kgCO_2$ per month and the CO_2 emission per ton of fabric was 3.7 x 10^3 $kgCO_2$/ton of fabric produced.

Result of the total CFP calculation is shown in Table 4.6:

Table 4.6: CO_2 emission from various components in the textile factory

Component	Calculation		
Electricity	Average electricity used	=	30,363 kWh per month
	Estimated CFP	=	30,363 x 0.70 $kgCO_2$/kWh
		=	2.1 x 10^4 $kgCO_2$ per month
Water	Average water used	=	1,419 m^3 per month
	Estimated CFP	=	1,419 x 0.32 $kgCO_2/m^3$
		=	4.5 x 10^2 $kgCO_2$ per month
Raw material	Average raw material used	=	4.01 ton per month
	Estimated CFP	=	4.01 x 21 $kgCO_2e$/ton
		=	8.4 x 10 $kgCO_2$ per month
Light fuel oil	Average fuel oil used	=	2,833 gallons per month
	Estimated CFP	=	2,833 x 10.21$kgCO_2$/gal
		=	2.9 x 10^4 $kgCO_2$ per month
Solid waste	Average solid waste generated	=	167 kg per month
		=	167 x 3.7 $kgCO_2$/kg
	Estimated CFP	=	6.2 x 10^2 $kgCO_2$ per month

Table 4.6, continued.

Wastewater	Average wastewater generated	=	428 m^3 per month
		=	428 x 21 x 1 x 1,000/1,000000
	Estimated CFP	=	9.0 $kgCO_2$ per month
Scheduled waste	Average scheduled waste generated	=	0.4 ton per month
		=	0.4 x 21 $kgCO_2e$/ton
	Estimated CFP	=	8.4 $kgCO_2$ per month

Based on Table 4. 7 below, the total CO_2 emission is 5.1 x 10^4 $kgCO_2$ per month and the CO_2 emission per ton of fabric was 3.7 x 10^3 $kgCO_2$/ton of fabric produced.

Table 4.7: Summary of the CO_2 emission components before CP options implementation

Component	CO_2 emission (kg CO_2)/month	$kgCO_2$/ton of fabric produced
30,363 kWh of electricity	2.1 x 10^4	1.5 x 10^3
1,419 m^3 of water	4.5 x 10^2	3.2 x 10
4.01 ton of raw material	8.4 x 10	6.0
2,833 gallon of light fuel oil	2.9 x 10^4	2.1 x 10^3
167 kg solid waste	6.2 x 10^2	4.5 x 10
428 m^3 of wastewater	9.0	0.6
0.4 ton of scheduled waste	8.4	0.6
Total	**5.1 x 10^4**	**3.7 x 10^3**

4.10 Safety and Health Issues in Textile Factory

From the observation and interview conducted with the employees, there were several safety and health issues able to be identified. The issues identified were listed in Table 4.8 below.

Table 4.8: Safety issues in the textile factory

No.	Safety Issue	Risk
1.	Incorrect climbing and balancing techniques used when employees are required to climb steps to reach the creel.	Improper lifting

Table 4.8, continued

2.	Warp beam storage are not enclosed or guarded.	Falling objects
3.	Absence of safety signs and hazard indicators in the workplace.	Falling objects, hot, wet and slippery surfaces, hearing loss
4.	Inadvertent/Unintentional startup of knitting machine by operators causing cut.	Injury
5.	Stagnant water spots on the floor.	Slip, trip and fall
6.	Lifting and carrying of heavy beam and fabric rolls.	Improper lifting/Overexertion
7.	Chemicals are handled without the use of personal protective equipment.	Accidents and injury
8.	Objects on the floor that causes worker to fall which include machine parts, fabric rolls and oil.	Trip and fall
9.	Knitting machine entrapment risks to employees' clothing, i.e. head scarf	Injury
10.	No proper storage area for PPE. Difficulty in finding PPE for use.	Falling objects, hot, wet and slippery surfaces, hearing loss
11.	The application of various chemicals in the dyeing process produces a strong and apparent chemical smell.	Chemical inhalation
12.	The surface of the floor at the dyeing process area is slippery due to overflowing water bath.	Slip and fall
13.	The dyeing machineries involve high temperature that produces heat that affects the operators.	Heat stress

Table 4.8 above shows 13 concerning safety issues occurring in the factory. The risks involved consist of improper lifting, trip, slip and fall, hot, wet and slippery surfaces,

hearing loss, chemical inhalation, heat stress, and also potential injury to the workers. These issues should be addressed to the safety personnel immediately to ensure that suitable safety measures are taken to avoid unfortunate events.

4.11 CP Option Generation

CP technique implementation at the textile factory is able to reduce the excess consumption of energy and raw materials, besides of also reducing the volume and characteristics of effluents discharged significantly. CP brings great economic benefits to the factory in which the production cost and the need for costly end-of-pipe pollution control facilities are able to be reduced. In addition, CP helps minimize the health and environmental impacts on the factory's employees and the neighbouring community.

4.12 CP options for Electricity Consumption Reduction

As with electricity conservation, attention paid to reductions in energy use can deliver cost savings and lower emissions from boilers or generating plants simultaneously. Textile plants are intensive energy users.

<u>CP 1: Switching off the lights</u>

Good housekeeping practices in the factory can help achieve efficient energy management. Switching off the lights during the one hour break everyday is able to reduce the unnecessary electricity consumption. This method can be applied immediately as it does not involve any investments. This CP option can lead to a reduction of 18 $kgCO_2$ per month as the electricity consumption is reduced by 26 kWh/month.

<u>CP 2: Increasing the temperature of air conditioner</u>

A good behavioral modification that can be implemented to ensure an energy efficient management is certain areas should implement the recommended temperature setting of air conditioner used. For example, in the office, the temperature should be increased from

20°C to the recommended temperature of 24°C. According to India's Bureau of Energy Efficiency, for every 1°C temperature increment, this would result in 6% electricity reduction without involving any investment cost. Thus, having 24% electricity reduction by implementing this CP option. The electricity saving per month that will be achieved is 998kWh, thus potentially reduce the CO_2 emission by 698.6 $kgCO_2$ per month.

<u>CP3: Installation of LED lighting system</u>

The current source of illumination inside the factory is the T8 fluorescent tubes with 36W that has an average lifespan of 5,000 hours. Sufficient illumination is important as some processes require sufficient lightings especially in warp-knitting where the employees are required to be attentive to observe for broken yarn and picks and to ensure the yarns are not entangled. Replacing them with light emitting diode (LED) is a better option as they have lower voltage. The advantage is that LEDs use 30% to 40% lesser energy than most fluorescent lamps (Ganandran, Mahlia, Ong, Rismanchi, & Chong, 2014).

T8 LED tube has longer lifespan than the T8 fluorescent tubes with 15,000 hours. This will help reduce costs needed on replacement and maintenance of the lights. The installation of T8 LED tube suggested in the factory has wattage of 16 W. They will consume 270.3 kWh/month with electricity saving reduction of 56%. This leads to a reduction 238.5 $kgCO_2$ per month.

The cost for the T8 LED tube was RM95.00 for 10 units that come with the bypass starter (Lazada, 2019). The total cost of 130 units is approximately RM1,235 not inclusive of installation cost. The calculation for ROI of installing LED lighting system is shown below:

Total investment	=	RM1,235
Total savings	=	RM1,788
ROI	=	RM1235 / RM1,788
	=	0.7 years

CP 4: Installation of compressed air monitoring system

Installing compressed air monitoring system is an effective tool to measure the energy performance of compressed air generating system and compressed air utilization. It assists in the detection and quantification of the losses due to compressed air leakages and losses due to poor efficiency of the compressors, while keeping track of the system's performance. It is a good tool to help reduce the energy usage and optimize energy consumption in textile. A reduction of 10% of electricity consumption is achievable with the installation of this system. The estimated electricity saving will be 1,321 kWh/month, thus potentially reduce the CO_2 emission by 925 $kgCO_2$ per month. ROI calculation for the installation of compressed air monitoring system is shown below:

Total investment	=	RM70,000
Total savings	=	RM6996
ROI	=	RM70,000 / RM6,996
	=	10 years

CP 5: Installation of solar panel

Solar energy is one of the most abundantly available renewable energy that is accessible in this country. Solar power is friendlier to the environment as to conventional power fuels for different air and water emissions as well as waste emissions.

Solar photovoltaic cells are used for power generation has been increasing in demand recently and currently, there is a drastic reduction in the price of the solar photovoltaic cells over time which makes them becoming cheaper. It can be substituted to generate electricity for process like warping, warp-knitting and brushing and even for the office works.

For this factory, one solar inverter unit of 10 kW is recommended for installation which cost RM65,000. This solar investment cost was provided by Spectra Energy & Marine Sdn. Bhd. whereby they are the authorised service provider of Suruhanjaya Tenaga Malaysia and Sustainable Energy Development Berhad (SEDA). Based on the feed on tariff, 10kW panels are able to generate 1,200 kWh per month, which is the electricity saved for that month. This will lead to the CO_2 emission to be reduced by 840 $kgCO_2$ per month. The ROI calculation for the installation of the solar panel is shown below:

Total investment	=	RM65,000
Total savings	=	RM6,324
ROI	=	RM65,000 / RM6,324
	=	10.3 years

CP 6: Installation of inverter for the compressors

One CP option that can be considered to reduce the electricity consumption is by the installation of an inverter unit in the compressor. Previously, a study conducted by (Rahim & Raman, 2015) in a fruit juice production plant found that a 10% energy consumption reduction can be achieved through the implementation of this option. This will result in electricity saving of 1,321 kWh per month and reduction in CO_2 emission by 925 $kgCO_2$ per month. The ROI calculation for the installation of inverters for the compressors is shown below:

Total investment	=	RM28,520
Total savings	=	RM12,549
ROI	=	RM28,520 / RM12,549
	=	2.3 years

4.13 CP Options for Water Consumption Reduction

Water conservation not only reduces water consumption, but it also significantly reduces effluent volume. It is not difficult to find solutions where more than 25% of reduction in water usage can be accomplished by following suitable water conservation practices.

CP 6: Implement counter-current washing

There are a total of nine machines used in the dyeing process. Therefore, dyeing process is known to be one of the most water intensive processes in the textile industry. Most of the effluent volumes arising from a textile mill come from the washing operations, mainly the dyeing operations. Used water in the various washing stages can be re-used since most of the washing cycles are conducted in a series.

This method of water recycling is known as counter current washing. Reuse water from the "cleaner" stages of production in "dirtier" stages of the next production cycle or in other words, reuse of the least contaminated water from the final wash for the next-to-last wash and so on until the water reaches the first wash stage, where it is then finally discharged. For example, final rinse water in first stage is used for rinsing of the next production batch. This technique helps decrease the fresh water volume intake.

According to the United States Environmental Protection Agency (US EPA) (2005), based on the number of washing steps done, an estimated 50% water saving is able to be achieved through counter-current washing implementation. This CP option leads to a reduction in the water bill with RM769.28 and CO_2 emission reduction of 126.24 $kgCO_2$. The water consumption has also reduced to 394.5 m^3. Counter-current is a straightforward and inexpensive method that is easily implemented in existing mills when there is already a synchronous operation of processes (Shaikh, 2009).

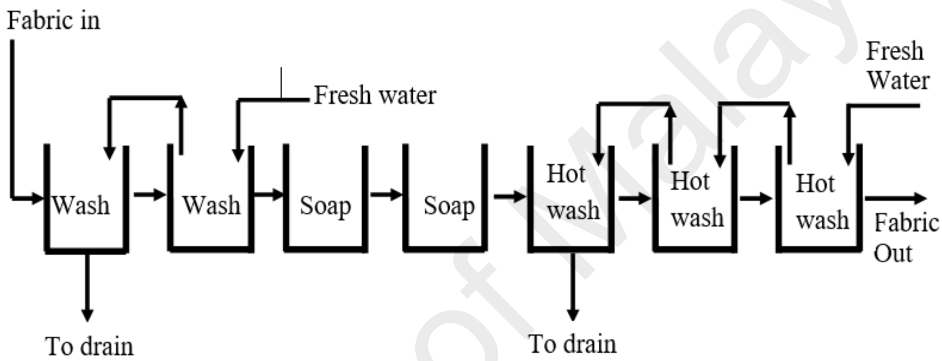


Figure 4.3: Counter-current washing flow

<u>CP 7: Use of high-pressure sprays for clean-up</u>

Usage of spray guns instead of open hoses during clean-up throughout the factory can ease cleaning and cut water usage. Therefore, water consumption can be reduced by 50% or more. In order to significantly reduce water wastage, only press on it when needed. This can reduce the water consumption to an estimated 106.5 m^3 with CO_2 emission reduction of 34.08 $kgCO_2$.

Total investment	=	RM60
Total savings	=	RM2,304
ROI	=	$\frac{\text{RM60}}{\text{RM2,304}}$
	=	0.03 years

CP 8: Use of low liquor ratio machines

Lower liquor ratio dyeing machines circulate fabric within a dyeing vat using compressed air instead of water, for example, air-flow machines. This reduces the use of water and auxiliary agents tremendously. These new dyeing machines' liquor bath ratio is only 1:3 or 1:4, compared to the older machines with ratios of 1:8 or even 1:12 which makes it much more fuel and water efficient. The estimated price is around RM180,000 (Alibaba.com, 2019a). This innovation can help save as much as 50% water as well as eliminating about 2-3 hours of production time per vat. The water consumption can be reduced by 394.5 m^3/month with a reduction in CO_2 emission by 126.24 $kgCO_2$/month. ROI calculation is shown below:

Total investment	=	RM180,000
Total savings	=	RM9,240
ROI	=	RM180,000 / RM9,240
	=	20 years

CP 9: Conduct dry clean up techniques

Cleaning and washing of the manufacturing process area is regularly done with the usage of water. Dry cleanup is recommended as an initial cleaning step as it involves sweeping and wiping down of the solid or semi-solid wastes from floors or machinery before washing is done. This technique helps reduce the amount of water needed during washing. Not only that, it also reduces the concentration of contaminants that goes to the drains as the waste is disposed of as solids.

Figure 4.4: Dry clean up technique

4.14 CP Options for Raw Material and Chemical Optimization

<u>CP 10: Use automatic chemical dispensing system</u>

In the dyeing process conducted at the factory, the chemicals are measured and weighed manually in the chemical storage room by the employees before it is added into the dye bath. When these chemicals or dyes are added in the bath, there is a possibility of imbalance dozing occurring which varies from the sample recipe prepared. Since it is done manually, the dyes or chemicals may be taken up more or lesser than the recipe.

The difference seems to be unapparent in the laboratory as it may appear as the proper dyed sample is obtained according to the buyers' demand. However, during bulk production of fabric dyeing, the effect implied on the fabric is big. Sometimes, it may even require the fabrics to be dyed several times to achieve the desired result.

The use of automatic chemical dispensing system is able to minimize the consumption of dyes and chemicals therefore cutting cost and reduction of effluents. Besides that, it also offers quicker delivery times, better laboratory-to-dye house correlation, a wider variety of styles with higher quality and also increases the productivity. Some of the chemicals are hazardous, thus automation helps minimize the employees' direct exposure to the chemicals and prevents injuries. The chemicals can be reduced up to 15% which would result in chemical reduction by 131.62 kg, thus resulting in a reduced CO_2 emission of 3.15 kgCO_2 emission. ROI for automated dispensing system is shown below:

Total investment	=	RM160,000
Total savings	=	RM21,240
ROI	=	RM160,000 / RM21,240
	=	8 years

CP 11: Inventory Control Management

There are instances when dyestuff in the chemical storage room has surpassed its expiration date as it was unable to be fully consumed as the fabric production is based on the customers' demand basis. Checking with the companies if they accept expired material for disposal would be great.

A significant way of minimizing pollution is by controlling the raw materials properly. Waste can either arise from the raw materials that have expired, no longer used, damaged or unwanted. Off-specification or damaged final products should also be a part of the inventory control management in order to make them more recoverable.

There are several steps that can be implemented to improve the inventory control management which consist of:

- Ordering materials to just-in-time (JIT) manufacturing techniques.
- Purchases only materials needed to minimize leftovers (chemicals, materials, etc.)
- Review the materials for possibility of their hazardous content. Decide on lesser hazardous alternative if available.
- Keep track of the material usage and control them to reduce excess usage.
- Assign the responsibility of purchasing and disposition of supplies and materials to dedicated employees or departments.

This technique can be done immediately as it does not require any investment.

CP 12: Pre-screen Chemicals and Raw Materials

Pre-screening chemicals by viewing the Safety Data Sheet (SDS) is important to avoid the usage of toxic chemicals. BOD, COD and toxicity are some of the important information that requires attention when viewing the SDS. Dyestuffs containing heavy metals, solvent-based products and carriers containing chlorinated aromatics should not be used in the operations.

CP 13: Chemical Substitution

The list of chemicals used in the factory should be reviewed. Hazardous chemicals should be replaced with less hazardous chemicals to reduce the impact to the environment. Besides that, choose the usage of dyes with high exhaustion rates and less salt requirement is better. If there is usage of potentially carcinogenic chemical inks in the dyeing process done, replace it vegetable inks. Using detergents with lower foams and solvents with less isopropyl alcohol is a better choice to reduce the effect to the environment.

4.15 CP Options for Fuel Consumption Reduction

CP 14: Rinse water temperature reduction

After dyeing process has been completed, rinse water for rinsing is heated up to a temperature of nearly 60°C in order to produce a product with great quality. Several plants have conducted their operational practices in the rinsing process with a reduction of the rinse water temperature to about 50°C and the results showed that product's quality was not affected. The temperature reduction will help reduce fuel consumption by 10%. This will lead to a fuel reduction of 1,073L per month with the CO_2 emission reduced by 2,889 $kgCO_2$ per month.

CP 15: Heat Insulation of hot surfaces

Based on the audit made, it shows that some of the insulation of the hot surfaces of the pipes, valves, tanks and machines at the factory has worn out after years of use. This may have resulted in some energy loss happening over time. There is a need for the maintaining the insulation of the machineries and equipments as it is a general principle of good housekeeping practice that should be applied in all steam consuming processes in textile plants. Through proper insulation of these equipments, the energy usage will be reduced by 5%.

CP 16: Installation of plate heat exchanger

Rinsing of fabric requires a vast amount of very hot water at a temperature of 80°C. It is beneficial to capture the heat from the hot rinse water to be used in preheating the incoming water for the following hot rinse cycle. The heat recovery technique involves the use of a plate heat exchanger. The purpose of the plate heat exchanger is to transfer the heat energy in the wastewater to the receiving cold freshwater. The price of the plate heat exchanger is estimated at RM8,000 not inclusive of the installation fees

(Alibaba.com, 2019). The estimated fuel saving percentage is about 7% (Council, 2010). This will result in fuel consumption reduction by 751 L per month and 2,021 $kgCO_2$ per month of CO_2 emission reduction.

Total investment	=	RM8,000
Total savings	=	RM18,385
ROI	=	RM8,000 / RM18,385
	=	0.4 years

CP 17: Installation of a waste heat boiler

The largest source of energy loss in a boiler comes from hot flue gas leaving the stack. Heat recovery from the smokestacks is a good solution in order to reduce fuel consumption. The heat recovered can be used to create steam for the steam network. Other than that, the heat can also be used for boiler feed water preheating. The fuel saving from the heat recovered is 1%. According to (Alibaba.com, 2019b), the cost of the installation of a compact waste heat boiler is estimated at RM30,000. Thus, the reduction of fuel consumption and CO_2 emission are 107 L per month and 286 $kgCO_2$ per month respectively.

Total investment	=	RM30,000
Total savings	=	RM2,625
ROI	=	RM30,000 / RM2,625
	=	11 years

CP 18: Installation of water reuse system

Non-contact cooling water from air compressor, for example, should be recycled. This is because they are uncontaminated, high quality and temperature thus making them reusable in several processes, i.e. washing, scouring or rinsing as rinse water or make-up water. The implementation of this technique will also prevent straining the WWTP since the discharge of the significant cooling water volume straight to the WWTP at a temperature of 45°C can be avoided.

The water reuse system requires a control system, valves, pumps, pipes and holding tanks. According to NDRC (2010), the installation cost of the water reuse system is not more than RM6,000 and lead to a fuel saving of 1.7%. Thus, resulting in fuel saving of 182 L per month and 490 $kgCO_2$ per month. ROI for water reuse system installation is shown below:

$$\text{Total investment} = RM6{,}000$$
$$\text{Total savings} = RM4{,}455$$
$$\text{ROI} = \frac{RM6{,}000}{RM4{,}455} = 1.3 \text{ years}$$

4.16 CP Options for Waste and Wastewater Management

CP 19: Proper waste management

A good waste management consist of segregating different waste streams that has been collected, which is then separated according to their categories before they are stored. The purpose is to allow material recovery to take place, besides recycling and re-use. The advantage of this implementation is waste disposal cost reduction, material and supply costs saving, and also gaining profit from selling of the saleable materials. This will lead to 10% reduction of CFP.

CP 20: Installation of camera fabric detecting device

In the warp-knitting process, there is a possibility of creating defects where the main reason is contributed by the yarn whereby the presence or absence of the yarn can result in defects such as miss-ends or picks, end outs, and broken end or picks. Besides that, other defects may include slubs, contaminations or waste, becoming trapped in the fabric structure during weaving process. Whereas additional defects are mostly machine related, and appear as structural failures (tears or holes) or machine residue (oil spots or dirt).

The process inspection is done when the weaving process is in operation whereby the employees need to constantly monitor the machinery for any occurrence of defects. This manual form of inspection is quite difficult as it strictly depends on the employees' eyes and focus in this tedious process in which in the end, there might be some flaws that goes undetected. Introducing an online automated fabric inspection technology can help solve the wastage issue. It is known as the camera fabric detecting device.

It consists of light, complementary metal oxide semiconductor (CMOS) camera, high speed image capture card, industrial control computer and artificial intelligence software which are able to detect the flaws of the fabric in the tricot machines production. When there is a flaw, the alarm goes on and the machine will stop automatically.

CP 21: Reuse of textile wastewater post-treatment

The textile wastewater has undergone stringent process in the WWTP before it is being released into the drainage system. Wasatex (2016) stated that there is a possibility for textile wastewater to be reused if they are thoroughly processed. The combination of physical, chemical and biological treatment methods done to treat wastewater effluent from secondary waste water treatment plant has made it possible for safe reuse for the cleaning of machineries and equipments in the factory.

CP 22: Rinse water reuse

Rinse water from the scouring operation is sufficient for reuse in other processes e.g. desizing, where the water quality requirements are less stringent, making them feasible. This is because the scouring wastes from synthetic fabrics do not contain a great amount of impurities as compared to cotton. In this factory, where desizing process is not conducted, the rinse water can also be reused cleaning of equipments and floors.

4.17 CP Options for Process Improvement

CP 23: Equipment inspection and maintenance

Regular inspection of equipments and machineries in the manufacturing processes is important in order to check for any fuel or water leakages and blockages in equipment such as pumps, valves, filters, switches and etc. Cleaning of debris from sumps and screen are also needed in which it can help improve efficiency. This will result in unnecessary surplus of water, energy and fuel consumption, off-quality products and filters clogging.

CP 24: Schedule dyeing operations

It is a good housekeeping practice to schedule the dyeing operations beforehand. Dyeing fabric of lighter shade first before proceeding to darker shade is recommended because it helps reduces the number of times a dye bath has to be released and machine cleaning is required due to the colour change.

4.18 Summary of CP Options Generation

A summary of the CP options generated are shown in Table 4.9 below.

Table 4.9: Summary of the CP options

CP options for Electricity Consumption Reduction				
No.	**CP Options**	**Investment Required (RM)**	**CFP Reduction per month ($kgCO_2$)**	**ROI (years)**
1	Switching off the lights	-	18	Immediate
2	Increasing the temperature of air conditioner	-	699	Immediate
3	Installation of LED lighting system	1,235	238.5	0.7
4	Installation of compressed air monitoring system	70,000	925	10
5	Installation of solar panel	65,000	840	10.3
6	Installation of inverter for the compressors	28,520	925	2.3
CP Options for Water Consumption Reduction				
7	Implement counter-current washing	-	126.24	Immediate
8	Use of high-pressure sprays for clean-up	60	34.08	0.02
7	Use of low liquor ratio machines	180,000	126.24	20
9	Conduct dry clean up techniques	-	-	Immediate
CP Options for Raw Material and Chemical Optimization				
10	Use automatic chemical dispensing system	160,000	3.15	8
11	Inventory Control Management	-	63	Immediate
12	Pre-screen chemicals and raw materials	-	-	Immediate
13	Chemical Substitution	-	-	Immediate
CP options for Fuel Consumption Reduction				
14	Rinse water temperature reduction	-	2,889	Immediate
15	Heat Insulation of hot surfaces	-	1,446	Immediate
16	Installation of plate heat exchanger	8,000	2,021	0.4

Table 4.9, continued.

17	Installation of a waste heat boiler	30,000	286	11
18	Installation of water reuse system	6,000	490	1.3
CP Options for Waste and Wastewater Management				
19	Proper waste management	-	63	Immediate
20	Installation of camera fabric detecting device*			
21	Reuse of textile wastewater post-treatment*			
22	Rinse water reuse*			
CP Options for Process Improvement				
23	Equipment inspection and maintenance	-	-	Immediate
24	Schedule dyeing operations*			

*These CP options require further study.

There are a total of 24 CP options which has been generated in which 6 CP options for Electricity Consumption Reduction, four CP Options for Water Consumption Reduction, four CP Options for Raw Material and Chemical Optimization, five CP options for Fuel Consumption Reduction, four CP Options for Waste and Wastewater Management and two CP Options for Process Improvement respectively. From the 24 CP options generated, the overall ROI calculated was 6.4 years. In selecting suitable CP options, one of the key parameters that is considered is ROI. If the estimated ROI is below two years, it is an acceptable CP option that can be implemented by the factory.

4.19 Safety and Health Issues Corrective Measures

Table 4.10: Solutions for arising safety and health issues

No.	Safety and Health Issue	Corrective measure
1.	Incorrect climbing and balancing techniques used when employees are required to climb steps to reach the creel.	Train the employees with the correct methods and technique to avoid strain.
2.	Warp beam storage are not enclosed or guarded.	Install a warp beam storage racks
3.	Absence of safety signs and hazard indicators in the workplace.	Safety personnel need to place the signage at the factory area.

Table 4.10, continued.

4.	Inadvertent/Unintentional startup of knitting machine by operators causing cut.	Fabricated shield should be placed over the start button.
5.	Stagnant water spots on the floor.	Regular cleaning and mopping to prevent trip.
6.	Lifting and carrying of heavy beam and fabric rolls.	Implement right techniques in lifting and work in a team to reduce weight load.
7.	Chemicals are handled without the use of personal protective equipment.	Educate the employees on the importance of PPE.
8.	Objects on the floor that cause worker falls include machine parts, fabric rolls and oil.	Conduct good housekeeping practices.
9.	Knitting machine entrapment risks to employees' clothing, i.e. head scarf	To set up a SOP on proper clothing attire for workers.
10.	No proper storage area for PPE. Difficulty in finding PPE for use.	Build a designated area for PPE storage.
11.	The application of various chemicals in the dyeing process produces a strong and apparent chemical fume smell.	-The operators need to wear mask when working in the dyeing process area. -Increase ventilation inside buildings and around chemical baths and the use of fans or covers to reduce fume inhalation. - Have alternate work shift for the operators to reduce exposure.
12.	The surface of the floor at the dyeing process area is slippery due to overflowing water bath.	-Provide the operators with slip resistant safety shoes.
13.	The dyeing machineries involve high temperature that produces heat that affects the operators.	-Increase ventilation inside buildings and around the dyeing machineries - Have alternate work shift for the operators to reduce exposure.

Table 4.10 above shows the suitable solutions for the arising safety and health issues happening in the factory. The solutions suggested not only involve educating and training the workers, but it also include improving the work schedule as well as having a good housekeeping practice. The safety personnel should work hand in hand with various

departments such as maintenance, purchasing, production and other related department to ensure that these solutions can be successfully done. Besides that, it may also include hiring external consultants who are responsible of conducting safety and environmental monitoring of the factory to ensure it is within safe level for the workers and trainers who are hired to educate the workers on the concerning matters.

4.20 Feasibility Studies of Recommended CP Options

Based on the findings of the audit conducted together with the carbon footprint analysis done, improvements need to be done in order to reduce the CO_2 emission generated. In order to decide on the suitable CP options to be implemented, economic and environmental feasibility studies of the recommended CP options were highlighted. The targeted CP options consist mainly of those without any investment cost that can be implemented immediately or those with low investment cost that has shorter payback period.

The consumption of electricity will experience a reduction of 2,494 kWh per month. The recommended CP options implemented on the other hand, will be able to reduce the CO_2 emission by 1,796 $kgCO_2$ per month.

Besides electricity, CP options can also be implemented for water consumption reduction which does not require high cost. The implementation of the recommended CP options will be able to reduce the CO_2 emission by 160 $kgCO_2$ per month while the water consumption will have a reduction of 502 m^3 per month.

The third contributor of the CO_2 emission is the fuel consumption. The implementation of the recommended CP options will be able to reduce the CO_2 emission by 6,846 $kgCO_2$ per month while the fuel consumption will have a reduction of 2,542 L per month. The implementation of proper waste management will further reduce the CO_2 emission by 185

$kgCO_2$ per month. The recommended CP options together with the resulting outcomes on electricity saving, CO_2 emission reduction and ROI are listed in Table 4.11 below.

Table 4.11: Summary of the economic and environmental feasibility of the recommended CP options

CP Options for Electricity Consumption Reduction					
No.	CP Options	Estimated investment cost (RM)	Savings		ROI (years)
			Electricity Reduction/month (kWh)	CFP Reduction per month ($kgCO_2$)	
1.	Switching off the lights	-	26	18	Immediate
2.	Increasing the temperature of air conditioner	-	998	699	Immediate
3.	Installation of LED lighting system	1,235	270	239	0.7
4	Installation of inverter for the compressors	28,520	1,200	840	2.3
CP Options for Water Consumption Reduction					
No.	**CP Options**	**Estimated investment cost (RM)**	**Savings**		**ROI (years)**
			Water consumption reduction/month (m^3)	**CFP Reduction per month ($kgCO_2$)**	
5.	Implement counter-current washing	-	395	126	Immediate
6.	Use of high-pressure sprays for clean-up	60	107	34	0.02

Table 4.11, continued.

CP options for Fuel Consumption Reduction					
No.	**CP Options**	**Estimated investment cost (RM)**	**Savings**		**ROI (years)**
			Fuel consumption reduction/month (L)	**CFP Reduction per month ($kgCO_2$)**	
7.	Heat Insulation of hot surfaces	-	536	1,446	Immediate
8.	Rinse water temperature reduction	-	1,073	2,889	Immediate
9.	Installation of plate heat exchanger	8,000	751	2,021	0.4
10.	Installation of water reuse system	6,000	182	490	1.3
CP Options for Waste and Wastewater Management					
No.	**CP Options**	**Estimated investment cost (RM)**	**Savings**		**ROI (years)**
			Consumption reduction/month (kg)	**CFP Reduction per month ($kgCO_2$)**	
11.	Proper waste management	-	17	63	Immediate

From the 24 CP options generated, 11 CP options were selected to be implemented. There are possible CFP reductions in the textile manufacturing factory if the recommended CP options are implemented. Table 4. below CO_2 emission components after CP options implementation.

Table 4.12: Summary of the CO_2 emission components after CP options implementation

Component	CO_2 emission ($kgCO_2$)/month	$kgCO_2$/ton of fabric produced
27,869 kWh of electricity	1.9×10^4	1.4×10^3
917 m^3 of water	2.9×10^2	2.1×10
4.01 ton of raw material	8.4×10	6.0
2,162 gallon of light fuel oil	2.2×10^4	1.6×10^3
150 kg solid waste	5.6×10^2	3.9×10^2
428 m^3 of wastewater	9.0	0.6
0.4 ton of scheduled waste	8.4	0.6
Total	$\mathbf{4.2 \times 10^4}$	$\mathbf{3.4 \times 10^3}$

From the analysis done, the implementation of the recommended CP options in the textile manufacturing factory will reduce the CO_2 emission per ton of fabric with a total of 3.4×10^3 $kgCO_2$ per ton of fabric which equals to 8% in reduction from the CO_2 emission per ton of fabric before CP options implementation.

The environmental feasibility of the recommended CP options implementation is calculated based on the overall estimated investment cost required and the expected annual savings accomplished. Thus, the ROI calculation for the recommended CP options is shown below:

Total investment = RM43,815

Total savings = RM39,481

$$\text{ROI} = \frac{\text{RM43,815}}{\text{RM39,481}} = 1.1 \text{ years}$$

A comparison between the components' value per ton of fabric before the implementation of CP options and components' value per ton of fabric after the implementation of CP options shows that the highest improvement can be seen in water consumption reduction by 34%. This is followed by fuel consumption and electricity consumption with 19% and 10% respectively.

Table 4.13: Difference between components' value per ton of fabric before and after CP options implementation

Component	Unit	Initial value/ ton fabric	Final value/ton of fabric	Percentage (%)
Electricity	kWh/ ton of fabric	2.1×10^3	1.9×10^3	10
Water	m^3/ ton of fabric	1.0×10^2	6.6 x 10	34
Raw material	ton/ ton of fabric	0.3	0.3	0
Light fuel oil	gallon/ ton of fabric	7.7×10^2	1.5×10^2	19
Solid waste	ton/ ton of fabric	0.01	0.01	0
Wastewater	ton/ ton of fabric	3.1 x 10	3.1 x 10	0
Scheduled waste	ton/ ton of fabric	0.03	0.03	0

From Table 4.13 above, it shows that the highest difference between components' value per ton of fabric before and after CP options implementation is achieved by water consumption with 34%, followed by fuel consumption with 19% and electricity with 10%. However, raw material consumption and the generation of solid waste, wastewater and scheduled waste had no difference at all in terms of percentage. This is due to the insignificance in value per ton of fabric of these components.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

5.1 Conclusion

This study presents an evaluation of CP options implementation in a textile manufacturing industry. It is estimated that the textile factory studied is able to reduce the CO_2 emission from 3,700 to 3,400 kgCO_2/ton of fabric per month. This is equivalent to 8% reduction of CO_2 emission with the implementation of CP options recommended. Thus, the reduction is equivalent to 50 tons of CO_2 a year.

50 tons of CO_2 emitted is equal to 4,456 gallons of diesel consumed by a vehicle. A *Hevea brasiliensis* (Getah) tree with a diameter of 9-17.5 and a height of 12-22 has a carbon sequestration of 1,596 kg per year (Alamah Misni, 2015). Therefore, in this study, in order to offset the carbon dioxide produced in the textile manufacturing factory, 32 *Hevea brasiliensis* trees needs to be planted.

Amongst the 24 CP options that have been identified from various components which were the consumption of electricity, water, fuel, raw material, chemical, and waste generation, 11 CP options were suggested for implementation in the textile manufacturing factory based on their environmental and economic feasibility.

Four CP options for electricity consumption reduction, which were switching off the lights, increasing the temperature of the air conditioner, installation of LED lighting system and also installing the inverter for the compressor were selected. Whereas four CP options for fuel consumption reduction selected consist of heat insulation of hot surfaces, reduction of rinse water temperature, installation of plate heat exchanger and the water reuse system.

Besides that, the two CP options chosen for water consumption reduction are the implementation of counter-current washing and the use of high-pressure sprays for clean-up and one CP options for waste and wastewater management is through proper waste management. The implementation is expected to save RM39, 481 per year with the ROI of 1.1 years.

5.2 Recommendation for Future Work

There are several suggestions that can be done for future studies. One of it is to conduct the audit in a larger textile company to study whether the ROI can be achieved at a faster rate as it involves larger production of textile. Besides that, a more detailed study should be done for each process would be of great advantage as it would be easier to determine suitable CP options to be implemented based on the CO_2 emitted accordingly.

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