# ECO-EFFICIENCY ASSESSMENT AS A SUPPORT TOOL FOR CLEANER TECHNOLOGY: CASE STUDY OF THE CANNED PINEAPPLE INDUSTRY IN THAILAND

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ECO-EFFICIENCY ASSESSMENT AS A SUPPORT TOOL FOR CLEANER TECHNOLOGY: CASE STUDY OF THE CANNED PINEAPPLE INDUSTRY IN THAILAND

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ABSTRACT

Cleaner technology (CT) is the continuous effort to prevent pollution; reduce the use of resources; and minimize wastes in the production process. Some new CT options generated from the CT assessment process provide only one dimension; either an economic dimension or environmental dimension. Each option must be evaluated for quality with the appropriate tool before being selected for implementation.

The concept of eco-efficiency has been widely accepted as a tool to judge the combined environmental and economic performance of production process. The environmental cost-effectiveness (ECE), one type of eco-efficiency, is defined as the ratio of net environmental benefit to net financial cost. In this research, ECE is proposed to support CT and to assess the quality of a CT option in terms of environmental cost- efficiency.

The canned pineapple industry was chosen as a case study whereby ECE was used to determine the most appropriate option to balance the environmental expenditure and economic gain. The reduction of total emissions ($CO_2$, $SO_2$ and $NO_2$) resulted from the proposed options was quantified as the net environmental benefit. The total investment cost was quantified the net financial cost. The relative eco-efficiency levels of each CT option were analyzed by snapshot graph. The results showed that improving the combustion efficiency of a boiler (option 6) provided the highest degree of eco-efficiency and was also located in the fully eco-efficiency level on the snapshot graph. Therefore option 6 presented the best balance an economic and environmental aspect. Option 6 was the most appropriate option and should be implemented in the production process.

Thus, eco-efficiency with ECE can be used as a tool to support CT and to assess the quality of a CT option in a comprehensive manner by considering both environmental and economic benefits at the same time.

KEY WORDS: ECO-EFFICIENCY/ ENVIRONMENTAL COST-EFFECTIVENESS/ CLEANER TECHNOLOGY/ CANNED PINEAPPLE INDUSTRY/ ECO-EFFICIENCY LEVEL

88 pp.

การใช้ตัวประเมินประสิทธิภาพเชิงนิเวศเศรษฐกิจเป็นเครื่องมือสนับสนุนกระบวนการทำเทคโนโลยีสะอาดในกรณีศึกษาโรงงานสับปะรดกระป๋องในประเทศไทย

(ECO-EFFICIENCY ASSESSMENT AS A SUPPORT TOOL FOR CLEANER TECHNOLOGY: CASE STUDY OF THE CANNED PINEAPPLE INDUSTRY IN THAILAND )

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บทคัดย่อ

หลักในการทำเทคโนโลยีสะอาด คือเพื่อป้องกันมลพิษ ลดการใช้ทรัพยากรที่ไม่จำเป็นในกระบวนการผลิต ตลอดจนลดของเสียที่เกิดขึ้นในกระบวนการผลิต แต่บ่อยครั้งพบว่าทางเลือกเทคโนโลยีสะอาดหรือ CT option ที่ผลิตออกมาจะมุ่งเน้นในการปรับปรุงทางด้านเศรษฐกิจหรือสิ่งแวดล้อมเพียงด้านเดียว เพราะฉะนั้นก่อนที่จะเลือกใช้ทางเลือกเทคโนโลยีสะอาดทางเลือกใดทางเลือกทุกทางควรจะได้รับการตรวจสอบคุณภาพด้วยเครื่องมือที่เหมาะสมเสียก่อน

ในการวิจัยนี้ ตัวประเมินประสิทธิภาพเชิงนิเวศเศรษฐกิจ หรือ environmental cost-effectiveness (ECE) ซึ่งแสดงสัดส่วนระหว่างผลประโยชน์สุทธิที่ทางเลือกเทคโนโลยีสะอาดให้กับสิ่งแวดล้อมกับจำนวนเงินลงทุนสุทธิ จะถูกใช้เป็นเครื่องมือประเมินคุณภาพของทางเลือกเทคโนโลยีสะอาด ทั้งในแง่เศรษฐกิจและสิ่งแวดล้อม

ในการประยุกต์ใช้ตัวประเมินประสิทธิภาพเชิงนิเวศเศรษฐกิจมาประเมินคุณภาพทางเลือกเทคโนโลยีสะอาดจะทำในกรณีศึกษาโรงงานสับปะรดกระป๋อง ทางเลือกเทคโนโลยีสะอาดที่นำมาประเมินมีทั้งหมด 6 ทางเลือก แต่ละทางเลือกจะให้ผลประโยชน์ต่อสิ่งแวดล้อมและต้องการจำนวนเงินในการลงทุนในปริมาณที่แตกต่างกัน การวัดประโยชน์ต่อสิ่งแวดล้อม จะคิดจากปริมาณ $CO_2$, $SO_2$ และ $NO_2$ ที่ลดลงต่อปี ส่วนทางด้านเศรษฐกิจจะคิดจากจำนวนเงินลงทุนของแต่ละทางเลือก นอกจากนี้ระดับประสิทธิภาพเชิงนิเวศเศรษฐกิจของทุกทางเลือกสามารถวัดได้โดยใช้ snapshot graph จากผลการวิเคราะห์พบว่า ทางเลือกเทคโนโลยีสะอาดที่ 6 ที่มีชื่อว่า การปรับปรุงประสิทธิภาพการเผาไหม้ของหม้อต้ม มีค่าประสิทธิภาพเชิงนิเวศเศรษฐกิจสูงที่สุด ดังนั้นทางเลือกที่ 6 สามารถให้ประโยชน์ทั้งทางสิ่งแวดล้อมและเศรษฐกิจมากที่สุดเมื่อเปรียบเทียบกับทุกๆทางเลือก ทางเลือกที่ 6 จึงเป็นทางเลือกที่เหมาะสมที่จะนำมาใช้มากที่สุด

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# CHAPTER I
# INTRODUCTION

## 1.1 Background and significance

Since the first era of industrial revolution occurred in the late 18$^{th}$ to early 19$^{th}$ century at some western countries, led to several countries around the world transformed their economic nature to industrialization [10]. Consequently, the exceeding limit on natural resource extraction, the processing with huge energy consumption, water degradation and withdrawals, and the pollution emissions without considering have become the subsequently enormous problems. Therefore, in further industrial revolution era, many countries around the world including world organization have paid much more attention on environmental issue; for instances in 1970s The Environmental Conservation Community of US published agenda of the ’70s to control the usage of natural resources and also limit the pollution emissions to environment [12], in 1972, The United Nations Conference on the Human Environment, at Stockholm, established The United Nations Environment Programme (UNEP) to provide leadership, to encourage partnerships in caring for the environment, and to publish the international regulation or United Nation agenda for challenging the partnership to reach the community targets as well [25]. In current situation, the most target of industrial community is reaching to sustainable development on three prospective pillars comprising of economic growth, ecological balance and social progress [33]. Therefore, to respond the question of how industry could work toward sustainable development, in 1989, UNEP launched the Cleaner Technology Programme as one kind of instruments to support the company to approaches the sustainable development goal [26].

Cleaner Technology (CT) means the continuous application of an integrated, preventative environmental strategy to processes, products and services to increase the efficiency of the company and also reduce risks to humans and the environment

[28]. Moreover, the actions can minimize resource use, and avoid the creation of pollutants, rather than trying to manage pollutants after they have been created. It involves rethinking products, processes and services to move towards sustainable development both environmental and economic sector [8]. This is beneficial to business, industry and environment of the country. Generally, the cleaner technology assessment composes of 5 steps; 1) planning and organization, 2) pre-assessment phase, 3) assessment phase, 4) feasibility analysis phase, and 5) implementation [26]. All procedures are proceeded by CT teamwork who are the expert in relevant parties with special knowledge of that particular industrial sector.

According to CT concept might imply that, CT starts from issues of environmental efficiency which has positive economic benefits, and also it is limited in manufacturing processes only [26]. Therefore, it should notice that some CT options were generated from assessment phase might concentrate at one perspective only (either environmental or economic perspective). Indeed, the characteristic of acceptable CT option has to mention concurrently both environmental and economic dimension [30]. Thus, before implementing any CT option into manufacturing process, each option should be assessed in comprehensive manner with an appropriate tool. Nevertheless, in nowadays, there is no specific tool using for supporting and evaluating the quality of CT option yet. However, in the recent year two world organizations name the World Business Council for Sustainable Development (WBCSD) and the United Nations Environment Programme (UNEP) have been developing and promoting the complementary concepts of CT and eco-efficiency and also have tried to link them for working together by aiming toward the common goal of sustainable development [3]. Moreover, in nowadays there are many examples have shown that both are linked to three dimensions as social, economic and ecological aspect. Applying both eco-efficiency and CT generates tangible economic savings for an enterprise by improving the overall efficiency of its processes. Optimizing resource use and reducing emissions may lead directly to significant savings, so that capital investments can have a short payback period [3]. According to this cooperation, eco-efficiency would be interesting tool which might be used to support CT and also assess the quality of CT options in term of environmental and financial efficiency.

Eco-efficiency was initially defined in 1990 by Schaltegger and Sturm as the ratio of value added to environmental impact added [22]. However, in 1991 the term of eco-efficiency was formally defined and adopted by the WBCSD as “the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth’s estimated carrying capacity” [31]. In generally, eco-efficiency is a key concept which can help companies, individuals, governments or other organizations become more sustainable. Because it brings together the essential ingredients economic and ecological progress which is necessary for economic prosperity to increase with more efficient use of resources and lower emissions of substances that can have adverse environmental consequences [32]. However, the measuring eco-efficiency in several companies usually uses eco-efficiency indicator which expresses by the equation between two eco dimensions of economy and ecology as well as the product or service value per environmental impact [29].

Environmental cost-effectiveness (ECE), one type of eco-efficiency, is defined as the ratio between the environmental improvements to the unit of cost [32]. When new technologies introduced to be employed, ECE is usually used to evaluate the quality of new technology in term of environmental cost efficiency. The technology which requires small amount of investment and produces less environmental impact is the preferred technology. In nowadays, ECE is applied into some kinds of business. For instance, in the recent year, a group of Swiss researches has applied the ECE concept to assess the eco-efficiency of four-end-of-pipe technologies by aiming to find out the most appropriate technology to handle with municipal wastes in the future [23].

The concepts of eco-efficiency and CT are almost synonymous. The slight difference between them is that eco-efficiency starts from issues of economic efficiency which have positive environmental benefits, while CT starts from issues of environmental efficiency which have positive economic benefits [27]. Though, they both help companies in their quest for continuous improvement in minimizing their consumption of resources, reducing environmental burdens and limiting concomitant risks and liabilities [3]. Hence, the linkage of eco-efficiency and CT to work together would boost the potency of CT assessment process and also promote the company to approach the sustainable development goal easily.

This research aims to ensure that the right decisions are made when selecting new CT option implements into the company. Each option would be evaluated the efficiency with ECE in comprehensive manner, by concerning concurrently both environmental and economic benefits for reaching the best CT option selection purpose. Moreover, this study mentions on the establishment of eco-efficiency as a tool to help the decision maker selects the most appropriate CT option to implement as well.

## 1.2 Research objectives

The objectives of this research are as follows:

1. To use eco-efficiency with ECE to evaluate the environmental-cost effectiveness of CT option.
2. To establish eco-efficiency with ECE as a tool to help the decision maker determine the appropriate CT option.
3. To support CT excelling in both economic and environmental area.

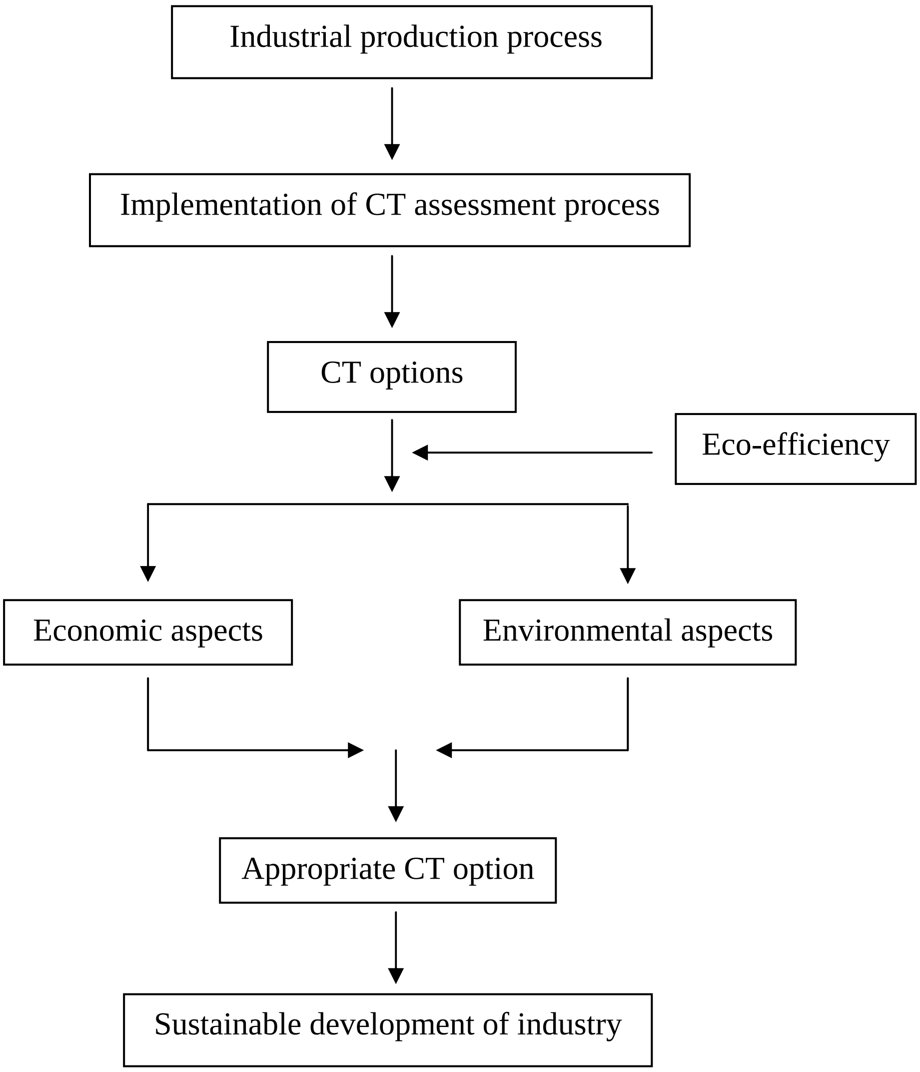
## 1.3 Research questions

1. Could eco-efficiency with ECE be used as CT supporter?
2. Could eco-efficiency with ECE be used as a tool to help the decision maker determine the appropriate CT option to implement in the company?
3. What is the appropriate CT option which should be selected to implement in the company?

## 1.4 Hypotheses

1. Eco-efficiency with ECE can be used as CT supporter.
2. The eco-efficiency indicator can be used as a tool to help the decision maker determines the appropriate CT option to implement in the company.
3. The selected CT option must concern both environmental and economic issue at the same time by reducing environmental impacts while increasing economic values to company.

## 1.5 Conceptual framework



## 1.6 Scope of research

The scopes of this research were to study the characteristic of CT and investigate which part of CT can be supported or evaluated by eco-efficiency with ECE. Afterward, the eco-efficiency with ECE was applied into canned pineapple industry for (i) analyzing the quality of six CT options, (ii) evaluating the most appropriate CT option of canned pineapple industry, and (iii) supporting CT excelling in both economic and environmental area.

ECE equation, which was defined as the ratio between net environmental benefit (NEB) to net financial cost (NFC), was used to analyze the quality of each CT option in term of environmental cost efficiency. The amount of emission gases reduction in a year after implementing CT option was quantified the amount of NEB whereas the total cost of implementing CT option was quantified the NFC.

The application of eco-efficiency with ECE in canned pineapple industry was separately studied in 4 steps: (i) the economic aspect and environmental aspect of proposed CT options was evaluated individually, (ii) the economic and environmental aspect of CT option was studied concurrently by calculating the environmental cost efficiency of each CT option (ECE figure) with ECE equation, (iii) the relation between economic aspect, environmental aspect and ECE figure of every option was analyzed by environmental fingerprint, and (iv) the eco-efficiency level of each option was determined by plotting on snapshot graph.

# CHAPTER II
# LITERATURE REVIEW

This chapter collects theories and basic information regarding to cleaner technology and eco-efficiency. Moreover, some practices of eco-efficiency in industries are also shown. The details of this chapter comprise the following topics:

2.1 Basic knowledge of cleaner technology
- 2.1.1 Principle of cleaner technology
- 2.1.2 Definition of cleaner technology
- 2.1.3 Cleaner technology assessment in industries
  - 2.1.3.1 Planning and organization
  - 2.1.3.2 Pre-assessment phase
  - 2.1.3.3 Assessment phase
  - 2.1.3.4 Feasibility analysis phase
  - 2.1.3.5 Implementation and Continuation
- 2.1.4 Benefit of cleaner technology applications

2.2 Basic knowledge of eco-efficiency
- 2.2.1 Eco-efficiency concept and purpose
- 2.2.2 Measuring eco-efficiency
- 2.2.3 Eco-efficiency indicators

2.3 Practices of eco-efficiency in industries

## 2.1 Basic knowledge of cleaner technology

### 2.1.1 Principle of cleaner technology

Cleaner technology (or Cleaner Production) is the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner technology can be applied to the processes used in any industry, to products themselves and to various services provided in society [3].

- For production process, cleaner technology results from one or a combination of conserving raw materials, water and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process.

- For product, cleaner technology aims to reduce the environmental, health and safety impacts of products over their entire life cycles, from raw materials extraction, through manufacturing and use, to the ultimate disposal of the product.

- For services, cleaner technology implies incorporating environmental concerns into designing and delivering services.

### 2.1.2 Definition of cleaner technology

"*Cleaner Technology is defined as a measure to improve or adjust production processes or products, so that consumption of raw materials, energy and natural resources is accomplished efficiently, with minimum waste or none at all.*
*It is pollution reduction at source, including substitution of raw materials, recycling and re-using, which will help conserve the environment and simultaneously reduce production costs*" [5].

This definition emphasizes the reduction of environmental impacts at the source.
It considers the inputs rather than the outputs in the search to produce more goods with less waste and emission. Optimizing the use of all inputs in production i.e., raw materials, energy, natural and human resources, is the cleaner technology approach.

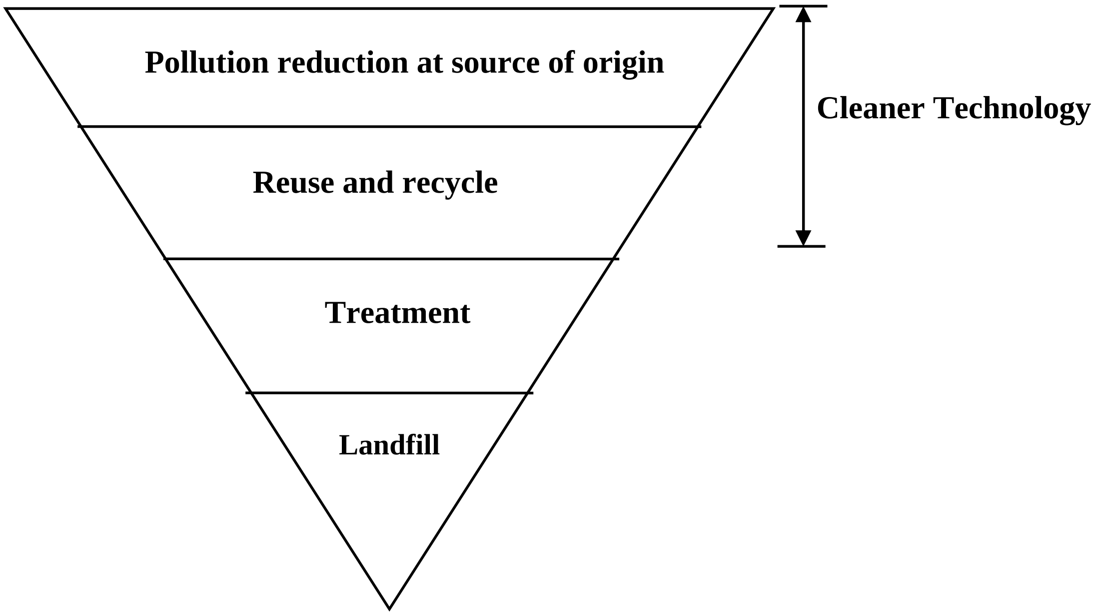



**Figure 2.1. Diagram for scope of cleaner technology** [26]

### 2.1.3 Cleaner technology assessment in industries

The cleaner technology assessment methodology is used to systematically identify and evaluate the cleaner technology opportunities and facilitate their implementation in industries. By the way, the main objectives of cleaner technology assessment can be divided into 3 categories as below:

1) to analyze the diagram of processing
2) to identify the waste source of origin and its cause
3) to propose selective proposals and guideline for correction

Normally, cleaner technology assessment process is most often separated in five phases which are outlined in Figure 2.2. This procedure is useful in organizing the cleaner technology program in a company and bringing together persons to be involved with the development, evaluation and implementation of cleaner technology measures [26]. The flow chart below illustrates process of cleaner technology assessment.

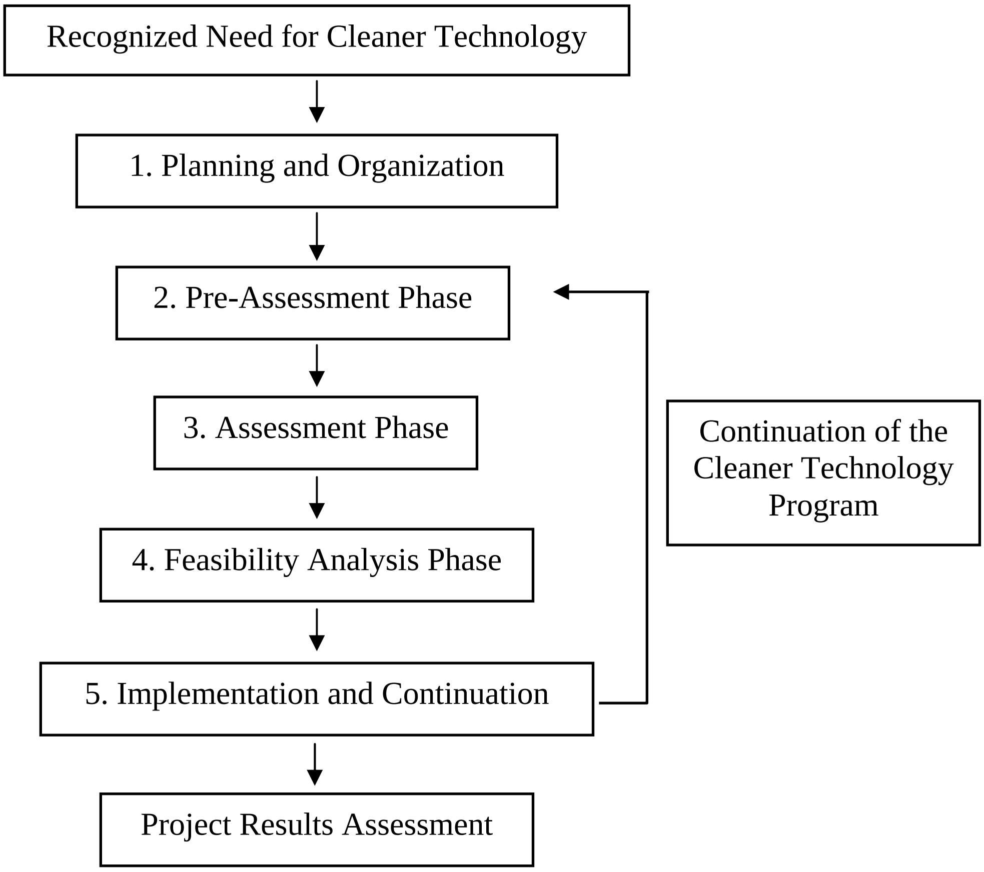



**Figure 2.2. Cleaner technology assessment process** [26]

**2.1.3.1 Planning and organization**

An organized approach is necessary to identify, evaluate and implement cleaner technology opportunities. Cleaner technology assessments are undertaken with a view to avoid or at least reduce the generation of waste and emissions. Moreover, it is expected that these options will in turn change existing management and information systems, and thus support and facilitate further cleaner technology activities [26].

The work starts firstly at organizing a project team. In order to be effective, the project team should have enough process knowledge to analyze and to review the present production practices, enough creativity to develop and to evaluate changes for the current production practices, and enough authority to implement and to maintain the proposed changes in the production practices. Second step, the barriers and solutions are identified. In order to develop workable solutions, the project team should identify the site-specific barriers to cleaner technology implementation which might exist. Finally step, the project team has to set plant-wide goals for the assessment. The tendency of companies to underestimate the cleaner technology potential in the first place, is often reflected in comparatively low goals.

Cleaner technology planning is a systematic, comprehensive method for identifying options to reduce or avoid the generation of waste. The cleaner technology planning process itself also has its own results and benefits. The benefits of cleaner technology planning can be classed as:

1) A careful planning process can ensure the selection and implementation of the most cost-effective cleaner technology options.

2) Systematic planning ensures that cleaner technology objectives and activities are consistent with those identified in the organization’s boarder planning process.

3) Effective cleaner technology planning facilitates boarder business planning investment analysis and decision-making (such as capital budgeting and purchasing).

4) A documented cleaner technology plan may be a condition for receiving financing or insurance at better rates.

### 2.1.3.2 Pre-assessment phase

Pre-assessment is the step for primary survey of area with loss and worth of adjustability. The operation is almost applied by common sense without detailing. The result of pre-assessment is applied for guideline of area or source identification leading to assessment in the 3rd procedure [26].

**Objective of pre-assessment phase**

Objectives of the pre-assessment phase are to prepare diagram of processing workflow, to assess an input/output of all substance, and to identify areas/issues for assessment.

**Procedure of pre-assessment phase**

The procedure of pre-assessment can be described as followed detail:

1) Preparation of diagram for processing workflow

Normally, the data that is used in this procedure is gained from 2 sources including from documents, and from walk through survey with remarkable principles. After collecting necessary data completely, the collected data were used for drawing the principle working flowchart by firstly: drawing material storage, logistics, maintenance, and waste disposal, secondly: linking of working steps subsequently, and finally, recording of input/ output in various steps of substances/ energy.

2) Input-Output of substances/energy assessment

This process starts by preparing checklist of input-output substances/energy of each working procedure for loss calculation in terms of expenditures and for both identification and priority of environmental issues such as the loss of unqualified products, so calculate the cost of loss by using product prices.

3) Identify area of assessment

In this process, the area or issues which are assessed are firstly arranged and further prepare preceding option checklist in monetary check loss cost. For instance, identify the area that produces high impact for workers, environment and also living things etc.

#### 2.1.3.3 Assessment phase

According to high loss in areas or point of sources and required improvement, the assessment is undertaken to substances balancing and input/output energy as well as identifying the cause and point of sources, energy loss, risk, improper working conditions. Then checklist and options priority of options is prepared for improvement.

**Objective of assessment phase**

Objectives of the assessment phase are: to prepare substances balancing, to identify the cause and point of sources of waste, energy loss, risk and improper working conditions, and to propose and prepare CT option priority of feasibility for further study.

**Procedure of assessment phase**

The procedure of assessment can be described as followed detail:

1) Substances balancing preparation

The procedure require consideration of input/output of system substances in respect of kinds and volume that details for kind, quantity, and substance prices of input/output of the system.

2) Cause and point of lost source analysis

This kind of analysis would be considered according to 5 factors of loss as well as raw material, technology, management, waste and products. Anyway, the point and source of loss is usually divided as a) point of pollution sources, waste and loss, b) cause of pollution, waste and loss.

3) CT option generation

In this process always considers regarding from 5 factors as well as raw material, technology, management, waste and products for responding to major purpose as well as creating a vision on how to eliminate or control each of the causes of waste and emission generation. However, the CT option generation is always provided by CT teamwork and the method for generating CT options is various up to the brainstorming of committee.

4) CT Option selection

The various kinds of generated CT option would be selected by decision maker of industry that might be the NGO or manager etc. By the way, the selected option should be appropriate and accord to the nature of problem, especially it should brings the better performance both economic and environmental sector of industry.

#### 2.1.3.4 Feasibility analysis phase

The feasibility studies have to prove whether each of the options is technically and economically feasible and whether it contributes to the environmental improvement.

**Objective of feasibility analysis phase**

Objectives of the Feasibility Analysis Phase are: to identify level of details for studying each option, to assess affordable investment, and to select CT option for further practice and find the most appropriate CT option

**Procedure of feasibility analysis phase**

The procedure of feasibility analysis can be described as followed detail:

1) Pre-assessment

The options are sorted in order to identify additional evaluation needs. Managerial options do not always require a technical evaluation, while equipment-based options do. Similarly, simple options normally do not require an environmental evaluation, while complex options do. Finally, cheap options do not require a detailed economic evaluation, while expensive options may.

2) Technical assessment

The technical evaluation consists of two interrelated parts. First, it should be evaluated whether the option can be put in practice. This requires a check on the availability and reliability of equipment, the effect on product quality and productivity, the expected maintenance and utility requirements and the necessary operating and supervising skills. Second, the changes in the technical specifications can be converted into a projected materials balance, reflecting the input and output material flows and energy requirements after implementation of the cleaner technology option. The options which do not need capital expenditure, for example housekeeping measures, can often be implement quickly. It is a typical fast-track approach. If capital investment is needed for the chosen option, it is advisable to appoint an ad-hoc group of experts, to make a technical evaluation based on selected evaluation criteria. Raw material, equipment or process changes are expensive and may effect changes in production line or product quality. Therefore, technical evaluation of such option requires more complex investigation.

3) Economic assessment

The economic assessment consists at least of data collection (regarding investments and operational costs, and benefits), choice between evaluation criteria (payback period, Net Present Value or Internal Rate of Return) and feasibility calculations. The economic data collection builds upon the results of the technical evaluation. In order to properly incorporate the long term economic advantages of cleaner technology, it is highly recommendable to apply Total Cost Assessment principles to the economic evaluation (especially for high cost options).

4) Environmental impact assessment

The objective of environmental evaluation is to determine the positive and negative impacts of the option for the environment. An environmental evaluation must take into account the whole life-cycle of a product or service. There are essentially two types of life-cycle analysis: quantitative and qualitative. The quantitative method involves developing a set of criteria against these criteria. Criteria may be developed using parameters such as: the cost of disposal or clean-up of the wastes generated at all stages in the life-cycle; the amount or cost of energy used at all stages in the life cycle; etc. The other, qualitative approach is more useful for this assessment. It involves drawing up a matrix of environmental issues versus life cycle stages.

5) CT option selection for implementation

First, the technical non-feasible options and the options without a significant environmental benefit can be eliminated. All remaining options can in principle be implemented. However a selection is required in case of completing options or in case of limited funds.

#### 2.1.3.5 Implementation and Continuation

In the last phase, the feasible prevention measures are implemented and provisions taken to ensure the ongoing application of cleaner technology. The development of such an ongoing program requires monitoring and evaluation of the results achieved by the implementation of the first group of prevention measures.

**Objective of implementation and continuation**

Objectives of implementation and continuation are: to prepare implementation plan, to propose CT option for implementation, to evaluate the result after implementation, and to proceed continuous CT activities.

**Procedure of implementation and continuation**

The procedure of implementation and continuation can be described as followed detail:

1) Prepare cleaner technology plan

The measures are organized according to the expected data of implementation. Additionally, the person or department with the prime responsibility for the implementation should be identified [26].

2) Implement feasible cleaner technology measures

The effort needed to implement cleaner technology measures can vastly differ substantially. Simple measures can easier be implemented. However, the focus should be on complex measures, which require a substantial investment. Implement of these options can require a detailed preparation such as planning the installation and funding requirements. Next, the installation of equipment requires supervision in order to safeguard optimal use of the new facilities [26].

3) Monitor cleaner technology progress

Simple indicators should be used to monitor progress and to keep the management as well as other interested parties frequently informed. The choice of the measurement method is crucial. It can be based on changes in waste quantities, changes in resource consumption or changes in profitability. The evaluation of the monitoring data should include changes in the production output and/or changes in the product mix [26].

4) Sustain cleaner technology

The ongoing application of the cleaner technology concept may require structural changes in the organization and management system of the company. The key areas are: integration into the technical development of the company, proper accountability of waste generation, and employee involvement. The integration into the technical development could include preventive maintenance schedules, integration of environmental criteria (such as energy and resource consumption) the selection of the new equipment or integration of cleaner technology into long-term research and development plans. Employee involvement can be achieved by staff education, creation of regular opportunities for two-way internal communication and employee reward program [26].

### 2.1.4 Benefit of cleaner technology applications

1) Saving for input of factory such as water, raw materials, and energy as well as pollution reduction by reuse or recycle.

2) In respect of increasing efficiency, it will make more benefit in term of raw material and energy saving, as well as cost reduction which makes more profit and increasing competition capacity.

3) Decreasing of waste disposal cost, pollution reduction at source of origin will efficiently eradicate the pollution volume that will automatically save the treatment cost.

## 2.2 Basic knowledge of eco-efficiency

### 2.2.1 Eco-efficiency concept and purpose

Development of technologies can help to diminish this generation of waste and pollution. The objective in eco-efficiency is to create more out of less input so that the standard of well being remains at least at its present level at the same time as environmental impacts are reduced. Eco-efficiency also offers clear quantitative measures and targets for the attainment of this goal.

The concept of eco-efficiency was first introduced and discussed by Schaltegger and Sturm in 1990 [22], [34] and arrived as a result of the need for instruments that can translate sustainable development into working targets. Eco-efficiency emerged in the 1990s as a ‘business link to sustainable development’ [14]. Several definitions and interpretation on the concept of eco-efficiency have emerged. The World Business Council for Sustainable Development (WBCSD) defines eco-efficiency as:

“The delivery of competitively-priced goods and services that satisfy human needs and bring life circle, to a level at least in line with the earth’s estimated carrying capacity”[31].

Eco-efficiency is a management strategy which encourages industry and business to achieve the sustainability with more economic benefits. Eco-efficiency is relevant throughout an entire organization and applies to marketing and product development as well as manufacturing and distribution [4]. It focuses on business opportunities and allows companies to become more environmentally responsible and more profitable parallel to this. It is expected to fosters innovation and create growth and competitiveness.

It is important to understand that eco-efficiency is not limited simply to make incremental efficiency improvements in existing practices and habits. That is much too narrow a view. On the contrary, eco-efficiency should stimulate creativity and innovation in the search for new ways of doing things. Nor is eco-efficiency limited to areas within a company’s boundaries, such as in manufacturing and plant management. It is also valid for activities upstream and downstream of a manufacturing plant and involves the supply and product value-chains. Consequently, it can be a great challenge to development engineers, purchasers, product portfolio managers, marketing specialists and even finance and control. Eco-efficiency opportunities can emerge at any point in the entire life-cycle of a product [15].

In order to improve the eco-efficiency in companies, there are several implementations that can be done. The WBCSD has identified seven elements that business can use to increase their eco-efficiency, this in order to achieve more value from lower inputs of material and energy with reduced emissions [15]. The elements reduce material and energy intensity, reduce dispersion of toxic substances, enhance recyclables, maximize use of renewable, extend product durability and increase service intensity.

Eco-efficiency calls for businesses to achieve more value from lower inputs of materials and energy and with reduced emissions [15]. The concept is comprised in three objectives where the seven elements are found in and objectives are:

1) Reducing the consumption of resources. Minimizing the use of energy, material, water and land. Increase the recyclability, product durability and closing material loops.

2) Reducing the impact on nature. Minimizing emissions to air and discharges to water, waste disposal and the use of non-renewable resources.

3) Increasing product or service value. Providing more customer benefits e.g. through product functionality and flexibility, the customer receives the same or an enhanced function with less resources and materials.

Many global, regional and national organizations have also formulated their own definition of eco-efficiency although the notion of “production more with less” is central to all of them (see Table 2.1).

**Table 2.1. Selected definitions of eco-efficiency [2]**

| No | Organizations | Definitions |
|---|---|---|
| 1 | World Business Council for Sustainable Development (WBCD) | Achieving more value from lower inputs of material and energy and with reduced emissions |
| 2 | Organization for Economic Cooperation and Development (OECD) | The efficiency with which ecological resources are used to meet human needs |
| 3 | European Environment Agency | Creating more welfare from less nature |
| 4 | United Kingdom Envirowise Program | Maximizing output of product or service from a given level of materials and energy (also referred to as resource efficiency) |
| 5 | Industry Canada | It is the art of doing more with less, of minimizing costs and maximizing value |
| 6 | Atlantic Canada Opportunities Agency | Creating quality products and services while reducing resource use, waste and pollution along the entire value chain |
| 7 | Australia Environmental Protection Agency | Going beyond resource use and pollution prevention by increasing the value of goods and services while providing for the competitive needs of business |
| 8 | BASF Corporation | Using as few materials and energy as possible in producing our products while keeping emissions as low as possible and helping our customers conserve resources |
| 9 | Environmental Finance Group International Finance Corporation | Increasing sustainability of resources use through more efficient production methods |

### 2.2.2 Measuring eco-efficiency

There are several reasons why companies choose to measure their eco-efficiency performance, because it can be tracking and documenting performance, identifying cost savings and benefits, identifying and prioritizing of opportunities for improvements. Eco-efficiency goes beyond simply preventing pollution and limiting the use of resources in manufacturing and production, it provides for the competitive needs of business by enabling increases in the value of goods and services [7].

The WBCSD has made a framework in order to measure eco-efficiency that is intended to be flexible and easy enough to be used in the whole business spectrum [29]. An eco-efficiency index measures the environmental performance of a company or product with considerations to its financial performance. The index is a ratio between the environmental and financial variables [24] and can be represented as:

$$\text{Eco-efficiency} = \frac{\text{Product or service value}}{\text{Environmental profile (influences)}}$$

Increasing the eco-efficiency can be accomplished by providing more value with a decrease in the environmental influence or resource consumed for the evaluated product or service.

### 2.2.3 Eco-efficiency indicators

Eco-efficiency indicators linking the environmental and financial performance can be used to forecast the impact of environmental issues on future financial performance [17]. When measuring eco-efficiency, it is important that the measurement programs are scientifically supportable, relevant, accurate and useful therefore the indicators should be based on a set of defined principles [29]. The WBCSD recommends that the indicators should be based on eight principles that can be adopted in any field of business when measuring the performance of an organization or a specific product. Thus, eco-efficiency indicators should be based on following:

1) The environmental and human health protecting - the principal goal of eco-efficiency is to bring comprehensive change on environmental performance that provides value to society with producing innovative goods or services [29].

2) The improvement of the organization performance - the immense concerns on how effectively processes and products can be modified to ensure the less consumption as well as less emission after having information on existing conditions.

3) The inherent diversity of organization or business indicators are different for specific nature of different industries that utilize special materials and producing products, however, assumption is here that sets of indicators are universal. This denotes environmental release of chemical industry is entirely different from steel industry and indicators are designed accordingly.

4) The benchmark and monitor overall time regularly monitor the process performance from past to present with respect to value of benchmarking. The design of indicator removes the impact of extraneous factors existed in products and environmental performance that is irrelevant and maximizes eco-efficiency. Data recorded amongst various processes and products within reporting period should result meaningful information.

5) Clearly defined, measurable, and verifiable different indicators should be defined prior to evaluation and stated process of data collection in order to have genuine result.

6) Understandable and meaningful to identified stakeholders clearly understandable to concerned managers and external stakeholders so that data from processes and products can be carefully considers and limitations of individual indicators are understood [29].

7) Based on an overall evaluations of industry's operation, products, and services, especially focusing on all those areas that are of direct management control use of resources, characteristics of products, manufacturing processes should be under influence so that it can be altered with selection of materials, modify the processes, and develop the design of products taking care of needs of end users. All relevant areas of industry should be carefully observed before indicators formulation.

8) Recognize relevant and meaningful issues related to upstream (e.g. suppliers) and downstream (e.g. product use) aspects of a industry's activities out of internal activities of industry there are indirect influences of environmental, economical, and social from both upstream and downstream agents. Upstream agents could be electricity suppliers and consumption of electricity in industry indirectly emits $CO_2$ in generating location that contributes to global warming potential. If it is considered to have life cycle evaluation of eco-efficiency, it includes also indirect effect from productions of materials in either extraction or processing phase also called "cradle-to-gate". Similarly, it accounts the downstream effect of using and disposing of products by end users ("gate-to-grave" concern). In line with this relevant issues and industry's concern, indicators are selected to evaluate much alarmed effects.

Anyway, the WBCSD defines two types of the eco-efficiency indicators as follows:

1) Generic eco-efficiency indicators

The generic eco-efficiency indicators determined by Global Reporting Initiative (GRI) and WBCSD are adopted as guiding indicators for evaluating eco-efficiency in all type of industry sectors according to their nature and requirements. These guiding indicators are applicable to regardless of any type and any size of specific industries/enterprises in accordance with processes and measurement required. Some of the generic eco-efficiency indicators are listed below and could be adopted according to following terms revealed in Table 2.2:

- Total energy use
- Total electricity use
- Total fuel use
- Other energy use
- Total material use other than fuel
- Total waste use
- Non product output (NPO, defined as waste) returned to processes or market and quantity of non product output to land by material type
- Emission to air by type
- Discharge to water by type

**Table 2.2. Generic eco-efficiency indicators [1]**

| Environmental withdrawals (Input) | Unit | Environmental releases (output) | Unit |
|---|---|---|---|
| **USE OF ENERGY** | | **POLLUTION RELEASES** | |
| - Energy consumption (excluding coke) | GJ | - Air emissions | T, |
| | | - $CO_2$, $N_2O$, $HFC_s$, $PFC_s$, | T $CO_2$ eqv., |
| - Type of energy consumption (fossil/non fossil or more detailed: coal, fuel, oil, natural gas or solid, liquid, gaseous, electricity) | GJ | $SF_6$, $SO_2$, $NO_x$, | T $SO_2$ eqv. |
| | | NMVOC | T |
| | | - Waste water discharge heavy metals: Pb, Hg, Cd, Cr, Cu, As, Ni, and Zn | T |
| - Energy sources (renewable/non renewable) | GJ | - Waste water discharge others: N, P, BOD, and COD | |
| **USE OF OTHER NATURAL RESOURSES** | | **WASTE GENERATION/ BY-PRODUCTS** | |
| - Water consumption | $m^3$ | | T |
| - Land-use | $m^2$ | - Waste generation ( all hazardous waste) | |
| - Use of renewable and non-renewable resources | T | | T |
| - Recovery of waste materials | T | - Total amount of industrial waste for disposal ( including hazardous) | |

2) Sub-sector eco-efficiency indicators

Despite above generic eco-efficiency indicators, some specific sub-sector eco-efficiency indicators could be selected in consistent with necessary indicators for implementation to metal industry tabulated in Table 2.3. However, other sub-sectors industry can constitute or adopt relevant eco-efficiency indicators according to their calculation of raw materials utilized, air emissions released or global environmental impacts on ozone (emission of Chlorine; $Cl_2$), green house gases ($CO_2$, $N_2O$, $HFC_s$, $PFC_s$, $SF_6$, and $CH_4$), acidification ($SO_2$). Indicators could be sorted depending upon other impacts on water, and surrounding trough discharge heavy metals (Pb, Hg, Cd, Cr, Cu, As, Ni, and Zn) or nature of generation of other wastes in order to track and evaluate it for ensuring better environmental performance. Sub-sectors industry may be chemical, tannery, diary and food, wine and beverages, oil and fat, textiles, cement and refractory, drugs and pharmaceuticals, pulp and paper, plastics, polymers etc [19].

**Table 2.3. Sub-sector eco-efficiency indicators [1]**

| Environmental withdrawals (Input) | Unit | Environmental releases (output) | Unit |
|---|---|---|---|
| **USE OF ENERGY** | | **POLLUTION RELEASES** | |
| - Type of energy consumption (fossil/non fossil fuel,coal, diesel oil, furnace oil, natural gas, gasoline, kerosene, electricity) | GJ | - Air emissions<br>- $CO_2$, $N_2O$, $HFC_s$, $PFC_s$, $SF_6$, $SO_2$, $NO_x$, NMVOC | T,<br>T $CO_2$ eqv.,<br>T $SO_2$ eqv.<br>T |
| - Energy sources (renewable/non renewable) | GJ | - Waste water discharge heavy metals: Pb, Hg, Cd, Cr, Cu, As, Ni, and Zn | |
| **USE OF OTHER MATERIALS AND NATURAL RESOURSES** | | **WASTE GENERATION/ BY-PRODUCTS** | |
| - Water consumption | $m^3$ | - Waste generation: iron cutting, chips, burrings, zinc dross, slag, and zinc powder | T |
| - Land-use | $m^2$ | | |
| - Iron billets, aluminum strips, hot rolled sheets, zinc ingot, tin ingot, aluminum ingot, lead ingot, hydrochloric acid, HDPE caps, bundling wire | T | - Liquid waste: oils and grease | T |

Eco-efficiency from a concept into a reality, industries must measure and monitor their performance in order to get goals for improvement and to track and quantify the improvement. According to WBCSD, eco-efficiency indicators assist in decision-making to evaluate performance, set targets, and initiate improvements measure in advance. Among various indicators mentioned above, necessary indicators could only be adopted to the extent of what industry requires, in accordance with their operation. During the study, it sound specify particular boundary, reporting duration of industry, and collect the data for measurement of indicators. Additionally, performance is compared by using indicators over time and between companies [18].

## 2.3 Practices of eco-efficiency in industries

Worldwide have many researches related business and industry which use eco-efficiency as tools for analysis. The ultimate aim of eco-efficiency is to consider activities with evaluation to improve the performance of enterprises. WBCSD has brought the eco-efficiency indicators with two dimensions comprising of economic and ecology as the ratio of product or service value to the environmental influence. This topic purposes to collect some researches which are related to this study and illustrate as information below.

Cote et al. (2006) and his colleague was research eco-efficiency of SMEs in Nova Scotia, Canada. This paper describes a study undertaken by the Eco-Efficiency Centre of the levels of eco-efficiency demonstrated by small and medium enterprises in Nova Scotia. After reviewing a large number of environmental management and eco-efficiency tools, they opted to develop its own checklist. The study has found that low levels of eco-efficiency were demonstrated by all businesses. This finding suggests that there is much room for improvement and further that economic and environmental benefits can be derived by working toward eco-efficiency.

Park et al. (2006) and his colleague studied in the Korean electronics industry. This study discusses how to stimulate the development of the eco-efficiency assessments in the Korean electronics industry. It surveyed best practices related to the eco-efficiency assessment and communication around the world. The applicability and usefulness of eco-efficiency assessments was tested through discussions with the Korean electronics industry. The five selected companies are presented in the trends classification of eco-efficiency, adopted from Anite system. The semi-structured interviews with corporate managers revealed that an eco-efficiency has an appeal for the companies as a philosophical concept denoted as doing more with less, while a lot of effort needs to be made to get companies to actually initiate eco-efficiency assessments. There is an urgent need to increase the simplicity in the eco-efficiency assessment framework and to clarify its implications to the business operation. In addition, the role of the government related to capacity building is very important.

Kharel and Charmondusit (2007) presented the eco-efficiency of energy intensity, material consumption, water use, waste generation, and $CO_2$ emission in terms of production value in net sales (US$) per environmental influence using empirical evaluation. Evaluation has been considered only within production process boundary of iron rod industry. Evaluation of eco-efficiency tried to couple the economic and environmental influences of industry to know economic and environmental excellence. Eco-efficiency of iron rod industry was quantitatively analyzed and determined such as energy, material consumption, water use, waste generation, and $CO_2$ emission, which have been increased gradually along with increased production during analysis period of five years (year 2001-2005). While comparing each year's eco-efficiency of all above mentioned parameters, eco-efficiencies were increased that indicates less resource use and less waste released. As a general statement of overall comparison and characterization of eco-efficiencies of five years duration, iron rod industry was eco-efficient in all aspects. Eco-efficiency being an emerging trend has not yet been implemented in Nepal. It is further recommended to adopt the eco-efficiency evaluation in other industries. In addition, it is high time to augment the provision of eco-efficiency concepts in industrial policy and legislation concerned.

Stefanie et al. (2005) have proposed the indicator called the environmental cost efficiency or ECE to assess four end-of-pipe technologies for municipal solid waste treatment, comprising of sanitary landfill, mechanical-biological treatment, modern gate incineration, and a staged thermal process. By the way, the ECE is defined as the ratio of net environmental benefits to the difference in costs. In term of environmental aspect, they performed life-cycle assessment on theses processes to quantify the net environmental benefit, while the approximate net costs (cost minus benefits) were quantified for economic aspect. The results showed that, relative to gate incineration, sanitary landfills and mechanical-biological treatment are less costly but environmentally more harmful. They also calculated the ECE for all combinations of technologies and the results indicated that the staged thermal process may be the most environmentally cost-efficient alternative to all other treatment technologies in the long run, followed by mechanical biological treatment and gate incineration, respectively.

Maxime et al. (2006) studied eco-efficiency indicators for the Canadian food and beverage industry. This paper presents the rationale and the framework of the project currently under development addressing the following environmental issues: energy use, emission of greenhouse gases, water use and wastewater generation, organic residues, and packaging residues. They will be developed based on collected data and estimated impact levels, and reported by FBI sub-sector, geographical location, and establishment size. The approach they have chosen is based on a physical gate-to-gate analysis in which input and output flows are considered (using assessments) across the boundaries of the system defined by the industrial establishment. They have problem about on getting quality and reliable data on selected indicators. This paper summarizes the initial steps in this effort, which involved identification of environmental issues that could be addressed through a set of simple yet robust eco-efficiency indicators. An initial formal expression of the indicators is presented.

# CHAPTER III
# METHODOLOGY

This chapter describes the research methodology that is divided into 2 sections; (i) the primary study of the characteristic of CT, and (ii) the application of eco-efficiency with ECE into case study. However, the topic of the application of eco-efficiency with ECE into case study is categorized into 4 subsections as economic aspect evaluation, environmental aspect evaluation, economic and environmental analysis with ECE, and eco-efficiency level analysis. Each methodology is described as information below.

## 3.1 The primary study of the characteristic of CT

The characteristic of CT and the five steps of CT assessment process were analyzed. Afterward, the strengths and weaknesses of CT were identified.

## 3.2 Application of eco-efficiency with ECE into case study

Twelve canned pineapple industries which were currently under the supervision of the Department of Industrial Works (DIW) were used as a model to study the application of eco-efficiency with ECE to support CT. The main goal of DIW to implement CT in twelve canned pineapple industries was to reduce the consumption of fuel oil with 2% of sulfur in the production process. Each canned pineapple industry generated different kinds of CT option. CT options were produced from twelve canned pineapple industries included six CT options as (i) The installing of a positioner system for controlling steam supply system in an exhaust box (option 1), (ii) The improving of steam supply system in a sterilizing cooker (option 2), (iii) The installing of an automatic steam supply system in an exhaust box (option 3), (iv) The installing of an automatic steam supply system in a sterilizing cooker (option 4), (v) The installing of a positioner system for steam supply control of a sterilizing cooker (option 5), and (vi) The improving of combustion efficiency of a boiler were introduced (option 6) were introduced. Each CT option from twelve canned pineapple industries required not only different amount of financial investment but also had different amount of fuel oil consumptions.

The application of eco-efficiency with ECE in canned pineapple industry was separately studied into 4 steps: (i) the economic aspect and environmental aspect of proposed CT option was evaluated individually, (ii) the economic and environmental aspect of CT option was studied concurrently by calculating the environmental cost efficiency of each CT option (ECE figure) with ECE equation (equation 1), (iii) the relation between economic aspect, environmental aspect and ECE figure of every option was analyzed by environmental fingerprint, and (iv) the eco-efficiency level of each option was determined by plotting on snapshot graph.

Environmental cost effectiveness (ECE), an eco-efficiency indicator, was defined as the ratio of net environmental benefit (NEB) to net financial cost (NFC) by showing in the equation (1).

$$ECE = \frac{NEB}{NFC} \qquad (1)$$

NFC included the net cost of implementing new CT option. The unit of measurement was monetary. NEB referred to the reduction of total emission gases comprised of $CO_2$, $SO_2$ and $NO_2$ in a year. The reduction of emission gases was calculated from the reduction of fuel oil consumption by following the IPCC guideline [11]. The unit of NEB was kilograms per year. The calculation of NEB was explained in equation (2).

$$NEB = \sum_{n=1}^{N} cf_n Rf \qquad (2)$$

Where: *cf* referred to conversion factor for computing gas *n*. *Rf* was liters of reduced fuel oil consumption in a year.

### 3.2.1 Economic aspect evaluation

In this section, the most appropriate option with the lowest investment was purposed to find out. The total investment of each option in unit of baht was compared and then was ranked. The option with smaller investment indicated more appropriate option whereas higher investment identified improper option.

### 3.2.2 Environmental aspect evaluation

In environmental aspect, three environmental indicators including (i) the requirement of fuel oil consumption yearly, (ii) the amount of total emission reduction in a year, and (iii) the reduction of annually environmental impact comprising of global warming potential, acidification potential, and human toxicity potential were used as the models to determine the suitable option. The value of each CT option in the same indicator category was compared and was then ranked. Lower amount of fuel oil requirement yearly indicated more appropriate CT option. Otherwise, the highest amount of emission reduction in a year and the biggest number of the reduction of annually environmental impact showed the preferred CT option to implement.

For the study of the requirement of fuel oil consumption yearly, the amount of fuel oil consumption of each CT option whether before implementing CT option or after implementing CT option was analyzed. Additionally, the amount of fuel oil consumption reduction of every CT option was studied as well. The unit of this study was l/yr.

In order to study the amount of total emission reduction in a year, the summation of $CO_2$, $NO_2$, and $SO_2$ reduction was determined. Each emission gas was calculated from multiplying the reduced amount of fuel oil consumption with the conversion factor. The conversion factor for calculating $CO_2$, $NO_2$, and $SO_2$, the emission gases from the combustion of fuel oil with 2% sulfur, is 2.5, 0.035, and 0.0019 kg/l, respectively [11]. The unit of total emission reduction in a year was kg/yr.

In term of studying the reduction of annually environmental impact, global warming potential (GWP), acidification potential (AP), and human toxicity potential (HTP) were computed by following IPCC method [11]. Every environmental impact category was calculated from the annual reduction of $CO_2$, $NO_2$, and/or $SO_2$ in kg/yr. The calculation of each environmental impact category was expressed in equation (4).

$$E_1 = \sum_{k=1}^{K} ec_k B_k \quad \text{(kg)} \qquad (4)$$

Environmental impact regarding to GWP, $B_k$ represents the reduction of greenhouse gas $k$. GWP factors, $ec_k$, for different greenhouse gases are expressed relative to the global warming potential of $CO_2$.

Environmental impact regarding to AP, $ec_k$ represents the acidification potential of gas $k$ expressed relative to the AP of $SO_2$, and $B_k$ is its emission reduction in kg per functional unit.

Environmental impact regarding to HTP, $ec_k$, is human toxicological classification factors. $B_k$ represents the emission reduction of different toxic substances.

The numerical values of the classification factors of the burdens were revealed in Appendix A.

### 3.2.3 Economic and environmental analysis with ECE

The proposed ECE equation (equation 1) was used to calculate ECE figure of each CT option. ECE figure of every CT option was further ranked and was compared with $ECE_{mean}$.

Furthermore, environmental fingerprint was used to show the relation between three aspects including economic aspect (NFC), environmental aspect (NEB), and ECE figure of CT option [21]. Three aspects were normalized and were then plotted in environmental fingerprint. NFC, NEB, and ECE calculation was plotted in the X axes, Y axes, and Z axes, respectively. The environmental fingerprint was revealed in Figure 3.1.

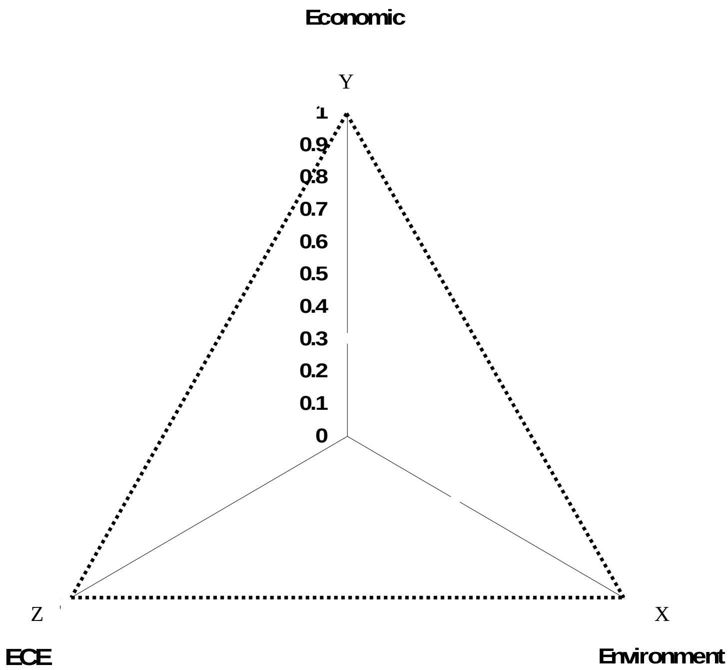



**Figure 3.1. Environmental fingerprint analysis adopted from BASF** [21]

### 3.2.4 Eco-efficiency level analysis

The snapshot graph was used to analyze the eco-efficiency level of each CT option [1]. The environmental and economic value of each CT option was respectively compared with $NEB_{mean}$ and $NFC_{mean}$, and then was converted to percentage before being plotted in the graph. The appropriate CT option with high emission reduction and low capital investment must be located in the fully eco-efficiency quadrant on the snapshot graph. The snapshot graph was viewed in Figure 3.2.

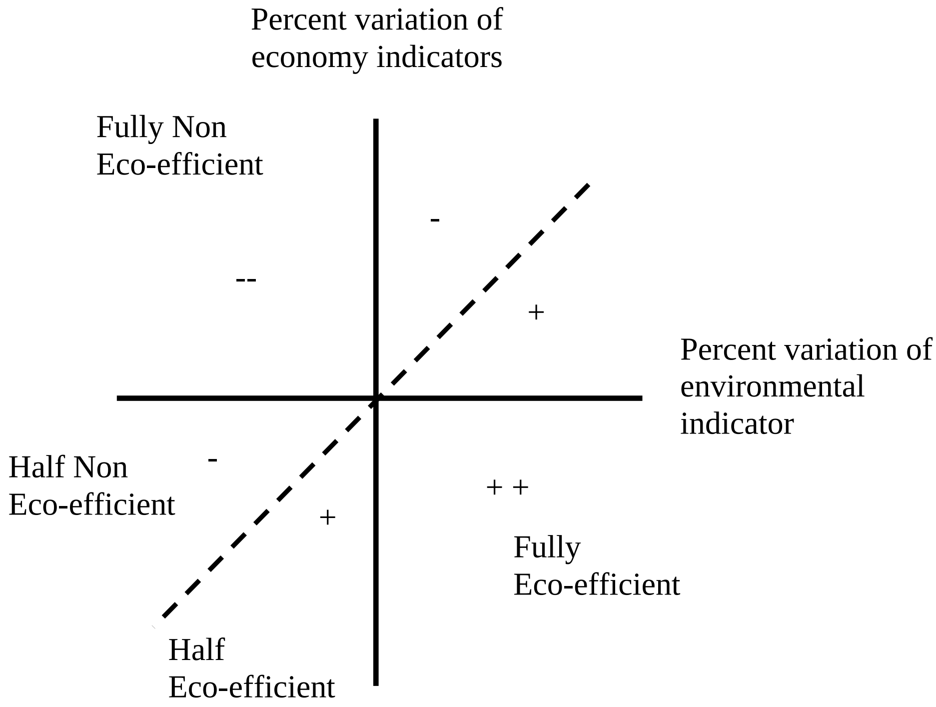



**Figure 3.2. The classification of eco-efficiency levels (adopted from [1])**

The X-Y plan is used to interpret snapshot graph. The plan is also divided into two sub-plans. The first sub-plan is fell over the bi-sector line. This sub plan provides the positive value and it is called eco-efficient plan. The other sub-plan is located below bi-sector line and also gives the negative value. It is named non eco-efficient plan. Moreover, each sub-plan can be categorized into two groups as well. The first group; eco-efficient plan, includes fully eco-efficiency (++) and half eco-efficiency (+). The second group; non eco-efficiency plan, comprises fully non eco-efficiency (--) and half non eco-efficiency (-).

Fully eco-efficiency (++) means both economic and environmental scheme varies in the preferable direction.

Half eco-efficiency (+) indicates either economic or environmental scheme varies in the preferable direction. The other scheme varies in the unfavorable direction. Besides, the variation of the scheme locating in the preferable direction can compensate the other.

Fully non eco-efficiency (--) shows neither economic nor environmental aspect varies in the unfavorable direction.

Half non eco-efficiency (-) means either economic or environmental aspects varies in the preferable direction. The other aspect varies in the unfavorable direction. Nevertheless, the variation of the aspect placing in the preferable direction can not compensate the other.

# CHAPTER IV
# RESULTS AND DISCUSSIONS

This chapter addresses about the outcome of the study of the characteristic of CT and the application of eco-efficiency with ECE into case study. The results are presented in terms of describing context, figures, and tables. The results and discussions of the study are expressed in subsequent section as follows:

- 4.1 The primary study of the characteristic of CT
- 4.2 Application of eco-efficiency with ECE into case study
    - 4.2.1 Economic aspect evaluation
    - 4.2.2 Environmental aspect evaluation
        - 4.2.2.1 The requirement of fuel oil consumption analysis
        - 4.2.2.2 Emission gases reduction analysis
        - 4.2.2.3. Reduction of environmental impact analysis
    - 4.2.3 Economic and environmental analysis with ECE
    - 4.2.4 Eco-efficiency level analysis
- 4.3 The summary of the study

## 4.1 The primary study of the characteristic of CT

Cleaner Technology (CT) is the continuous application of an integrated, preventative environmental strategy to processes, products and services to increase eco-efficiency and also reduce risks to humans and the environment [28]. It applies to three prospective schemes comprising of production process, product and service for aiming to eliminate or significantly reduce the amount of any hazardous substance, pollutant, or contaminant released to the environment. Moreover, the emphasis of cleaner technologies is on process changes that can prevent pollution [7].

Generally, the CT assessment in the industrial perspective mostly divided in 5 procedures as respectively as; (i) planning and organization, (ii) pre-assessment phase, (iii) assessment phase, (iv) feasibility analysis phase, and (v) implementation [26]. All procedures are proceeded by CT teamwork who are the expert in relevant parties with special knowledge of that particular industrial sector.

According to CT concept, it was found that CT started from the issue of environmental improvement providing the efficiency to economic sector. Thus, in CT assessment process, the auditor needed to concern on environmental aspect as initially by attempting to identify the environmental problems resulting from production process. Furthermore, the auditor introduced a number of relevant CT option for being selected to implement. The particular property of acceptable CT option was to erase the environmental problems and to provide the economic advantage returning to company at the same time. Hence, new addressed option should perform as better, cleaner and also safer than the existing one. After implementing new CT option into production process, the environmental aspect and economic aspect of company would be improved. For instance, in environmental aspect, the company would increase the efficiency of natural resources consumption and would eliminate the releasing of hazardous substances. For economic aspect, the production would be gradually increased, at the same time the company would earn more profits and eventually reach the financial target. Nevertheless, some faults according to the quality of CT options were investigated. Almost introduced options mentioned on the improving of economic aspect only and frequently did not provide any benefit to environmental scheme.

According to CT concept and the intensive study of CT assessment process, the strengths, weaknesses, opportunities, and threats of CT could be classified as described in Table 4.1.

**Table 4.1. The SWOT analysis of CT**

| SWOT analysis of CT | Details |
|---|---|
| **Strengths** | - Reducing pollutions from the source<br>- Effective use of resources<br>- Increasing more efficiency of production process<br>- Leading to sustainable development<br>- Gaining both environmental and economic benefits |
| **Weaknesses** | - More complexity<br>- Starting with the environmental improvement purpose but some introduced option mention only on economic development<br>- Each CT options need to be supported and assessed the quality with proper tool |
| **Opportunities** | - Can be implemented in every kind of industry both SME and SML<br>- Can be cooperated with other tools such as eco-efficiency and LCA |
| **Threats** | - Some biases occur from assessment process |

| | |
|---|---|
| | - Some inefficient CT options would be introduced |

In general, most of new options have been claimed to provide both environmental and economic benefits. Therefore, it is not always appropriate to believe the enthusiastic claims of a particular option. Each option needed to be assessed in a systematic and comprehensive manner with an appropriate tool before implementing in the production process. Consequently, the eventual option represented the most environmentally friendly option and the most economic gaining option.

The suitable tool using for supporting and evaluating CT option should perform as environmental cost effective supporter and evaluator at the same time. The tool must support the options providing both environmental and economic benefits to company. Concurrently, it should evaluate the inefficient options giving the benefits just one perspective only (either environment or economic). Importantly, the characteristic of proposed tool, the supporting process or assessing process including the assessment outcomes offered from proposed tool should be reliable and accurate as well.

Unfortunately, there is no specific tool using for supporting CT and also assessing the efficiency of CT option yet. However, in the recent year, world organization has paid much more concerning on the environmental impact and also the overall consequences of inefficient options. Thus a number of appropriate procedures have been launched to assess the options in term of their environmental and related impact. These proposed procedures included Environmental Technology Assessment (EnTA) [30] and Environmental Assessment Method for Cleaner Production Technologies [9].

UNEP has promoted EnTA as a tool used for analyzing new technology options by focusing on the consequences of those technologies to environment, human health and community. EnTA was used to analyze the life cycle of those technologies. The ultimate goal of EnTA was to support the eventual decision making on selecting the most suitable technology in term of environmental friendliness sounds to replace the existing technology in manufacturing process [30].

The Environmental Assessment Method for Cleaner Production Technologies aimed to analyze the environmental impact of cleaner technology. The proposed method used a set of profile indices comprising of material and energy flows as a basis to determine an integrated index for overall environmental assessment of cleaner production technologies. This method could be employed to evaluate environmental nuisance of implemented, to modernize and to modify technological processes and products for performing comparative analyses of alternative technologies [9].

Eco-efficiency is one interesting tool used to support CT and assess the quality of CT option in term of environmental and financial efficiency. According to eco-efficiency concept, eco-efficiency can be used as an indicator to measure the efficiency of economic aspect and environmental aspect at the same time. Therefore, using eco-efficiency as CT option assessing tool could help the decision maker select the best option to implement. Not only performing as a CT option assessing tool, but eco-efficiency can perform as a CT supportable tool also. It can use to support the efficiency of employed option and to increase the reliabilities of the decision making process as well. Moreover, in the recent year, two world organizations (WBCSD and UNEP) have tried to link CT and eco-efficiency to work together by aiming toward the common goal of sustainable development [3]. Hence, eco-efficiency is ensured on its particular ability that it can be used as CT option assessing tool and CT supportable tool.

### 4.2 Application of eco-efficiency with ECE into case study

Twelve canned pineapple industries proposed by DIW [6] were used as case study. Each of industries was different in size and also required the different amount of materials. The requirements of raw materials of every canned pineapple industry were revealed in Appendix B. During canned pineapple production process of twelve industries, DIW found three major environmental problems comprising of (i) the exceeding requirement of fuel oil, (ii) the over consumption of electricity, and (iii) the over supply of water. Therefore, DIW launched three groups of CT options to handle with these particular problems. The canned pineapple production process was shown in Appendix C.

According to the hot issue of energy crisis and global warming, the CT option group with the reduction of fuel oil consumption was selected to concern. The group of CT options regarding to the reduction of fuel oil consumption consisted of 15 CT options but only 6 CT options which required the big amount of investments and needed to change to the new technologies were selected to study. The details of each selected CT options were shown in Table 4.2. The locations of implementing every proposed CT options in canned pineapple production process were shown in Appendix D.

The application of eco-efficiency with ECE in canned pineapple industry was separately studied into 4 steps: (i) the economic aspect and environmental aspect of proposed CT option was evaluated individually, (ii) the economic and environmental aspect of CT option was studied concurrently by calculating the environmental cost efficiency of each CT option (ECE figure) with ECE equation, (iii) the relation between economic aspect, environmental aspect and ECE figure of every option was analyzed by environmental fingerprint, (iv) the eco-efficiency level of each option was determined by plotting on snapshot graph. The results of all study helped the decision maker to evaluate the most suitable CT option to implement. The results of each analyzed procedure were showed in the respective topics below.

### 4.2.1 Economic aspect evaluation

In this section, the most appropriate option with the lowest NFC was purposed to find out. NFC of each option was compared and then was ranked. The option with smaller NFC indicated more appropriate option whereas higher NFC identified improper option. The results were revealed in Table 4.2 and in Figure 4.1.

**Table 4.2. The information of six alternative CT options [6]**

| No. | CT options | NFC (Baht) | Fuel oil consumption in a year (l/yr) | | |
|---|---|---|---|---|---|
| | | | Before implementing CT options | After implementing CT options | Total fuel oil consumption reduction |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 105,000 | 97,500 | 81,000 | 16,500 |
| 2 | Improving of steam supply system in a sterilizing cooker** | 57,000 | 164,571 | 135,750 | 28,821 |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 160,000 | 77,143 | 73,286 | 3,857 |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 160,000 | 244,286 | 232,072 | 12,214 |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 200,000 | 244,286 | 205,715 | 38,571 |
| 6 | Improving of combustion efficiency of a boiler** | 60,000 | 294,840 | 261,859 | 32,981 |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.

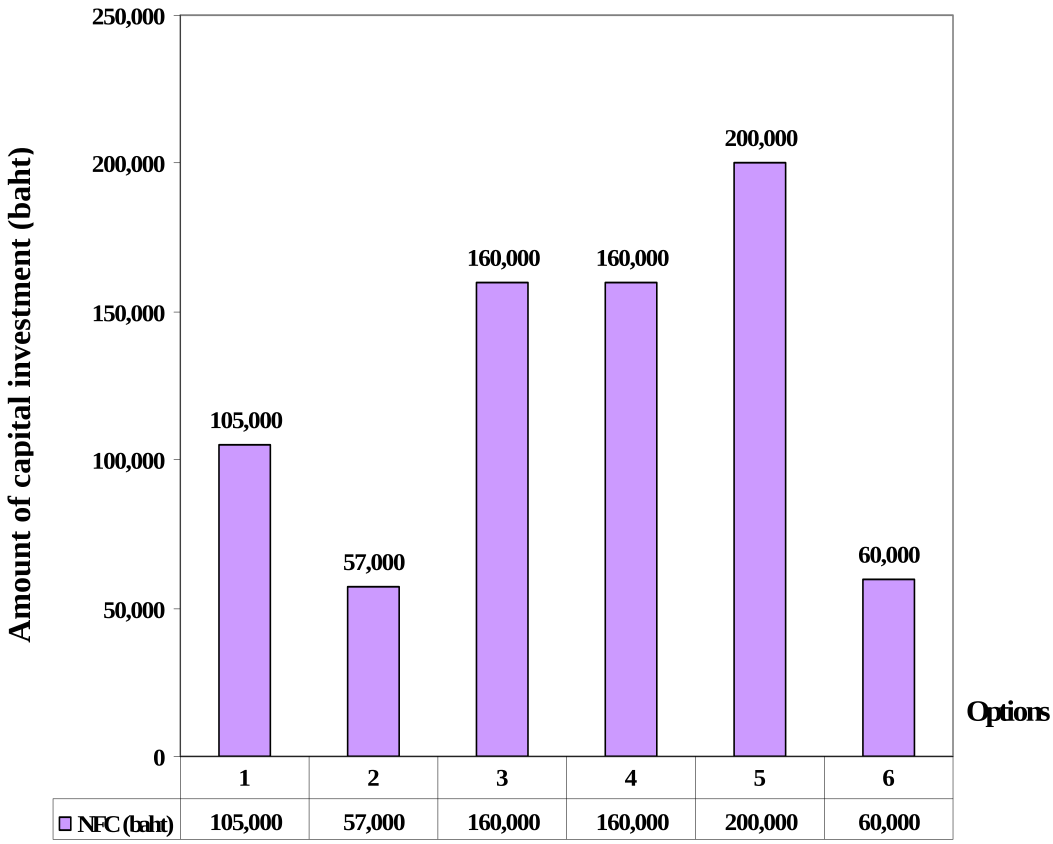



**Figure 4.1. NFC of each CT option**

The results showed that option 2 required the lowest NFC (57,000 baht) whereas option 6 and option 1 required 60,000 and 105,000 baht respectively. Option 3 and option 4 had the same amount of NFC of 160,000 baht. Option 5 had the highest NFC as much as 200,000 baht.

Thus, in the evaluation of economic aspect, option 2 was the most appropriate CT option whereas option 5 was the most inappropriate CT option to implement in canned pineapple industry.

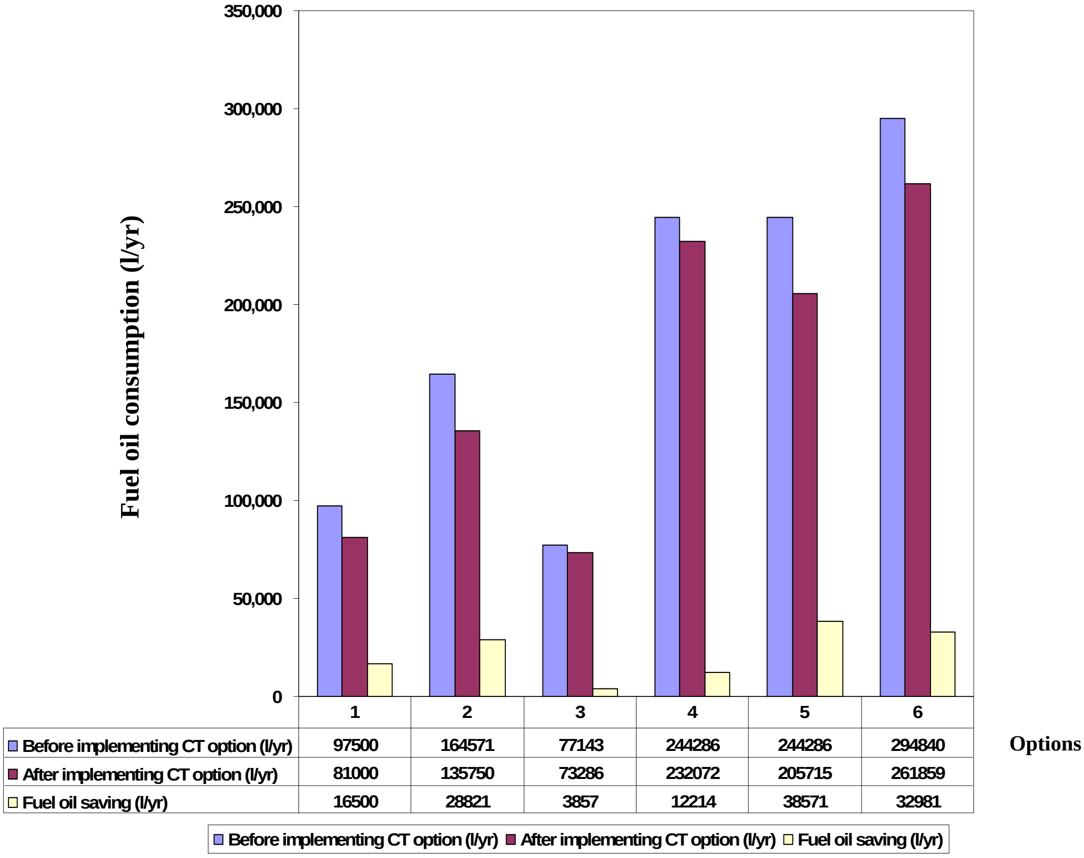
### 4.2.2 Environmental aspect evaluation

In this aspect, the most environmental friendly CT option was pointed to determine. Three indicators comprising of 1) the requirement of fuel oil consumption yearly, 2) the amount of total emission reduction in a year, and 3) the reduction of annually environmental impact involve with global warming potential (GWP), acidification potential (AP), and human toxicity potential (HTP) were used as the models to determine the suitable option. The value of each CT option in the same indicator category was compared and was ranked. Lower amount of fuel oil requirement yearly indicated more appropriate CT option. Otherwise, the highest amount of emission reduction in a year and the biggest number of the reduction of annually environmental impact showed the preferred CT option to implement.

#### 4.2.2.1 The requirement of fuel oil consumption analysis

This section, the amount of fuel oil consumption of each CT option whether before implementing CT option or after implementing CT option was focused. Additionally, the amount of fuel oil consumption reduction of every CT option was concentrated as well. The results of study were declared in Table 4.2 and also in Figure 4.2.

The results found that before option 6 implementing, the production process required the highest amount of fuel oil consumption as much as 294,840 l/yr. The lowest requirement of fuel oil consumption was the production process of option 3. This process necessitated fuel oil consumption as 77,143 l/yr. Before option 1 and option 2 implementing, the production process needed the fuel oil consumption as 97,500 l/yr and 164,571 l/yr, respectively. The demanding of fuel oil of the production process before option 4 and option 5 implementing was similar. They both required fuel oil consumption as 244,286 l/yr.




| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Before implementing CT option (l/yr) | 97500 | 164571 | 77143 | 244286 | 244286 | 294840 |
| After implementing CT option (l/yr) | 81000 | 135750 | 73286 | 232072 | 205715 | 261859 |
| Fuel oil saving (l/yr) | 16500 | 28821 | 3857 | 12214 | 38571 | 32981 |

**Figure 4.2. The amount of fuel oil consumption of before implementing CT option, after implementing CT options and fuel oil saving**

After implementing all CT option in production process, each process required fuel oil consumption lower than the fuel oil requirement of before implementing any CT option. Most option demanded different amount of fuel oil consumption as option 1, option 2, option 3, option 4, option 5, and option6 necessitated fuel oil consumption as 81,000 l/yr, 135,750 l/yr, 73,286 l/yr, 232,072 l/yr, 205,715 l/yr and 261,859 l/yr, respectively. However, after option 6 implementing, the production process still needed the highest amount of fuel oil consumption whereas after option 3 implementing the production process still required the lowest. The implementation of option 4 and option 5 made two kind of production process demanded the different amount of fuel oil consumption.

In term of fuel oil consumption reduction, option 5 was the highest fuel oil saving option. It could reduce the amount of fuel oil consumption up to 38,571 l/yr. Contrarily, option 3 was the lowest fuel oil saving option. It had fuel oil saving amount of 3,857 l/yr. Option 6, option 2, option1, and option 4 was the second, the third, the fourth and the fifth highest fuel oil saving option. They could reduce the fuel oil consumption as much as 32,981 l/yr, 28,821 l/yr, 16,500 l/yr, and 12,214 l/yr, respectively.

#### 4.2.2.2 Emission gases reduction analysis

In this section, the reduction of emission gases including $CO_2$, $SO_2$, and $NO_2$ was referred as the net environmental benefit (NEB). The reduction of annual emission gases was calculated by multiplying the reduction amount of fuel oil consumption in a year of each option with the conversion factor by following the IPCC methodology. The conversion factor of $CO_2$, $SO_2$, and $NO_2$ are 2.5 kg/l, 0.035 kg/l, and 0.0019 kg/l, respectively [11]. Further, the summation of emission gas reduction was used to calculate the NEB. The results were shown in Table 4.3 and in Figure 4.3.

**Table 4.3. The amount of total emission gases reduction**

| No. | CT options | The reduction of fuel oil consumption (l/yr) | Amount of emission reduction (kg/yr) | | | |
|---|---|---|---|---|---|---|
| | | | $CO_2$ (kg) | $SO_2$ (kg) | $NO_2$ (kg) | Total emissions reduction ($CO_2$+$SO_2$+$NO_2$) (kg) |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | **16,500** | 41,250 | 578 | 31 | **41,859** |
| 2 | Improving of steam supply system in a sterilizing cooker** | **28,821** | 72,053 | 1,009 | 55 | **73,117** |
| 3 | Installing of an automatic steam supply system in an exhaust box** | **3,857** | 9,643 | 135 | 7 | **9,785** |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | **12,214** | 30,535 | 427 | 23 | **30,985** |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | **38,571** | 96,428 | 1,350 | 73 | **97,851** |
| 6 | Improving of combustion efficiency of a boiler** | **32,981** | 82,453 | 1,154 | 63 | **83,670** |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.

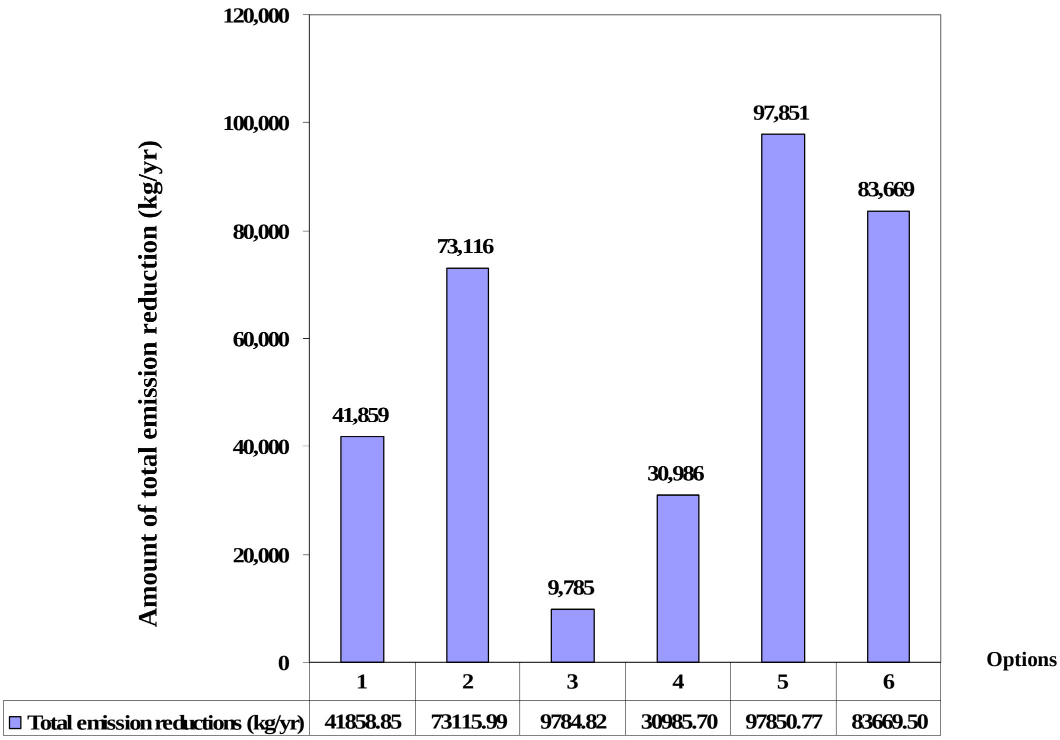



**Figure 4.3. NEB in a year**

Table 4.3 showed every CT option reduced $CO_2$ as the primary reduced gas followed by $SO_2$, and $NO_2$**,** respectively. Hence, the number of $CO_2$ influenced to the quantity of total emission gases reduction of all option.

From Table 4.3 and Figure 4.3, the results showed option 5 provided the highest NEB as 97,850 kg/yr, followed by option 6 (83,669 kg/yr), option 2 (73,115 kg/yr), option1 (41,858 kg/yr), and option 4 (30,985 kg/yr), accordingly. The option giving the lowest NEB was option 3. Its NEB was 9,784 kg/yr.

The results also found the quantity of NEB was depended on the reduction amount of fuel oil consumption. Thus, the option providing more fuel oil reduction would give higher NEB. Option 5 presented the highest amount of fuel oil reduction therefore this option would offer the highest amount of NEB as well. Contradictorily, option 3 provided the lowest fuel oil reduction so that it proposed the lowest NEB.

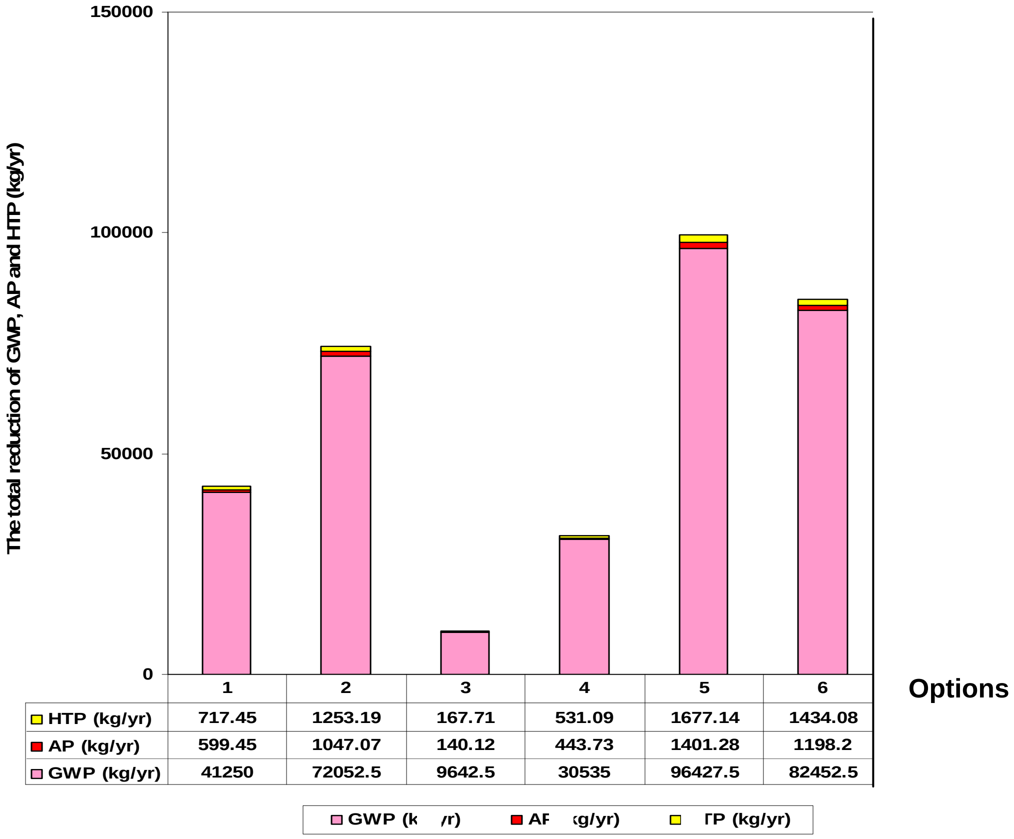
#### 4.2.2.3. Reduction of environmental impact analysis

In this part, the reduction of some environmental impacts affected by the emission gases from each CT option was mentioned. Three kinds of environmental impact category comprising of global warming potential (GWP), acidification potential (AP), and human toxicity potential (HTP) were used to study. The calculation of the amount of environmental impact was described in chapter 3. The results of this study were shown in Appendix E, Table 4.4 and Figure 4.4.

**Table 4.4. The total reduction of annually environmental impact of each CT option**

| No. | CT options | GWP (kg/yr) | AP (kg/yr) | HTP (kg/yr) |
|---|---|---|---|---|
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 41,250 | 599 | 717 |
| 2 | Improving of steam supply system in a sterilizing cooker** | 72,052 | 1,047 | 1,253 |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 9,642 | 140 | 167 |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 30,535 | 443 | 531 |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 96,427 | 1,401 | 1,677 |
| 6 | Improving of combustion efficiency of a boiler** | 82,452 | 1,198 | 1,434 |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.




| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| HTP (kg/yr) | 717.45 | 1253.19 | 167.71 | 531.09 | 1677.14 | 1434.08 |
| AP (kg/yr) | 599.45 | 1047.07 | 140.12 | 443.73 | 1401.28 | 1198.2 |
| GWP (kg/yr) | 41250 | 72052.5 | 9642.5 | 30535 | 96427.5 | 82452.5 |

**Figure 4.4. Total reduction of GWP, AP, and HTP of each CT option in a year**

From Table 4.4 and Figure 4.4, the primarily environmental impact released from every CT option was global warming. Human toxicity and acidification was the second and the third highest environmental impact, subsequently. The amount of each impact depended on the amount of different kind of emission gases. For GWP, its quantity was followed directly by the number of $CO_2$ emission. The quantity of $SO_2$ and $NO_2$ emissions influenced to the amount of AP and HTP.

The study also found that option 5 provided the highest reduction of environmental impact in every category, while option 3 gave the lowest. Option 6, option 2 gave the second and the third highest reduction of environmental impact, accordingly. Otherwise, option 4 and option 1 provided the second and the third lowest reduction of environmental impacts, subsequently.

Therefore, option 5 not provided only the highest reduction of $CO_2$, $SO_2$, and $NO_2$ but presented the highest reduction of environmental impact in every category also. Adversely, option 3 was the option which gave the both lowest of emission reduction and the reduction of environmental impact in every category.

On the over view, the amount of the reduction of fuel oil consumption yearly influenced to number of total emission reduction in a year and the quantities of annually environmental impact reduction of all CT option, either. The option which presented a large amount of fuel oil saving would increase more both emission reduction and environmental impact reduction. The environmentally friendly option had to: require a big number of fuel oil reduction, decreased more emission, and gave higher environmental impact reduction.

According to the study of environmental aspect, option 5 was the most environmentally friendly option. It offered the highest reduction of fuel oil consumption, provided the biggest emission reduction and gave the highest environmental impact reduction in all categories. Thus, in environmental aspect, this option was the most appropriate option to implement. Contrarily, option 3 presented the lowest reduction of fuel oil consumption and also gave the highest adverse effects to environment. Therefore it was ranked to the most improper option to implement. Option 6 and option 2 was respectively ranked as the second and the third suitable option to implement. Oppositely, option 4 and option 1 was leveled to the second and the third improper option to implement, accordingly.

### 4.2.3 Economic and environmental analysis with ECE

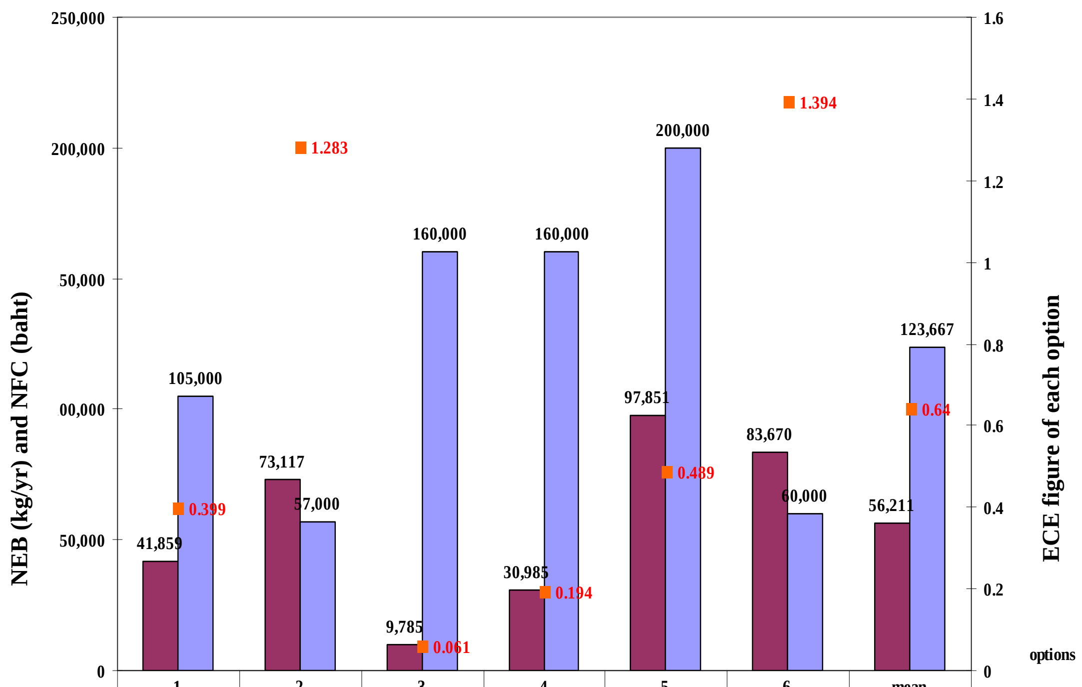
This section aimed to investigate the balance between economic and environmental aspect of all CT option. The proposed ECE equation was used to compute ECE figure of every CT option. Each ECE figure of every CT option was then ranked and was further compared with $ECE_{mean}$. The option with the highest ECE figure indicated the most environmental-cost balancing option while the lowest number of ECE showed the most non environmental-cost balancing option. The proper option selected to implement must give higher ECE figure.

The information of NEB and NFC of each option were presented in subtopic of 4.2.2.2 and 4.2.1, accordingly. Additionally, ECE figure of all option was revealed in Table 4.5 and in Figure 4.5.

**Table 4.5. The information of ECE figure of each CT option**

| No. | CT option | NFC (Baht) | NEB (kg/yr) | ECE |
|---|---|---|---|---|
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 105,000 | 41,859 | 0.399 |
| 2 | Improving of steam supply system in a sterilizing cooker** | 57,000 | 73,117 | 1.283 |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 160,000 | 9,785 | 0.061 |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 160,000 | 30,985 | 0.194 |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 200,000 | 97,851 | 0.489 |
| 6 | Improving of combustion efficiency of a boiler** | 60,000 | 83,670 | 1.394 |
| | **Mean** | **123,667 ($NFC_{mean}$)** | **56,210 ($NEB_{mean}$)** | **0.64 ($ECE_{mean}$)** |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.




| | 1 | 2 | 3 | 4 | 5 | 6 | mean |
|---|---|---|---|---|---|---|---|
| NEB (kg/yr) | 41,859 | 73,117 | 9,785 | 30,985 | 97,851 | 83,670 | 56,211 |
| NFC (baht) | 105,000 | 57,000 | 160,000 | 160,000 | 200,000 | 60,000 | 123,667 |
| ECE calculation | 0.399 | 1.283 | 0.061 | 0.194 | 0.489 | 1.394 | 0.64 |

NEB (kg/yr) NFC (baht) ECE calculation

**Figure 4.5. ECE figure of each CT option**

The results indicated that option 6 gave the highest ECE figure as 1.39, followed by option 2 (1.28), option 5 (0.49), option 1 (0.39) and option 4 (0.19), subsequently. The option giving the lowest ECE figure was option 3. Its ECE figure was 0.06. In the comparison between ECE figure of every option and $ECE_{mean}$ ($ECE_{mean}$ = 0.64), the results showed that option 2 and option 6 had ECE figure higher than $ECE_{mean.}$ Contrarily, the ECE figure of option 1, option 3, option 4, and option 5 were lower than $ECE_{mean.}$

The summary of the economic and environmental analysis with ECE, option 2 and option 6 showed high balance between environmental aspect and economic aspect. They both required small amount of NFC while giving high value of NEB. Thus, both CT options were the suitable option to implement. However, option 6 still was the most proper CT option to implement because it offered the biggest ECE figure. The

CT options providing the fair balance between two aspects were option 1 and option 5. They both gave ECE figure nearby $ECE_{mean}$. However, option 5 could balance the economic and environmental aspect better than option 1 because option 5 offered ECE figure bigger than option 1. Option 3 and option 4 gave imbalance between two aspects. Their NFC was high whereas their NEB was small. Hence, they were classed to the unsuitable CT option to implement, either. Nevertheless, option 3 was proposed to the most inappropriate CT option to implement because this CT option offered the lowest ECE figure.

Environmental fingerprint was also used to show the relation between three aspects including economic aspect (NFC), environmental aspect (NEB), and ECE calculation of each CT option. The value of NFC, NEB and ECE calculation of each CT option was normalized and then was plotted into the environmental fingerprint by following BASF guideline [21]. The normalized values of three aspects and environmental fingerprint were revealed in Appendix F and Figure 4.6, subsequently.

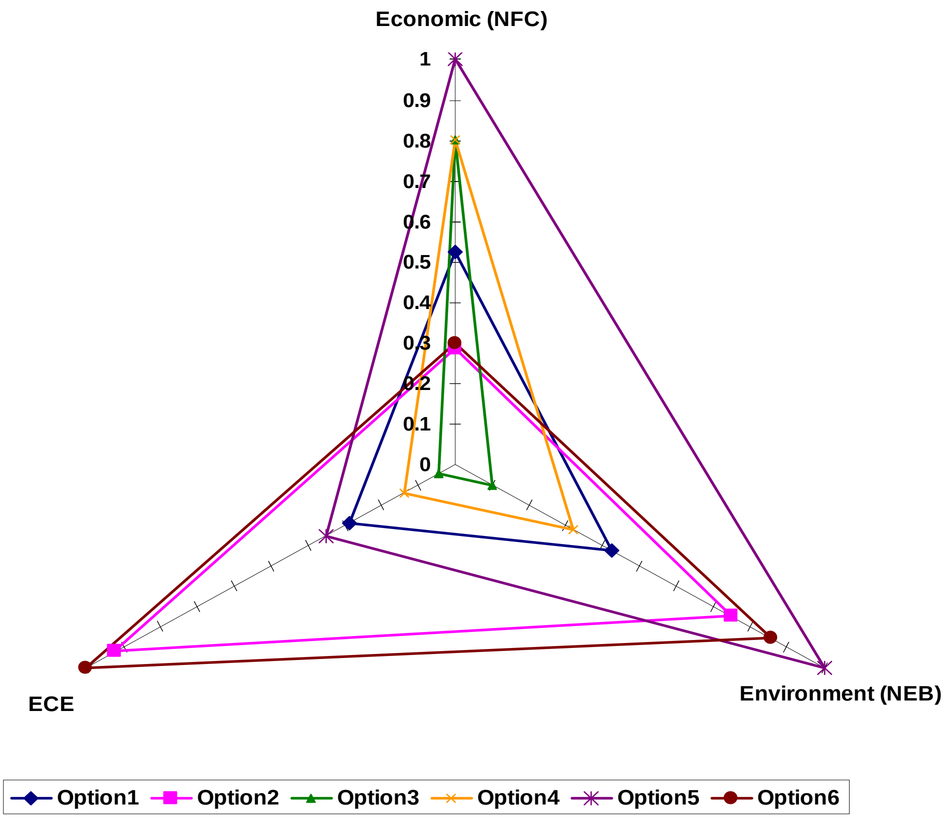



**Figure 4.6. Environmental fingerprint analysis (adopted from BASF method)**

The environmental fingerprint showed option 6 had the highest ECE figure. It required a second lowest amount of NFC while providing the second highest number of NEB. This option showed the most appropriate proportion between economic and environmental aspect. Therefore, in order to ECE figure ranking, this option was the most proper CT option to implement.

Option 2 had the third biggest number of NEB and also gave the smallest amount of NFC. This option could balance the economic and environmental aspect in good performance because it offered the second highest ECE figure. In term of ECE figure ranking, option 2 was the suitable CT option to implement as well.

Option 5 provided the highest number of both NFC and NEB. However, its NFC number was still bigger than NEB value. Consequently, this CT option proposed the small amount of ECE figure. However, in term of ECE figure ranking, this CT option was grouped to the third appropriate CT option to implement.

Option 1 offered the third and the fourth highest of NFC and NEB, accordingly. Its ECE figure was also classed to the fourth highest. In ECE figure ranking, this CT option was categorized as the fourth proper CT option to implement also.

Option 4 gave the second biggest of NFC while providing the second smallest of NEB. ECE figure of this option was leveled to the second lowest. This option presented the imbalance between economic and environmental aspect. According to the ECE figure ranking, this CT option was graded to the second improper CT option to implement.

Option 3 not presented only the second highest of NFC but gave the lowest NEB also. This option provided the most imbalance between economic and environmental aspect, thus its ECE figure was smallest. In order to ECE figure ranking, this CT option was grouped to the most unfavorable CT option to implement.

### 4.2.4 Eco-efficiency level analysis

This section, the eco-efficiency level of each CT option was analyzed by using snapshot graph which was adopted from Anite system [1]. The eco-efficiency of all CT option was categorized into four levels including fully eco-efficiency level (++), half eco-efficiency level (+), half non eco-efficiency level (-), and fully non eco-efficiency level (--). The CT option falling in fully eco-efficiency quadrant was the most appropriate option to implement whereas the most improper CT option located in fully non eco-efficiency quadrant.

The percentage of variation of both economic (NFC) and environmental aspect (NEB) or snapshot graph plotting values were computed by following the method in chapter 3 (subtopic of 3.3.4). The calculated values of both aspects were revealed in Appendix G. Snapshot graph plotting values and snapshot graph analysis were shown in Table 4.6 and in Figure 4.7, respectively.

**Table 4.6. Snapshot graph plotting values of NFC and NEB**

| No. | CT options | % variation of NFC (baht) | % variation of NEB (kg/yr) |
|---|---|---|---|
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | -15.09 | -25.53 |
| 2 | Improving of steam supply system in a sterilizing cooker** | -53.91 | 30.08 |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 29.38 | -82.59 |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 29.38 | -44.88 |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 61.73 | 74.08 |
| 6 | Improving of combustion efficiency of a boiler** | -51.48 | 48.85 |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.

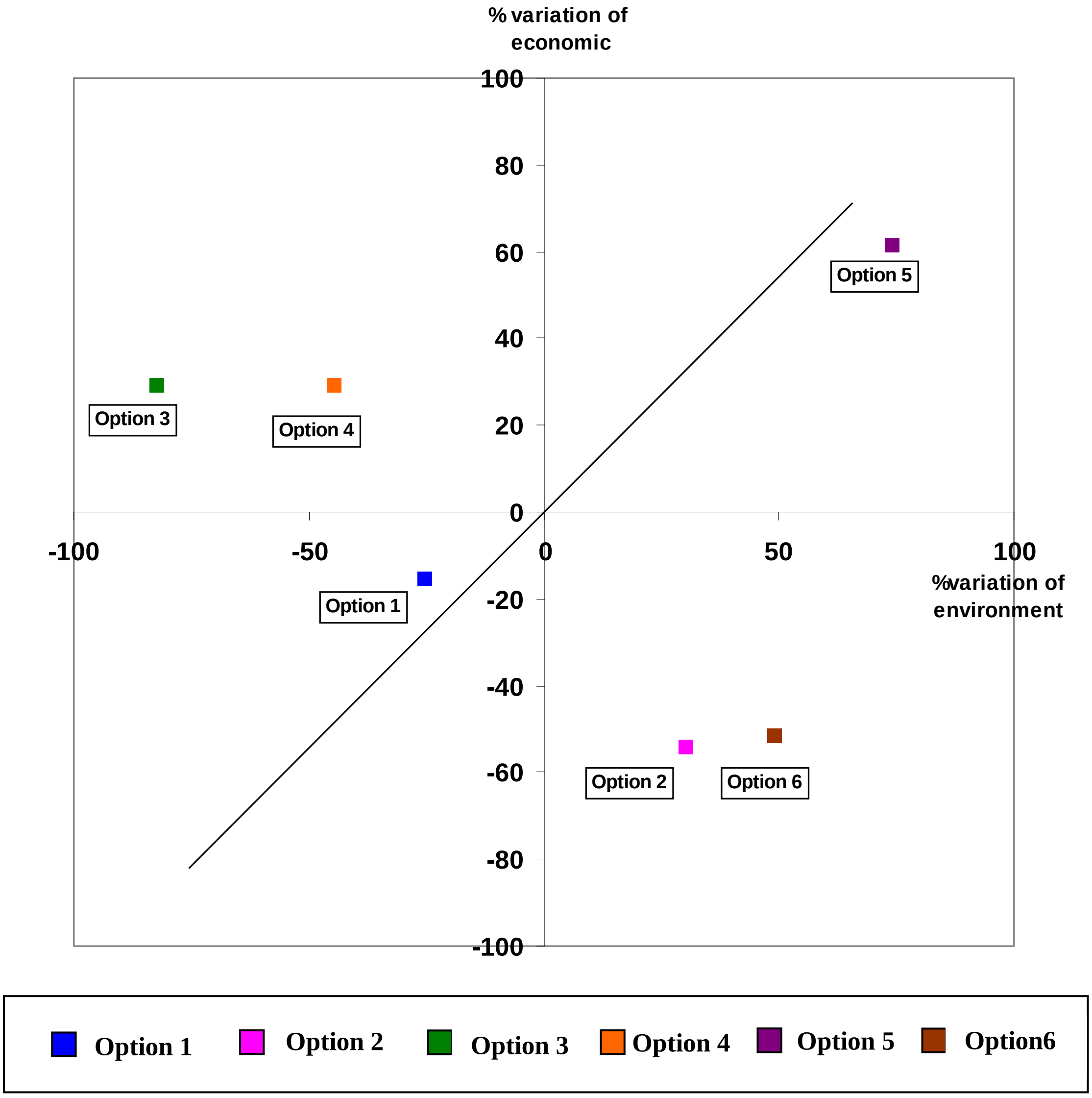



**Figure 4.7. Snapshot graph analysis (Adopted from [1])**

The snapshot graph showed option 2 and option 6 were fell into fully eco-efficiency area. Option 5 was settled in half eco-efficiency area. Option 1 was located in half non eco-efficiency area. Option 3 and option 4 were placed in non eco-efficiency area.

The results from snapshot graph analysis indicated option 2 and option 6 were the most appropriate CT option to implement. Their NFC was lower than $NFC_{mean}$ while their NEB was higher than $NEB_{mean}$. Hence, they both provided more positive gain to environment while requiring less amount of investment. These CT options gave both environmental and economic benefit at the same time. Other CT option could not do like both of them.

Option 5 was categorized to the second proper option to implement, in order to snapshot graph analysis. This CT option provided more NEB and the same time needed a big number of NFC. Nevertheless, it located in haft fully eco-efficiency area. Thus, its NFC and its NEB were quite balance. Implementing this CT option, the company will pay more money but they will provide a small adverse effect to environment as well.

From snapshot graph analysis, option 1 was the unsuitable CT option to implement because it settled in half non eco-efficiency area. Although this CT option demanded NFC lower than $NFC_{mean}$ but it still gave NEB below $NEB_{mean}$. Hence, option 1 provided the benefit to economic aspect only. If this CT option is selected to implement, the company will spend less investment and will produce more negative effects to environment concurrently.

According to snapshot graph analysis, option 3 and option 4 were categorized to the least favorable CT option to implement. They were stated in non eco-efficiency area. Moreover, both of them necessitated a large amount of NFC while presenting a small number of NEB. Thus, this CT option provided the negative gain to economic and environmental aspect, either. The company should not select these CT options to implement.

## 4.3 The summary of the studies

The summary of the study in all aspects of every CT option could be revealed in Table 4.7.

**Table 4.7. The summary of the studies**

| No. | CT options | NFC (Baht) | Environmental aspect | | | ECE figure | Eco-efficiency level |
|---|---|---|---|---|---|---|---|
| | | | Fuel oil reduction (l/yr) | NEB (kg/yr) | Environmental impact reduction (kg/yr) | | |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 3rd | 4th | 4th | 4th | 4th | Half-non fully EE |
| 2 | Improving of steam supply system in a sterilizing cooker** | 5th *(highest)* | 3rd | 3rd | 3rd | 2nd | Fully EE |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 2nd | 6th *(lowest)* | 6th *(lowest)* | 6th *(lowest)* | 6th *(lowest)* | Fully non EE |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 2nd | 5th | 5th | 5th | 5th | Fully non EE |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 1st *( lowest)* | 1st *(highest)* | 1st *(highest)* | 1st *(highest)* | 3rd | Half-fully EE |
| 6 | Improving of combustion efficiency of a boiler** | 4th | 2nd | 2nd | 2nd | 1st *(highest)* | Fully EE |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.

Option 1 required the third highest NFC and had the fourth highest NEB. This CT option reduced the fuel oil consumption and reduced the environmental impact in the fourth highest. Its ECE figure was also ranked to the fourth highest. Moreover, It located in the half-non fully eco-efficiency area.

Option 2 gave the second highest ECE figure and also located in the fully eco-efficiency area. Its NFC was the lowest but NEB was in the third rank. Additionally, this CT option offered the third highest of both fuel oil consumption reduction and environmental impact reduction as well.

Option 3 provided the lowest ECE figure. Its NFC was classed in the second highest. This CT option required the highest amount of fuel consumption. Consequently, it presented the lowest NEB and produced highest negative effect to environment as well. Furthermore, option 3 settled in fully non eco-efficiency area.

Option 4 presented the second lowest ECE figure. This CT option necessitated NFC as much as NFC of option 3. The fuel oil consumption reduction, NEB, and environmental impact reduction of this CT option was leveled in the fifth highest. Also it located in fully non eco efficiency area.

Option 5 needed the maximum NFC and provided the maximum NEB at the same time. It offered the biggest fuel oil saving and produced the least amount of environmental impact.  According to ECE figure, its ECE figure was classed in the third highest. It also fell into half eco efficiency area.

Option 6 involved the second least NFC. Its NEB was graded in the second highest. Additionally, this CT option was categorized to the second highest of both fuel oil saving and environmental impact reduction. ECE figure of this option was highest. It also fell in eco-efficiency area.

When comparing the quality of the implemented CT option (option 1) with the introduced options (option 2-option 6) in order to ECE analysis, found that option 2 option 5 and option 6 offered better balance between economic and environmental aspect than option 1. However, option 5 provided the ECE figure nearby ECE figure of option 1. Hence, the quality of option 1 and option 5 was quite similar. When comparing with $ECE_{mean}$, they both were grouped to the economic-environmental fair balancing option.

Option 2 and option 6 presented the ECE figure much more than ECE figure of option 1. These CT options gave more benefits on both economic and environmental aspect than option 1. If the company selected theses CT options to implement, the company will spend small amount of investment while gaining more environmental benefits. Thus, option 2 and option 6 provided more environmental cost effectiveness than option 1.

Oppositely, option 3 and option 4 presented smaller number of ECE figure than option 1. They both necessitated bigger investment and offered smaller amount of emission reduction than option 1 as well. Therefore, the environmental cost effectiveness of these CT options was less than option 1.

From the study of economic aspect, environmental aspect, and the relation between economic and environmental aspect of proposed CT option found that CT option which provided the benefits only on economic or environmental aspect was not always the most appropriate option to implement. The actually suitable CT option must provide the benefits on both dimensions at the same time.

The study on environmental aspect only was suitable for determining the group of CT options which required the same amount of investments. In this case, the most appropriate CT option to implement was the CT option with the highest environmental gaining. Similarly, the study on the economic aspect only should be used to analyze the preferred CT option in case of every introduced CT options presented the equal environmental benefits. The selected CT option must demand the lowest amount of investment. However, the results interpretation of the study on one aspect only was simple, convenient and easy to understand. The decision maker could translate the results accurately.

In general, almost introduced CT options were required the different amount of investments and also provided vary amount of environmental positive gains as well. Usually, the CT option with the lower investments gave maximize adverse effects to environment whereas the CT option with higher investments offered minimize negative effects. Therefore, the study of one dimension only could not help the decisions maker determining the most proper CT option to implement. The study of economic and environmental dimension at the same time was necessary to use for selecting the most suitable CT option.

The eco-efficiency with ECE helps the decision maker studying the economic and environmental aspect of CT option at the same time. The ECE figure guided the decision maker know: how balancing between economic and environmental aspect of each CT option was, and which CT option can perform well in both economic and environmental aspect. Eventually, the decision maker can selected the most proper CT option with the highest environmental cost efficiency to implement. However, the study of economic and environmental aspect concurrently by using eco-efficiency with ECE was quite difficult and complex. Some confusion might be occurred within the results interpretation process.

# CHAPTER V
# CONCLUSIONS AND RECOMMENDATIONS

The aim of this chapter is to conclude the findings from the study on the characteristic of CT and on the application of eco-efficiency with ECE into case study. This chapter also describes the limitation faced during the study toward the recommendations for further relevant study.

## 5.1 Conclusions

CT started from the issue of environmental improvement which was providing the efficiency to economic sector. Thus, the employed CT option should mention on both environmental and economic aspect at the same time. Frequently, new CT options provided the benefits to one dimension only (either economic or environmental aspect) and mostly prefer to economic prospective. Hence, to reach to the best CT option selection purpose, every CT option should be evaluated with specific tool before being selected to implement in production process.

According to the study of the application of eco-efficiency with ECE into canned pineapple industry indicated that:

Option 6 was the most suitable CT option to implement. Although this CT option required the second lowest NFC and the second highest NEB, but it provided the highest balance between both aspects. Moreover, this CT option was fell in eco-efficiency area. Therefore, if this CT option was selected to implement the company will spend less investment but gave the positive gain to environment.

The second proper CT option was option 2. This CT option gave the second highest ECE value and also located in the fully eco-efficiency area. Its NFC was the lowest but NEB was in the third rank. However, it could balance the both economic and environmental aspect in excellent manner. In sprit of option 6, option 2 was the appropriate CT option to implement too.

Option 5 required the maximum NFC although it provided the maximum NEB also. In economic aspect, this CT option was classed to the most improper CT option to implement because it required the highest payout. Oppositely, this CT option was the most favorable option to implement in environmental aspect because it offered the biggest number of annual emission reduction. According to ECE figure, its figure was ranked in the third highest. It was also settled into half eco efficiency area. Therefore, in term of ECE analysis, it was categorized into the third appropriate CT option to implement.

Option 1 required the third highest NFC and had the fourth highest NEB. From its small ECE figure and its half non eco-efficiency level, this CT option was classified to the inappropriate CT option to implement. If this CT option is selected to implement, the company will spend more capital investment by gaining less environmental benefit.

Option 4 and option 3 gave the second lowest and the lowest ECE figure, respectively. Their NFC was high while NEB was low. They both gave minimum score of ECE figure and were located in fully non eco efficiency area. These options not only required the maximum investment but giving the maximum total emission in a year also. Hence, they were the most unfavorable CT options to implement.

According to environmental cost efficiency analysis, the implemented CT option (option 1) was not the most appropriate CT option to implement. This CT option provided poor balance between economic and environmental aspect. Therefore, every introduced CT option ought to be evaluated the quality before being selected to implement in production process. The CT option with high ECE figure should be employed firstly because it gave more balance on both economic and environmental aspect. The CT option with low ECE number should not be selected to implement. The results also indicated the proper CT option must have both environmental and economic positive gain concurrently. The suitable CT option should require a small amount of investment while presenting as environmental friendliness. The CT option providing the best only one prospective (either economic or environment) was not always the appropriate CT option to implement.

Eco-efficiency with ECE could be used as a tool to support CT excelling in both economic and environmental area and to assess the quality of CT option at the same time. The amount of ECE figure indicated how efficient CT option was. When a number of new CT options were introduced, ECE figure could help the decision maker determining the most suitable CT option to implement. Additionally, the measurement of CT option with ECE could increase the reliability on CT option's efficiency. For implemented CT option, calculation of ECE figure help the company ensuring on the quality of particular option and also help the company predicting the environmental cost effective trend of production process as well.

## 5.2 Limitation of study

### 5.2.1 Limitation of data

In the study of application of eco-efficiency with ECE in canned pineapple industry, almost studied data: for instance the amount of fuel oil consumption reduction including the number of $CO_2$, $SO_2$, and $NO_2$ reduction, acquiring from DIW was come from the calculation. The data of option 2 to option 6 was the estimated data except data of option 1. Option 1 was the implemented option so that all acquired data came from measuring the actual activity of production process. Therefore, the number presenting in the result of option 2 to option 6 was not the exact number of production process.

Additionally, there was no eco-efficiency standard of canned pineapple industry in this time. Therefore, the average ECE figure of six CT options was used as eco-efficiency standard to indicate the efficiency of each CT option. Consequently, the result interpreting of the study was not accurate enough. Some biases might be occurred.

DIW did not present the standard amount of fuel oil consumption of every canned pineapple industry in Thailand. Therefore, the quantity of fuel oil consumption of proposed CT option could not be compared with the actual standard. Consequently, the efficiency of fuel oil consumption of every CT option could not be identified actually.

5.2.2 Limitation of the format of snapshot graph

The original format of snapshot graph adopted from Anite system was not appropriate to analyze the eco-efficiency level of CT option. According to the different kind of indicators, the result interpretation of X and Y axes had to be adjusted. In general, the original format of snapshot graph was presented as Figure 5.1. However, the environmental aspect of this study was concerned on the reduction of emissions in a year so that the option with the positive X referred the environmental benefit gaining option. Otherwise, the option with negative Y proposed the proper investment option. The developed snapshot graph was revealed in Figure 3.2 (chapter3).

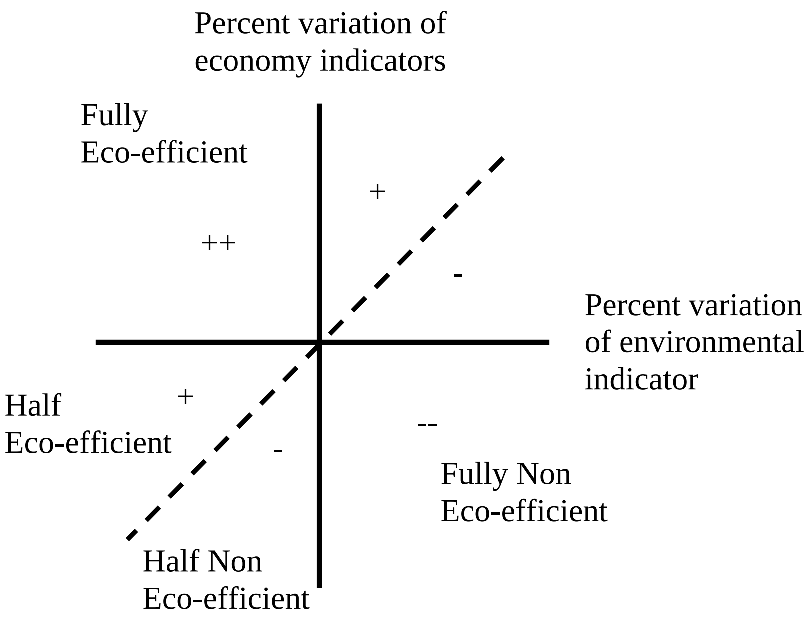



**Figure 5.1. The original format of snapshot graph [1]**

### 5.2.3 Limitation of the environmental fingerprint's format

BASF proposed environmental fingerprint by using five indicators including energy consumption, emissions, toxicity potential, risk potential, and materials consumption to present the relative ecology of each alternative technology. Each indicator was located in each axes. The alternative technology bearing a value of 1 was the least favorable technology whereas the technology locating in the innermost of the axes was the favorable option. The environmental fingerprint of BASF was presented in Figure 5.2.

In this study, the original format of environmental fingerprint adopted from BASF was improper to be used to analyze the relation of NEB, NFC and ECE of CT option. New environmental fingerprint's format was developed accord to the aims of study. Proposed five environmental indicators were transformed to three indicators comprising of economic, environment and ECE figure. The result interpretation had to be changed also. The outermost option holding value of 1 was the most suitable option to implement for ECE figure and environmental concern. Otherwise, the result interpretation of economic aspect was done similarly as BASF method. Therefore, some confusion might be occurred. However, the developed format of environmental fingerprint using in this study was revealed in Figure 3.1 (chapter3).

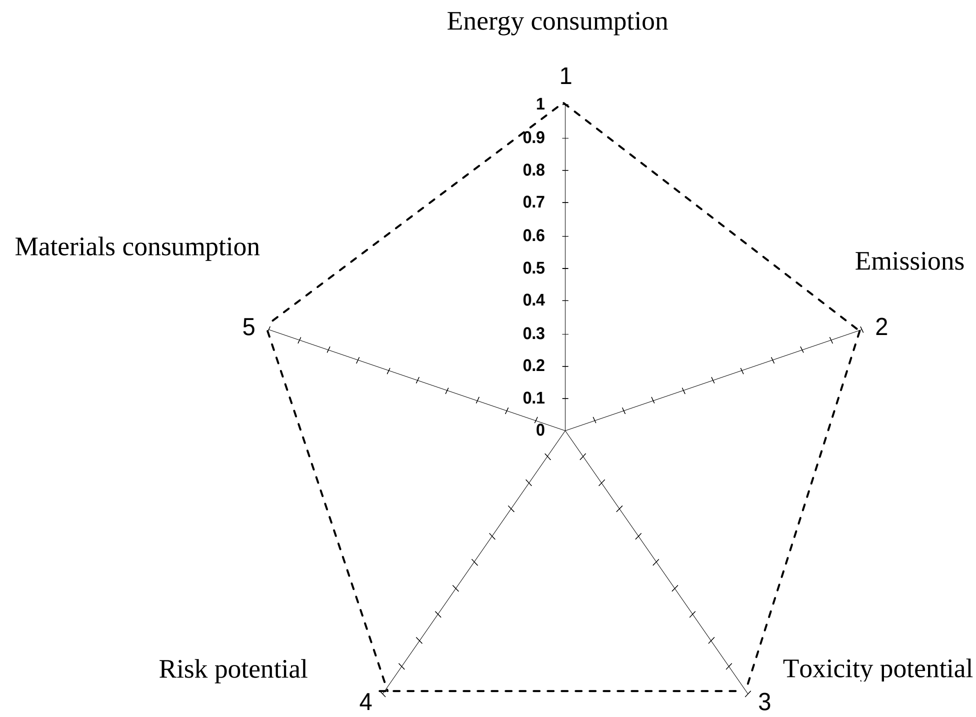



**Figure 5.2. Environmental fingerprint's format of BASF [21]**

## 5.3 Recommendation

This research concentrated to study the CT options group which regard to the reduction of the fuel oil consumption in the production process of canned pineapple industry only. In further work, ECE can be proposed as a CT supportable tool for other kinds of CT option group and for other types of industry as well. However, the auditor should keep in mind that the proposed ECE equation used in this research was suitable for measuring the quality of some CT option group only. When using ECE for evaluating several kinds of CT option group or other types of industry, the auditor should firstly set studied target and then develop ECE equation accord to the nature of case study and the purpose of study. The number of annual production, the total amount of incomes in a year, etc. can be used in economic term. For environmental term, the reduction of total wastes including the reduction of any kind of environmental impact (such as global warming, acidification, human toxicity, etc.) was the relevant topic can be studied.

However, the proposed ECE was mentioned on environmental and economic aspect only. To increase more reliability on CT option's quality, the further work should concern on the affect of CT option to social aspect also. Determining three particular prospective comprising of economic, environmental, and socialization at the same time can help the decision maker selecting the most suitable CT option of three aspects to implement. Consequently, the company will eventually reach to the sustainable development goal.

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# APPENDIX

# APPENDIX A

## Classification factors* for LCA impact categories [11]

| Burdens | Resource depletion (world reserves) | Global warming GWP 100 years (equiv. to $CO_2$) | Ozone depletion ODP (equiv. to CFC 11) | Acidification AP (equiv. to $SO_2$) | Eutrophication EP (equiv. to $PO_4{}^{3-}$) | Photo-chemical smog POCP (equiv. to ethylene) | Human toxicity | Aquatic toxicity ($m^3mg^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Coal reserves | 8.72E+13 | | | | | | | |
| Oil reserves | 1.24E+11 | | | | | | | |
| Gas reserves | 1.09E+14 | | | | | | | |
| CO | | | | | | | 0.012 | |
| $CO_2$ | | 1 | | | | | | |
| $No_x$ | | | | 0.7 | 0.13 | | 0.78 | |
| $SO_2$ | | | | 1 | | | 1.2 | |
| HC | | | | | | 0.416 | 1.7 | |
| $CH_4$ | | 11 | | | | 0.007 | | |
| Aldehydes | | | | | | 0.443 | | |
| Chlorinated HC | | 400 | 0.5 | | | | 0.98 | |
| CFCs | | 5000 | 0.4 | | | | 0.022 | |
| Other VOC | | 11 | 0.005 | | | 0.007 | | |
| As | | | | | | | 4700 | |
| Hg | | | | | | | 120 | |
| $F_2$ | | | | | | | 0.48 | |
| HCl | | | | 0.88 | | | | |
| HF | | | | 1.6 | | | 0.48 | |
| $NH_3$ | | | | 1.88 | | | 0.02 | |
| Cr | | | | | | | 0.57 | 9.07E + 08 |
| Cu | | | | | | | 0.02 | 1.81E + 09 |
| Fe | | | | | | | 0.0036 | |
| Hg | | | | | | | 4.7 | 4.54E + 11 |
| Zn | | | | | | | 0.0029 | 3.45E + 08 |
| Pb | | | | | | | 0.79 | 1.81E + 09 |
| Ni | | | | | | | 0.057 | 2.99E + 08 |
| Fluorides | | | | | | | 0.041 | |
| Nitrates | | | | | 0.42 | | 0.00078 | |
| Phosphates | | | | | 1 | | 0.00004 | |
| Olis and greases | | | | | | | | 4.54E + 07 |
| Amonia | | | | | 0.33 | | 0.0017 | |
| Chlorine | | | | | | | 0.29 | 5.44E + 07 |
| Cyanides | | | | | | | 0.057 | |
| Pesticides | | | | | | | 0.14 | 1.18E + 09 |
| Phenols | | | | | | | 0.048 | 5.35E + 09 |
| COD | | | | | 0.022 | | | |

All classification factors are expressed in kg kg-1, unless otherwise stated.

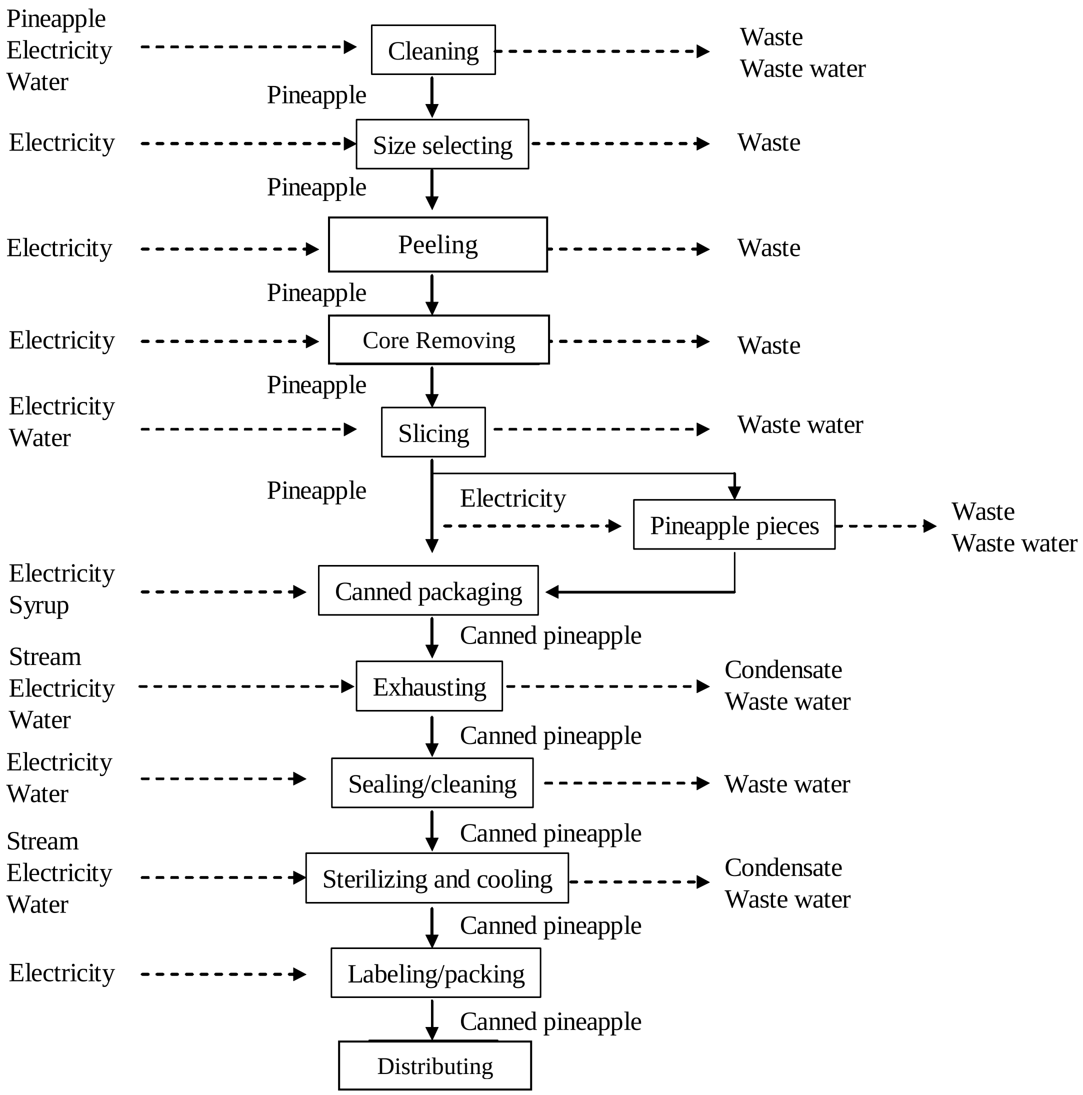
# APPENDIX B

## The requirements of raw materials of 12 canned pineapple industries [6]

| Industries | Products (ton/yr) | Pineapples (ton/ton of product) | Sugar (ton/ton of product) | Citric acid (kg/ton of product) | Water ($m^3$/ton of product) | Fuel oil (l/ton of product) | Electricity (kWh/ton of product) |
|---|---|---|---|---|---|---|---|
| 1 | 50,000 | 1.43 | 0.03 | 0.05 | 3.24 | 111 | 17.83 |
| 2 | 60,000 | 2.91 | 0.10 | 0.29 | 2.13 | 50.12 | 43.91 |
| 3 | 31,200 | 5.25 | 0.16 | 1.07 | 6.99 | 109.73 | 134.06 |
| 4 | 72,690 | 5.34 | 0.08 | 0.97 | 6.06 | 63.94 | 43.90 |
| 5 | 90,000 | 4.33 | 0.11 | 0.80 | 8.49 | 71.57 | 158.28 |
| 6 | 100,000 | 4.58 | 0.12 | 2.52 | 4.76 | 60.53 | 60.45 |
| 7 | 105,000 | 5.75 | 0.13 | 0.99 | 21.22 | 51.06 | 65.32 |
| 8 | 120,000 | 3.79 | 0.17 | 3.67 | 15.46 | 119.98 | 69.21 |
| 9 | 130,000 | 6.96 | 0.13 | 2.71 | 43.53 | 107.09 | 35.83 |
| 10 | 180,000 | 5.63 | 0.12 | 0.84 | 5.51 | 63.02 | 68.35 |
| 11 | 180,000 | 4.78 | 0.07 | 0.74 | 16.35 | 68.01 | 48.56 |
| 12 | 220,000 | 4.60 | 0.16 | 2.00 | 4.98 | 40.91 | 31.94 |

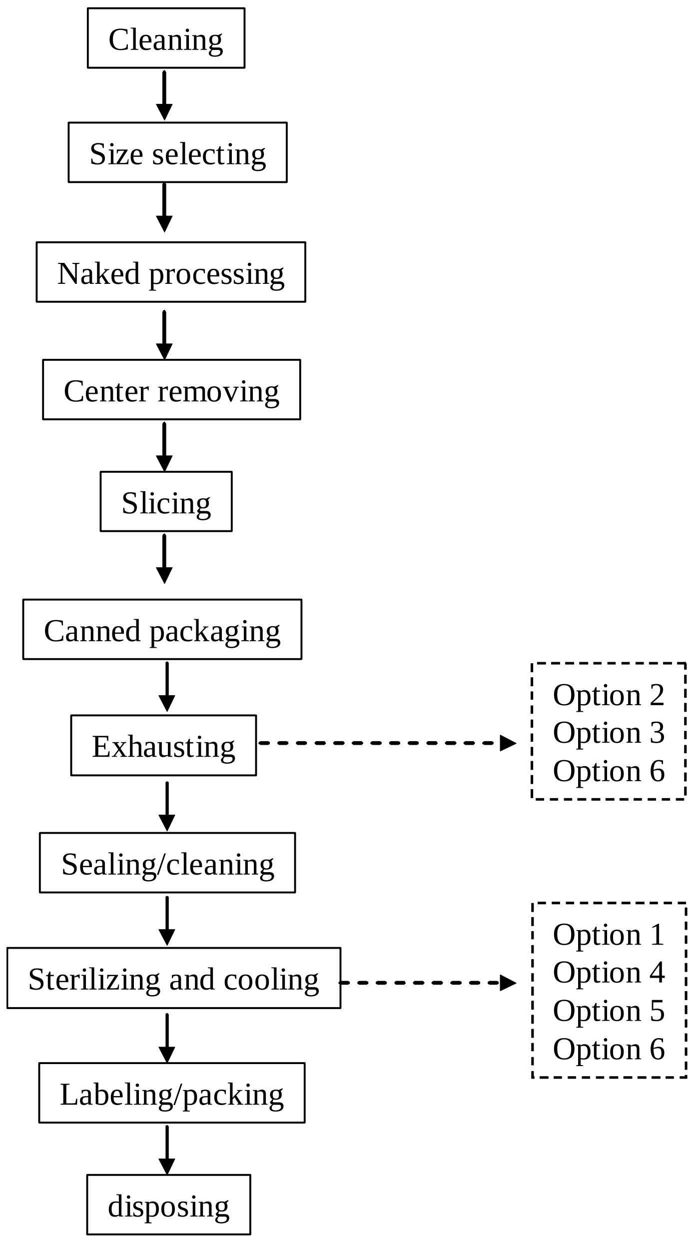
# APPENDIX C

## Canned pineapple production process [6]



# APPENDIX D

## The locations of implementing every proposed CT options in canned pineapple production process [6]



# APPENDIX E

## The calculation of the reduction of GWP of each CT option

| No. | CT options | The amount of $CO_2$ emission reduction (kg/yr) | | | The total reduction of GWP (kg/yr) |
|---|---|---|---|---|---|
| | | $CO_2$ | GWP | Total | |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 41,250 | 1 | 41,250 | **41,250** |
| 2 | Improving of steam supply system in a sterilizing cooker** | 72,052 | 1 | 72,052 | **72,052** |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 9,642 | 1 | 9,642 | **9,642** |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 30,535 | 1 | 30,535 | **30,535** |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 96,427 | 1 | 96,427 | **96,427** |
| 6 | Improving of combustion efficiency of a boiler** | 82,452 | 1 | 82,452 | **82,452** |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.

## The calculation of the reduction of AP of each CT option

| No. | CT options | The total $SO_2$ emission reduction (kg/yr) | | | The total $NO_2$ equivalents for $SO_2$ reduction (kg/yr) | | | The total reduction of AP (kg/yr) |
|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | AP | Total | $NO_2$ | AP | Total | |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 578 | 1 | 578 | 31.35 | 0.7 | 22 | **599** |
| 2 | Improving of steam supply system in a sterilizing cooker** | 1,009 | 1 | 1,009 | 54.76 | 0.7 | 38 | **1047** |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 135 | 1 | 135 | 7.33 | 0.7 | 5 | **140** |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 428 | 1 | 428 | 23.21 | 0.7 | 16 | **443** |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 1,345 | 1 | 1350 | 73.28 | 0.7 | 51 | **1401** |
| 6 | Improving of combustion efficiency of a boiler** | 1,154 | 1 | 1,154 | 62.66 | 0.7 | 44 | **1198** |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.

## The calculation of the reduction of HTP of each CT option

| No. | CT options | The total $SO_2$ emission reduction (kg/yr) | | | The total $NO_2$ emission reduction (kg/yr) | | | The total reduction of HTP (kg/yr) |
|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | HTP | Total | $NO_2$ | HTP | Total | |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 577.5 | 1.2 | 693 | 31.35 | 0.78 | 24 | **717** |
| 2 | Improving of steam supply system in a sterilizing cooker** | 1008.74 | 1.2 | 1210 | 54.76 | 0.78 | 43 | **1,253** |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 135 | 1.2 | 162 | 7.33 | 0.78 | 5 | **167** |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 427.49 | 1.2 | 513 | 23.21 | 0.78 | 18 | **531** |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 1349.99 | 1.2 | 1620 | 73.28 | 0.78 | 57 | **1677** |
| 6 | Improving of combustion efficiency of a boiler** | 1154.34 | 1.2 | 1385 | 62.66 | 0.78 | 49 | **1,434** |

* refer to the options which have been implemented already in caned pineapple production process.

** refer to the options which have never been implemented in caned pineapple production process.

# APPENDIX F

## The normalized values of NFC, NEB, and ECE calculation of each CT option

| No. | CT options | NEB (kg/yr) | | NFC (baht) | | ECE calculation | |
|---|---|---|---|---|---|---|---|
| | | Total | Normalized value | Total | Normalized value | Total | Normalized value |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 41,859 | **0.42** | 105,000 | **0.53** | 0.399 | **0.29** |
| 2 | Improving of steam supply system in a sterilizing cooker** | 73,117 | **0.75** | 57,000 | **0.29** | 1.283 | **0.92** |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 9,785 | **0.1** | 160,000 | **0.8** | 0.061 | **0.04** |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 30,985 | **0.32** | 160,000 | **0.8** | 0.194 | **0.14** |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 97,851 | **1** | 200,000 | **1** | 0.489 | **0.35** |
| 6 | Improving of combustion efficiency of a boiler** | 83,670 | **0.86** | 60,000 | **0.3** | 1.394 | **1** |

* refer to the options which have been implemented already in caned pineapple production process.
** refer to the options which have never been implemented in caned pineapple production process.

# APPENDIX G

## The information of each CT option for calculating value of snapshot graph

| No. | CT options | NFC (Baht) | NEB (kg/yr) | Snapshot graph plotting values | |
|---|---|---|---|---|---|
| | | | | % variation of NFC $\frac{(NFC_n - NFC_{mean}) * 100}{NFC_{mean}}$ | % variation of NEB $\frac{(NEB_n - NEB_{mean}) * 100}{NEB_{mean}}$ |
| 1 | Installing of a positioner system for controlling steam supply system in an exhaust box* | 105,000 | 41,859 | -15.09 | -25.53 |
| 2 | Improving of steam supply system in a sterilizing cooker** | 57,000 | 73,117 | -53.91 | 30.08 |
| 3 | Installing of an automatic steam supply system in an exhaust box** | 160,000 | 9,785 | 29.38 | -82.59 |
| 4 | Installing of an automatic steam supply system in a sterilizing cooker** | 160,000 | 30,985 | 29.38 | -44.88 |
| 5 | Installing of a positioner system for steam supply control of a sterilizing cooker** | 200,000 | 97,851 | 61.73 | 74.08 |
| 6 | Improving of combustion efficiency of a boiler** | 60,000 | 83,670 | -51.48 | 48.85 |
| | **Mean** | **123,667** | **56,210.94** | **-** | **-** |

* refer to the options which have been implemented already in caned pineapple production process.

** refer to the options which have never been implemented in caned pineapple production process.

# BIOGRAPHY

| | |
|---|---|
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