CHAPTER 1
INTRODUCTION

The research outlined in this thesis relates to the cause–effect chain from environmental interventions to damage to the environment, modeled for global warming causing damage to human health, social assets, and primary production; human toxicity causing damage to human health; eco–toxicity causing damage to biodiversity; eutrophication causing social assets damage; and acidification causing both primary production and social assets damage. The improved and adjusted methods in this thesis make it possible to present actual damage caused by environmental interventions in terms of loss of human health, social assets, primary production, and biodiversity. Moreover, it is possible to use weighting across of four safeguard subjects are human health, social assets, primary production, and biodiversity into a single index. The research contributes to the discussion of whether information on actual damage can be obtained in such a way and weight across those it's applicable in environmental life cycle assessment (LCA).

This chapter provides (1) background and statement of the problem, (2) focuses on the objectives of the research, (3) research scope, (4) future benefits of the research, and (5) provides an outline of the thesis.

1.1 Background and statement of the problems

1.1.1 Environmental problems in Thailand

Thailand has experienced rapid economic growth over the last three decades, which has at the same time caused serious environmental problems threatening the survival of Thai people. For the past few years, environmental problems in Thailand have worsened due to the transformation from a traditional agricultural country to an industrially developing country. There are six specific environmental problems in Thailand Thailand – climate change, intensive farming, water pollutants, air pollutants, resource depletion, and waste generation as follows (PCD, 2013) (Figure 1.1):

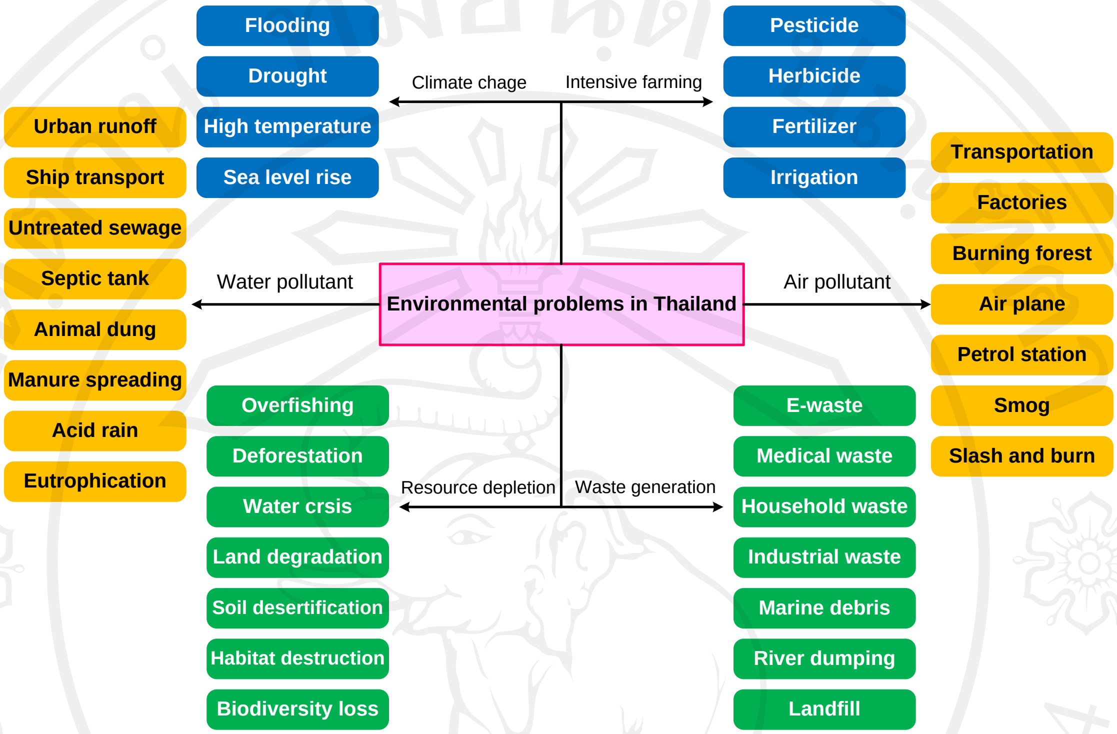

Figure 1.1: Summary of the environmental problems in Thailand

- **Climate change**

The impacts of climate change in Thailand – namely prolonged droughts, decreased agricultural and fishery yields, violent flooding, sea level rise, and health–related issues – are already serious and will likely create or exacerbate a number of additional problems in the future. Two years ago, the effects of climate change on Thailand caused torrential rains and mega floods in the central part of the country and Bangkok Metropolitan area (Corben, 2011). The next year, Thailand had a drought emergency, which threatened farmers whose survival depended on their rice harvest and water supply (Kisner, 2011). Additionally, this year malaria is becoming more prevalent, also an effect of climate change, (MOPH, 2013).

- **Intensive farming**

Traditionally, Thailand is an agricultural country. Intensive farming in northern Thailand is a reality and has been a problem to the environment due to chemical use. Heavy use of pesticides and chemical fertilizers on farmed land has increased environmental pollution by poisoning soil, rivers, and groundwater with agricultural chemicals. Ndeve *et al.,* (2007) analyzed soil containing potassium, which caused a change in biodiversity over 20 years, characterized by loss of species, crops, wild plants and animals.

- **Water pollutants**

Cheevaporn and Menasveta, (2003) pointed out serious water pollution in Thailand – 90 percent of industrial waste consists of untreated municipal and industrial wastewater, including hazardous chemicals which are discharged without treatment (UNEP, 1999), and eutrophication is an emerging problem in the Songkhla Lake in southern Thailand.

- **Air pollutants**

The three major sources of air pollution in Thailand are vehicular emissions in cities, biomass burning and transboundary haze in rural and border areas, and industrial discharges in concentrated industrialized zones. In cities such as Bangkok, air quality monitoring performed by the Pollution Control Department (PCD) over the past 10 years revealed that the levels of PM10 have exceeded both annual (50 $\mu g/m^3$) and 24-hr (120 $\mu g/m^3$) national standards (PCD, 2008). The main source of PM10 in Bangkok is vehicular emissions (Chuersuwan, 2008).

In the rural and border areas, most notably Chiang Mai, agricultural burning and forest fires, including transboundary haze from Myanmar, have contributed to high levels of PM10, which have increased to critical levels since 2006 [175-300 $\mu g/m^3$]. Moreover, the Southeast Asian haze that originated in Indonesia has continually affected the health of residents of the southern provinces (PCD, 2010).

Consequently, expansion of petrochemical plants rose sharply, particularly in Rayong province in eastern Thailand, with more than 73 million tonnes of chemicals used annually (Department of Industrial Works, 2012). Although environmental management has been instituted, levels of volatile organic compounds (VOCs) continue to exceed Thailand's standards (PCD, 2010).

- **Resource depletion**

Natural resource depletion is an increasing problem due to economic growth and population increase. Nowadays, natural forest is decreasing due to forest encroachment for agriculture or household use. The changes are causing storms to intensify, the loss of places for wildlife to retreat to, the loss of biodiversity, and soil erosion.

- **Waste generation**

Waste generation is a serious problem, especially electronic waste coming from discarded mobile phones, computers, televisions, refrigerators, etc. Nowadays people frequently change their mobile phones not because of malfunction or technical problems but just because of fashion. In addition to electronic waste, there is also medical waste, household waste, industrial waste, marine debris, river dumping, and landfill.

Several countries tried to manage the environmental problems by employing various tools to help inform them in the decision–making process such as environmental impact assessment (EIA), risk assessment (RA), etc. Life Cycle Assessment (LCA) is an effective tool for assessing the environmental burden associated with a product or service throughout its life cycle. It considers impacts from raw materials procurement, manufacturing, transportation, and usage and disposal or, in other words, all the stages of a product's life from–cradle–to–grave. LCA is covered by ISO 14040 Standard Series which includes four steps: goal and scope definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA), and interpretation (ISO, 2006a).

In Thailand, there have been more than 700 datasets of LCI databases established such as energy, petrochemical materials, agricultural materials, etc. However, there is no common method that can be used to analyze the impact assessment in the third phase of LCA framework. Several LCA studies in Thailand selected foreign methods for evaluating the results. Taking this into account, this research aims to develop an LCIA method by adapting existing models so that they are suitable for Thailand.

1.1.2 Life cycle impact assessment

LCIA according to ISO 14042/14044 standard aims to convert inventory data into potential environmental impacts (Ryding, 1999; ISO, 2006b; Margni and Curran, 2012), and it can be divided into mandatory elements and optional elements. The mandatory elements include selection impact categories, classification, and characterization, whereas optional elements include normalization, grouping, weighting, and/or data quality (ISO, 1997; ISO, 2000; ISO, 2006a; Bare, 2010).

One of the earliest significant publications in LCIA provided characterization factors for the following impact categories: resource depletion, global warming, ozone layer depletion, acidification, eutrophication, human toxicity, eco–toxicity and photochemical oxidation, and those factors for Europe only (Bare, 2010). After that, Society of Environmental Toxicology and Chemistry (SETAC) stated that time horizon, spatial differentiation, midpoint and endpoint analysis, and Areas of Protection (AoP) could be considered in LCIA development (Bare, 2000; Bare *et al.*, 2002).

In LCIA, the choice of time horizons for integrating impacts and distribution of those impacts through time is an important discussion subject. de Scheyver *et al.*, (2008) compared time horizon differences for global warming damage on human health and ecosystems, typically 20, 100, and infinity (> 500) years. Depending on the choice, the global warming damage of pollutants differed considerably.

The second most important, spatial differentiation, has been considered as a subject of improvement for LCIA methods (Potting and Hauschild, 2006; Humbert *et al.*, 2009). Three levels of spatial differentiation were defined; site–generic is considered to contribute to the same generic receiving environment. Then, site–dependent is performed by distinguishing between classes of sources and determining their subsequent receiving environment. Only five LCIA methods have been released which include spatial differentiation in their characterization models: EDIP2003, TRACI, IMPACT 2002^{+}, LIME, and LUCAS methods (Hauschild and Potting, 2003; Jolliet *et al.*, 2002; Itsubo and Inaba, 2003; Bare *et al.*, 2003; Toffoletto *et al.*, 2007). Thus, in the following impact categories spatial differentiation was divided into three levels: global (global warming and ozone layer depletion), regional (acidification and land use), and local (eutrophication, human toxicity and eco-toxicity) (Bare *et al.*, 2000; Lohani *et al.*, 1997; SETAC-Europe, 1999; Reap *et al.*, 2008). Tolle *et al.*, (2001) developed characterization factors for toxic impact potential and found that those factors differed under site–generic and site–specific spatial differentiation.

Early LCIA models were not up endpoint categories and only addressed up to midpoint categories because the cause and effect relationships are not necessarily part of LCA. This means that, taking the example of ammonia (NH_3) causing acidification, and eventually a loss of biodiversity, it was not the purpose of an LCA to prove that NH_3 release is responsible for biodiversity loss. This was one of the key issues that arose that became the focus of the third international workshop to summarize midpoint and endpoint categories (Bare *et al.*, 2000). Midpoint was defined as the links in the cause-effect chain (environmental mechanism) of an impact category, prior to the endpoints, at which characterization factors or indicators can be derived to reflect the relative importance of emissions or extractions. A common example of midpoint is ozone layer depletion. Midpoint level analysis is characterized as allowing greater comprehensiveness and modeling certainty, whereas endpoint analyses are considered to be more useful when an aggregation of impacts across the traditional impact categories is being conducted (Bare, 2010). In later years, the need to follow cause-effect chains up to damage was slowly realized and applied in practice, resulting in endpoint methods such as EPS (Steen, 1999b), Eco-Indicator 99 (Goedkoop and Spriensma, 2000), ReCiPe (Goedkoop *et al.*, 2009), and LIME (Itsubu *et al.*, 2004).

Finally, areas of protection (AoPs) have had the most significant effect on advancement in LCIA. This distinguishes four areas of protection: resources, human health, biodiversity, and life support systems. Individual impact categories are related to one or more of these areas of protection. Each LCIA method identified difference areas of protection. Eco-indicator99 involved human health, ecosystems and resources whereas LIME involved human health, social assets, biodiversity and primary production. Only some LCIA models added AoPs, such as Eco-indicator99, ReCiPe, IMPACT 2002$^+$ and LIME.

1.1.3 Life cycle impact assessment methods

In the above-mentioned methods the framework of the LCIA model should be considered. However, a practitioner may also want to compare impact categories, or even areas of protection, to priorities or to resolve trade-offs between product alternatives (e.g. lower global warming indicators for one option, but higher human toxicity indicator results for another). This can be achieved, to some extent, using natural science approaches – particularly within areas of protection such as human health. Comparing across impact category indicators is an optional step in some applications of LCA (ISO 14042, 2000). In common LCA practice, this optional step draws not only on natural sciences, but often relies heavily on social science and, in some cases, on economics. The following subsections introduce some of the techniques for normalization, grouping and weighting. Normalization relates the magnitude of impacts in different impact categories to reference values, (Finnveden *et al*., 2002) e.g. the impacts caused by one person during one year, in order to facilitate comparisons across impact categories. According to ISO 14042, grouping is an assignment of impact categories to groups, commonly referred to as AoP. In the recent LIME method, proposed AoPs are human health, social assets, biodiversity and primary production, as presented in Figure 1.2. Finally, there is the optional step of weighting across those AoPs to provide a final impact indicator, such as LIME converts in monetary terms.

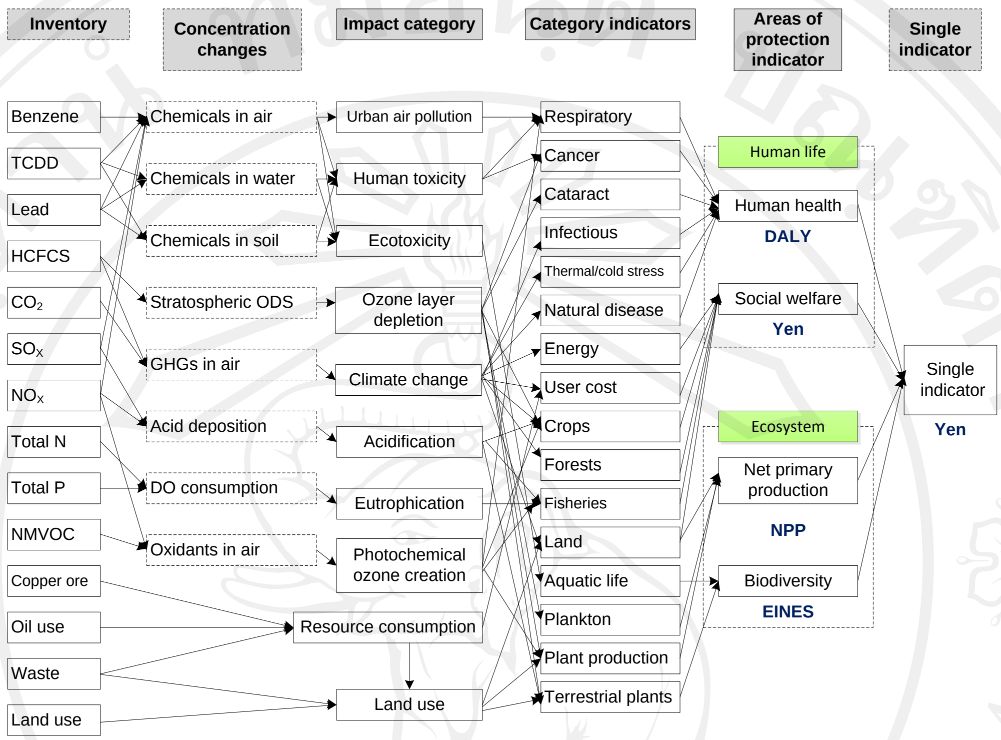

Figure 1.2: Illustrative inventory data, category indicators, areas of protection, as well as an optional step to estimate a final indicator in terms of Yen (based on LIME) (Source: Itsubo and Inaba, 2003)

The LCIA method will be developed to be suitable for Thailand. But, due to limitations of time, it should be based on other LCIA methods. LIME is one LCIA method developed for Japan which included mandatory and optional elements, and consists of the cause–effect chain of environmental problems. The areas of protection considered involved human health, social assets (mean natural resource depletion), biodiversity and primary production. However, as LIME was also developed for an Asian–Pacific country, Thailand could also develop its own environmental impact model based on the LIME method.

Currently, Thailand is going to impose an environmental tax but of an inappropriate value. LCA is an environmental assessment tool for the evaluation and improvement environmental included from the cradle to the grave. Weidema, (2009) applied LCIA damages on human health, ecosystems and mineral resources to externality cost. Thailand is expected to impose environmental tax on three main industries: electricity power plants, oil refineries, and the petrochemical industry (NPC–SE, 2013).

Based on the framework of the LIME method under conditions specific to Thailand, this study has developed a damage model (including midpoint and endpoint), normalization and weighting factors. The environmental assessment is performed with respect to electricity power plants with two main cases studied: fossil fuel and renewable power plants. The expect results are damage factors at least five damages which the main and hot issue problems in Thailand and damage guidelines would be developed in the future.

1.2 Objective of the research

1.2.1 To develop the environmental impact assessment model for Thailand based on endpoint modeling.

1.2.2 To develop characterization factors for midpoint impact categories, damage factors for endpoint impact categories, normalization and weighting factors, and convert those factors to monetary valuation of safeguard areas.

1.3 Research scope

1.3.1 The endpoint modeling was based on the LIME method in the development of the environmental impact assessment model for Thailand.

1.3.2 Normalization factors were excluded from development due to lack of information data and those factors were estimated by using unit transfer with income adjustment. This method estimated the ratio between income levels in both sites and the income elasticity of demand for the environmental good (European Communities, 2005), so that the benefit value in the policy–site can be assumed. Formulary for estimates in this part is shown in equation (1.1).

$$B_{TH} = B_{JP} \cdot \left(\frac{Y_{TH}}{Y_{JP}} \right)^{\beta} \tag{1.1}$$

where

B_{TH} is the adjusted policy–site benefit for Thailand

B_{JP} is the original benefit based on the LIME method

Y_{TH} , Y_{JP} are the domestic product at purchasing power parity per capita (GDP(PPP)$_{percap}$)

β is the income elasticity of demand for analyzing the environmental good, which is assumed equal to one (European Communities, 2005)

Based on the year 2012, the GDP(PPP)$_{percap}$ of Thailand and Japan was 8,703 and 34,298 Baht, respectively (exchange rate 38.70 Baht/100 Yen) (Bank of Thailand, 2013). However, any factors which could not be estimated from Thailand data used unit transfer with income adjustment for estimation values.

1.3.3 The model was applied to LCA of electricity production in Thailand. The data collection used secondary data from the Electricity Generation Authority of Thailand 2011 (EGAT). However, the LCI stage used the SimaPro 7.1 program to convert the LCI data from raw material, waste, and emissions to air, water, and soil.

1.4 Future benefits of research

1.4.1 As original research, the model has developed three new factors related to data and Thai information: characterization, damage, and weighting factors. Those factors can indicate external cost for Thailand.

1.4.2 The model has been developed as the political decision–making tool for environmental taxation of products and/or environmental policy in Thailand.

1.4.3 The findings from this research can be used as guide to develop life cycle impact assessment models for Thailand in the future.

1.5 Research procedure and methodology

The research procedure and methodology of this study comprises seven operational steps that are summarized in Figure 1.3, with additional details of these steps as follows:

1.5.1 Theory and principle review

The reviewing of principles, theory and related literatures in this step aims to review the relevant knowledge for utilization in the preparation of the concept and methodology of the research process. In essence, this can be classified into five groups as follows:

- Life cycle impact assessment model based on the LIME method.
- Impact assessment including four areas of safeguard: human health, social assets, biodiversity, and primary production, and 11 impact categories: global warming, ozone layer depletion, resource depletion, acidification, land use, human toxicity, eco-toxicity, eutrophication, photochemical ozone creation, urban air pollution, and waste.
- Normalization.
- Contingent Valuation Method (CVM) and weighting method.
- Life cycle assessment of electricity.

1.5.2 Analysis of environmental problems in Thailand

The analysis of the LCIA model for Thailand in this step aims to evaluate the major environmental problems in Thailand, and then analyze the cause–effect chain of the major problems related to impact category. Finally, weighting across safeguard subjects for the LCIA model in Thailand through the application of CVM could be applied. In this procedure analysis is conducted in four parts as follows:

- Survey of the main environmental problem in Thailand.
- Analysis of the cause–effect chain of the major problems related to impact categories.
- Analysis of weighting factors to monetary valuation.
- Integration of the factors to environmental impact model.

1.5.3 Data collection

The data collection in this step aims to survey and collect site–specific data related to a life cycle impact assessment model for Thailand, of which the collected data will be useful into two main parts: (1) application to develop the relationship of the model, and (2) its initial parameters for imparting a model. The data in this survey consists of two main parts as follows:

- The primary data consisted of interview data from 40 samples in pre–survey and 400 samples in the main survey, and included LCA, impact assessment model, forestry and biodiversity experts, and Thai people from all sub–regions of Thailand.
- The secondary data survey collected information related to impact assessment models such as population, nutrient loading in water, acid deposition, and LCI of electricity power plants in Thailand.

1.5.4 Data analysis

The data analysis in this step aims to analyze environmental problems in Thailand related to global warming, human toxicity, eco–toxicity, eutrophication, and acidification impact categories. Then, data was collected from selected areas for weighting safeguard subjects. The process in this section included six main parts as follows:

- Global warming model
- Human toxicity model
- Eco–toxicity model
- Eutrophication model
- Acidification model
- Preparing the questionnaire, sample data and areas collected.

1.5.5 Model development

The model development aims to develop the midpoint, endpoint, and weighting factors for Thailand's situation. The details of each model are as follows:

- Global warming model of the relationship development between temperature increases, effects of global warming on health and disease – diarrheal, malaria, cardiovascular diseases, malnutrition, and natural diseases, agricultural products such as rice and soybeans, and primary production of forests based on site–generic data.

- Human toxicity and eco–toxicity model of the relationship development between fate and exposure analysis, potency, and severity model, which used data such as population, land and water areas, amount of agricultural products, etc.
- Eutrophication model of the relationship development between two selected site–specific areas – Songkhla and Phayao lakes – analyzing nutrient loading, hydrodynamic and ecosystem models, and amount of benthic production.
- Acidification model of the relationship development between wet and dry depositions, Al^{3+} concentration, and soil profile.
- Weighting factors of the survey sampling involving 400 samples, and, using the CVM technique, an evaluated valuation of Willingness–to–Pay (WTP) to protect safeguard areas.

1.5.6 Model application

The model application aims to estimate the impacts of the testing of LCA of electricity generation in Thailand. The process in this step included two parts as follows:

- The scenarios defining, and data information for, estimate models.
- The application of the decision to support environmental tax in Thailand.

1.5.7 Conclusion and recommendations

Finally, all results from this study are summarized into conclusions and prepared as recommendations to be used for application to other environment impact models, and planning and management of the environmental tax of products or services in Thailand. In addition, it can also be a guideline for related research in the future.

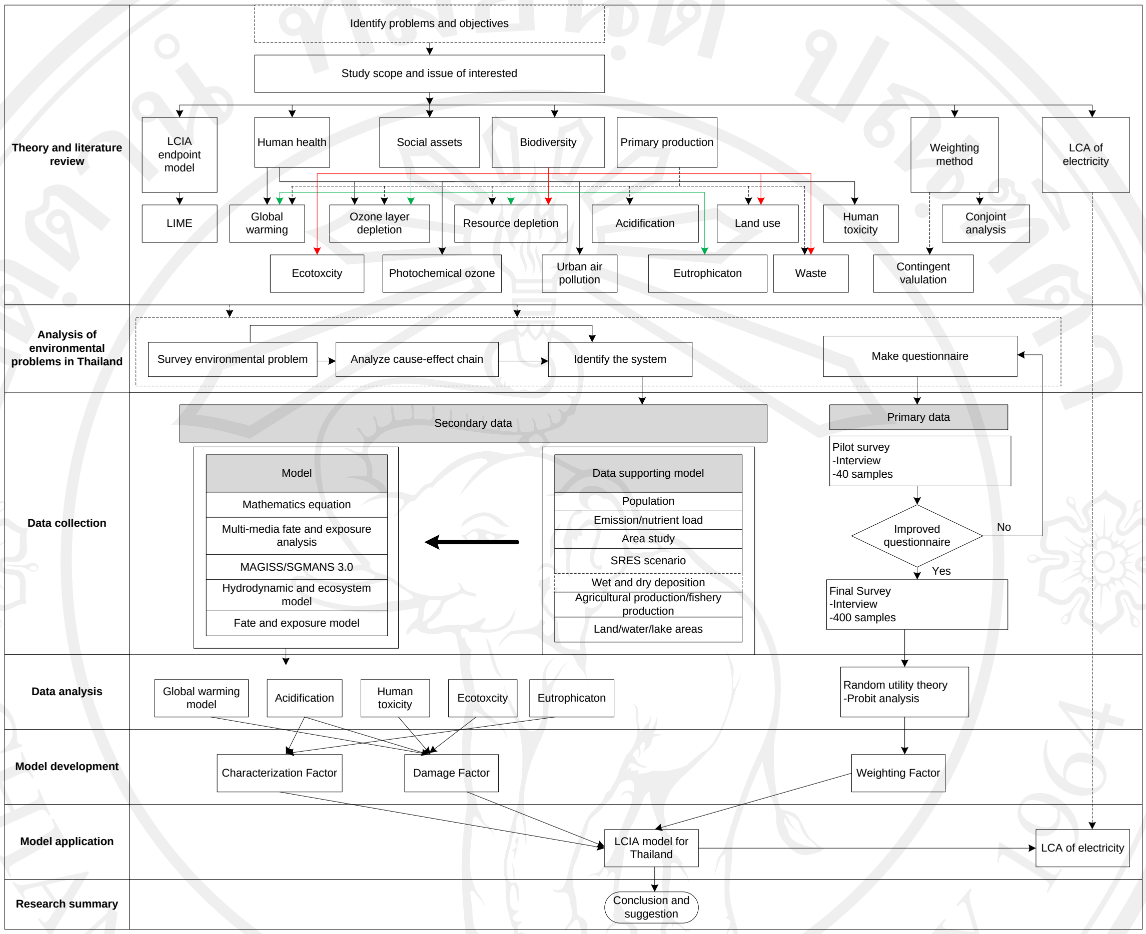

Figure 1.3: The research procedure and methodology