CHAPTER 3

MODELING CONCEPT

This chapter presents the model concept which represents the impact assessment model in this study. The content in this chapter includes:

- Opinion concerning major environmental problems in Thailand
- Cause and effect chain of global warming
- IMPACT2002 model for human toxicity and eco-toxicity
- Cause and effect chain of eutrophication
- Cause and effect chain of acidification
- Weighting factors

The details of these are as follows:

3.1 Opinion concerning major environmental problems in Thailand

There are many environmental occurring in Thailand. The environmental impact model developed in this study can only include 5 major cause and effect chains of environmental problems in Thailand. Surveys were based on reports from MPH, (2012), and MNRE, (2012), including face-to-face interviews of 100 people. The content of questionnaires described the cause-effect chain of all 15 impact groups and then respondents selected the one impact they thought was the major environmental problem in Thailand. The results found that respondents thought the top five environmental problems occurring in Thailand are climate change, human toxicity, eco-toxicity, water pollution, and eutrophication (Table 3.1). However, this study is based on the LIME method and/under which the water pollution impact category is undergoing development. Thus, the study will instead address the problems of the acidification model.

Table 3.1: Opinion concerning major environmental problems in Thailand

No.	Environmental impact	Rating (%)	Ranking
1	Water resource	3.75	9
2	Water pollution	6.25	5
3	Eutrophication	13.75	4
4	Photochemical smog	4.75	8
5	Urban air pollutant	2.50	10
6	Climate change	21.25	1
7	Acidification	5.25	6
8	Ozone layer depletion	0.00	12
9	Land use	5.00	7
10	Forest	2.50	10
11	Abiotic resource	0.00	12
12	Biotic resource	1.25	11
13	Human toxicity	16.00	2
14	Eco-toxicity	14.00	3
15	Waste	3.75	9

3.2 Cause and effect of global warming

Global warming is an issue of our world at-large. Carbon dioxide (CO_2) and other gases in the atmosphere make it difficult to maintain natural environmental conditions. The act of burning fossil fuels therefore gives rise to the most serious problem – the release of carbon dioxide into the air.

The main effects of massive global warming can be witnessed in the form of extended climate. The frequency of floods and hurricanes in coastal areas around the globe has increased. Temperature extremes are commonplace these days. Similarly, many areas are experiencing droughts and forest fires every now and then. The change in the atmospheric temperature brings about several artificial changes to wild animals. The migration pattern of various animals and birds is being adversely affected by global warming as more and more creatures tend to move farther from the equatorial regions. For example, butterflies and mosquitos are now found in areas away from their natural habitat. Butterflies are not dangerous to human health. However, mosquito's damage fewer may cause malaria which is obviously a fatal disease. Not only animals, but vegetables also are not safe from the negative effects of global warming. The growth patterns of various flowers and plants have deviated from their natural route. Due to extreme temperatures, agricultural yields also cannot meet demand. The cause and effect chain of global warming is presented in Figure 3.1.

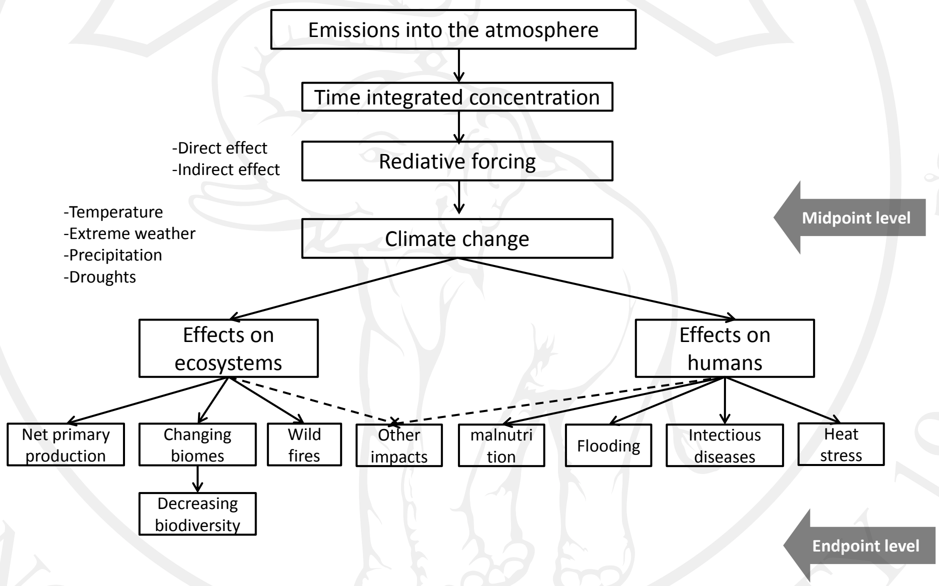

Figure 3.1: Cause and effect relationship of global warming

(Source: European Commission, 2010)

The cause-effect chain of global warming can be divided into two factors, midpoint and endpoint (damage). For the midpoint factor, the Global Warming Potential (GWP) index expresses the ratio between the increased infrared absorption due to the instantaneous emission of 1 kg of a substance and that due to an equal emission of CO_2, both integrated over time as in equation (3.1):

$$GWP_{TH,i} = \frac{\int_0^{TH} a_i c_i(t)\,dt}{\int_0^{TH} a_{CO_2} c_{CO_2}\,dt} \tag{3.1}$$

where a_i is radiative forcing per unit concentration increase of greenhouse gas *i* ($W{\cdot}m^{-2}{\cdot}kg^{-1}$);

$c_i(t)$ is the concentration of greenhouse gas *i* at time *t* decay ($kg{\cdot}m^{-3}$);

TH is time horizons of 20, 100, and 500 years.

GWP from the above equation is a measure of the potential contribution a substance can make to global warming and incorporated fate analysis. Damage Factors (DFs) of global warming can be calculated in the equation (3.2) as follows (de Schryver *et al*., 2009):

$$DF_{i,e} = \frac{dC_i}{dE_i} \cdot \frac{dRF}{dC_i} \cdot \frac{dTEMP}{dRF} \cdot \frac{dIMPACT_e}{dTEMP} \tag{3.2}$$

where

dE_i is the change in emission of greenhouse gas *i* (kg/year);

dC_i is the change in air concentration of greenhouse gas *i* (ppb);

dRF is the change in radiative forcing (W/m^2);

$dTEMP$ is the change in global mean temperature (°C) based on 1990;

$dIMPACT_e$ is the marginal change in damage for environmental endpoint *e*.

In general, the damage of environmental endpoint factors has changed. For instance, data from diseases due to global warming has started to change in sub-regional countries. SRES models have been applied for changes in temperature.

3.3 IMPACT2002 model for human toxicity and eco-toxicity

After being released into the environment, some chemicals have the potential to migrate from medium to medium. A danger to human health is presented when contaminated media are consumed, inhaled, or brought into dermal contact. In the LIME method, human health impacts are addressed by aggregating the toxic chemical release. However, toxins are not only toxic to human health, but they also affect ecological living organisms in many ways. LIME also addressed eco-toxicity impact due to specific types of loss of biodiversity. The cause and effect chain of both human toxicity and eco-toxicity is presented in Figure 3.2.

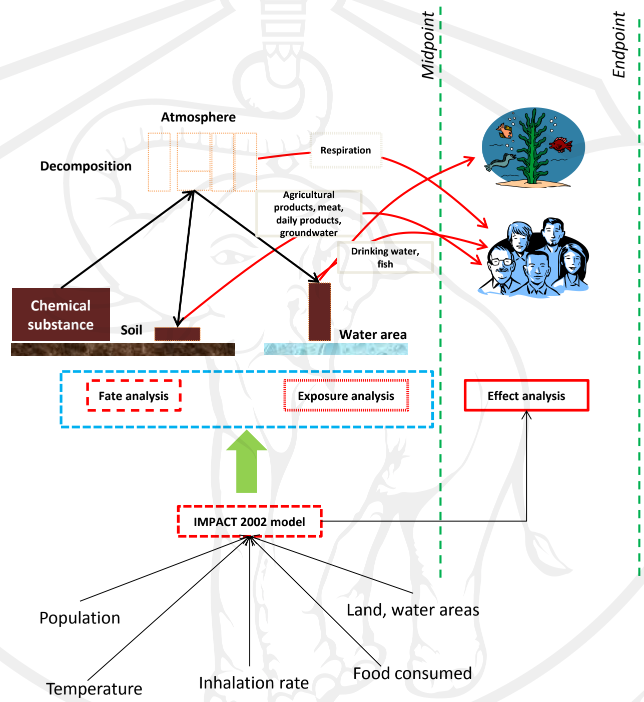

Figure 3.2: Cause and effect relationship of toxic chemicals

(Source: European Commission, 2010)

For toxic chemical uses IMPACT2002, developed by Pennington *et al*. (2005), uses a multimedia, multi-pathway, fate, exposure, effect, and damage steady-state model (Figure 3.3). It predicts chemical concentrations in environmental media for direct indoor surroundings as well as at local (urban), regional and global scales. Furthermore, it predicts multiple exposure pathways that link chemical concentrations in the atmosphere, soil, surface water, and vegetation to human intake through inhalation and ingestion. It allows the calculation of human toxicity (carcinogenic and non-carcinogenic effects) and aquatic and terrestrial ecotoxicity caused by organic and inorganic pollutants.

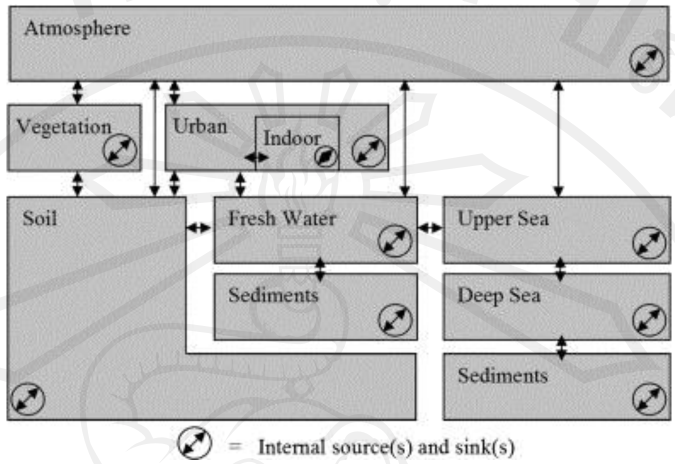

Figure 3.3: Framework for fate modeling (Source: Humbert *et al.*, 2009)

In IMPACT2002 the three main scales are (1) direct surroundings (indoor or outdoor); (2) local scale (urban or non-urban); and (3) regional scale (in which air cell, watershed or ocean zone is considered). This model can be adapted to Thai conditions which are presented in Appendix B. The numerical values are presented directly in excel tables and can be downloaded at http://www.sph.umich.edu

3.3.1 Human toxicity

This study has estimated the characterization factor for chemical toxicity effects on human health at endpoint level using the IMPACT 2002 model under conditions for Thailand and has adopted methodology based on the LIME method.

The development procedures of the damage function of chemical substances on human health and biodiversity are shown in Figure 3.4. The effects of chemical substances on human health are divided into four phases: fate analysis, exposure analysis, potency, and severity. Fate and exposure analysis concern the relationship between the movement of the chemical substance i from compartment m to compartment n in the environment to humans through inhalation, ingestion, and skin contact. The result of fate and exposure analysis can anticipate the Predicted Daily Intake (PDI) that can affect humans exposed to toxic substances. Potency is considered as the relationship between dose and response by converting the increased amount of exposure to the incident rate of cancer and other chronic diseases caused by various chemical hazards detected according to the Integrated Risk Information System (IRIS) of the U.S. Environmental Protection Agency (US EPA) (US EPA, 2012) database and Environmental Health Criteria Monographs (EHCS) of the International Programme on Chemical Safety (IPCS) (IPCS, 2012). The last factor, severity, is the damage function that will occur to each person, which can be measured as DALYs (Disability Adjusted Life Years), in relation to the rate of incidence of cancer and chronic disease. The Damage Factor (DF) of chemical substances on Human Health $\left(DF_{HH_i}\right)$ in unit (DALY/kg) can be shown in equation (3.3).

$$DF_{HH_i} = \sum_i \left\{ \left(PDI \cdot Pop_{TH} \right) \cdot EF_i \right\} = \sum_i \left\{ \left(iF \cdot Pop_{TH} \right) \cdot \left(\beta_i \cdot D_i \right) \right\} \tag{3.3}$$

The intake Fraction (*iF*) depends on ingestion and inhalation exposure (mg/kg/day). The Effect Factor (EF) is the relationship between potency and severity (case/(mg/day)). β_i is the toxicological potency (dose – response function) (risk of incidence/(mg/day)). D_i is the toxicological severity (DALY/incidence). i is any chemical toxic substance. Pop_{TH} is the population of Thailand based on the year 2012 (Applied from Kubo and Itsubo (2006), and Jolliet *et al*. (2003)).

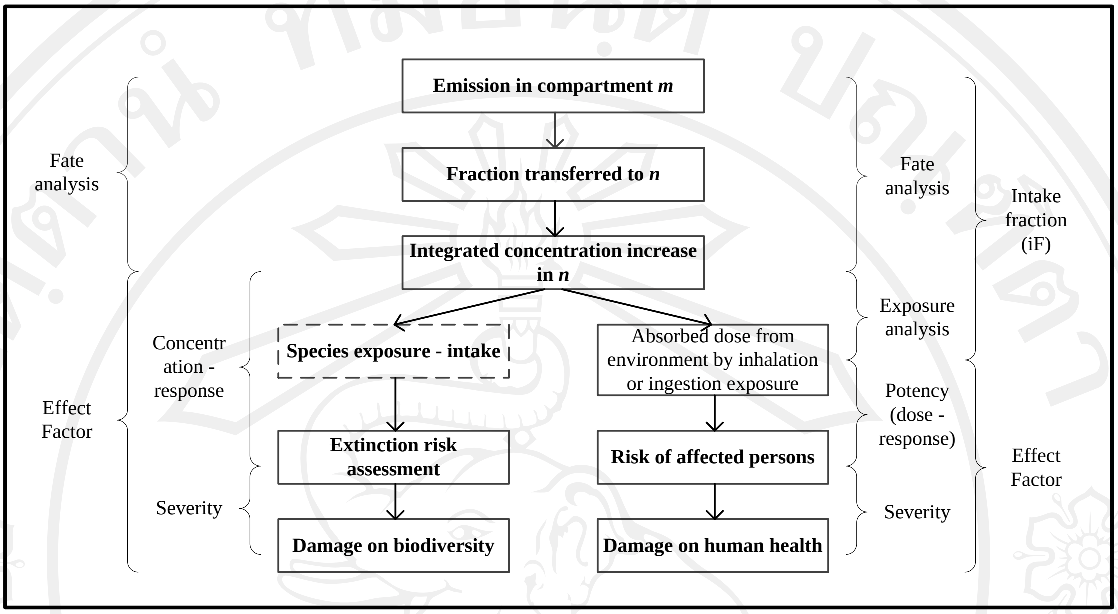

Figure 3.4: Development procedure to determine damage function on human health and biodiversity (applied from Jolliet *et al*., (2003), and Kubo and Itsubo, (2006))

3.3.1.1 Fate and exposure analysis

The model parameters change for watershed zone, coastal/ocean, and air zone models. For instance, watershed zone modeling is divided into 11 sub-zones: soil module, surface layer, agricultural root zone, vadose layer, bulk vegetation module, water module, sediment-land module, exposure module, usable production in considered zone, number of heads, and specific to emission modeling, adjusted using data from Thailand such as temperature, rainfall, Thailand areas, the pH of water, and number of eggs, pigs, and goats. Coastal/ocean zone modeling is divided into three sub-zones: oceanic water module, sediment module, and exposure module, adjusted using data such as sea fish. Air zone modeling is divided into six sub-zones: air module, surface soil layer module, exposure module, usable production in considered zone, number of heads, and specific to emission modeling, adjusted using data such as dry deposition, Thai population, unexposure and exposure production, and burnable area.

3.3.1.2 Dose-response

The unit response factor is an estimate of the probability that an individual will develop cancer when continuously exposed to an agent at a concentration of 1 μg/l in water, 1 μg/m3 in air over the average lifetime of population (LT_h) at 73 years and average weight (BW) at 63 kg in Thailand. Hence β_{ED10} can be represented as:

$$\beta_{ED10} = \frac{0.1}{ED_{10h}} \cdot \frac{1}{BW \cdot LT_h \cdot N_{365}} \qquad (3.4)$$

where

β_{ED10} is the slope factor for individual lifetime risk of cancer and chronic disease (risk of incidence/kg-day);

ED_{10h} is the dose inducing a response over a background of 10% for humans (h) (mg/kg–day);

0.1 is the response level corresponding to the ED_{10h} (individual lifetime risk of cancer);

N_{365} is the number of days per year (days/year).

3.3.1.3 Severity

Human health effects on endpoint levels of the environmental mechanism are quantified in terms of DALY including mortality – measured as YLL and morbidity effect, as developed by Murray and Lopez, (1996), and supported by data from WHO. In this study, the toxicological severity average value is around 6.7 and 0.67 DALY per incidence for most cancer and chronic effects, respectively (Crettaz *et al*., 2002a).

3.3.2 Ecotoxicity

The characterization factor for chemical toxicity effects on aquatic species loss at endpoint level uses the IMPACT 2002 model under conditions for Thailand and has adopted methodology to biodiversity loss based on the LIME method.

To model the effect of chemical substances on biodiversity, the calculation scheme used is similar to that of chemical substances on human health and it also includes fate and effect analysis. The human damage model is concerned with fate, exposure, and effect, while the biodiversity damage model focuses on the relationship between the increasing concentration of a substance and the severity, as shown in Figure 3.4. Fate analysis is related to the change in concentration in the pure aqueous phase of freshwater. Exposure is indirectly taken into account in the effect factor of the risks of characterization at species level, eventually leading to EINES of species and to a preliminary indicator of damage on biodiversity. The equation (3.5) for the damage factor on biodiversity (DF_{BD}; EINES/kg) is as follows:

$$DF_{BD_i} = \sum_G \left\{ \left(N_G \times FF_i \times EF_i \right) \right\} = \sum_G \left\{ N_G \times FF_i \times \left(\gamma_i \times D_i \right) \right\} \quad (3.5)$$

where

N_G is the number of species *G*;

FF is the fate factor, which is the relationship between substance *i* from compartment *m* to compartment *n* and the increase in concentration of this substance in surface water (mg/l);

EF is the effect factor, which is the relationship between concentration–response and extinction of species (EINES/(mg/l));

γ_i is the value of concentration–response function (mg/l);

D_i is the increasing number of extinct species (EINES).

3.3.2.1 Fate analysis

Fate analysis uses the IMPACT 2002 model and substance spread for human health damage. However, the biodiversity damage model has limited scope in this study, using the surface water compartment.

3.3.2.2 Effect factor

For the EF of chemical substances on biodiversity, the conceptual framework is similar to that of human damage, which involves finding the area under a relationship curve for toxic concentration increase in the volume of water and extinction risk assessment – expressed as EINES/(mg/l). The equation for the relationship is shown as:

$$EF_i = \frac{\Delta EINES}{\Delta C} \tag{3.6}$$

where ΔC (mg/l) is the concentration of the increasing toxin in water that affects species.

Data requirement for estimated ecotoxicity is number of extinct species of algae, Crustacea, fish, Mollusca, Annelida, and Amphibia.

3.4 Cause and effect of eutrophication

Eutrophication is the enrichment of water bodies with inorganic nutrients, typically nitrates and phosphates. Phosphate–rich detergents and washing powder in sewage are also food sources for phytoplankton. All these are responsible for the phenomenon of eutrophication. It induces algal bloom where the water becomes densely populated with phytoplankton. In addition, the inorganic nutrients, especially nitrates and phosphates, are the nutrients most commonly limiting primary productivity in aquatic ecosystems. The damage of eutrophication is the depletion of oxygen associated with the decomposition of dead biomass. With the depletion of dissolved oxygen in water, there is a loss of biodiversity because some aquatic biota cannot survive under very low or near anaerobic conditions. The cause and effect chain of eutrophication is shown in Figure 3.5.

When considering the causes and effects of eutrophication, it was found that increased nutrient loading causes eutrophication that will affect fishery production in lakes. Thus, this study focused the problem of eutrophication in Thailand on two main areas – Songkhla and Phayao lakes. The economics of fishery production also requires an estimate of eutrophication damage

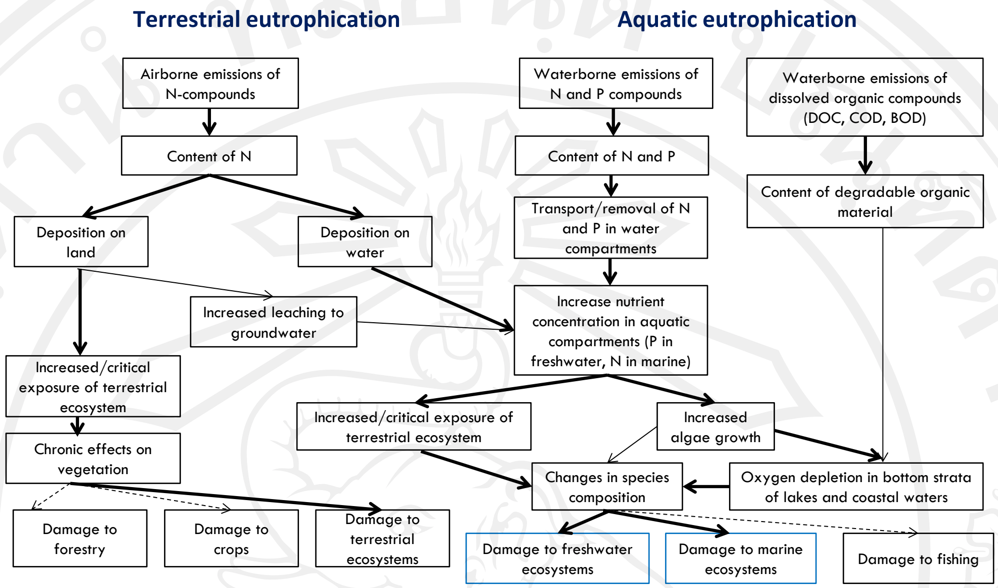

Figure 3.5: Cause and effect chain of eutrophication

(Source: European Commission, 2010)

3.5 Cause and effect of acidification

Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems, and materials (buildings). When considering the causes and effects of acidification, as shown in Figure 3.6, it was found that the increase of acid deposition in air causes acidification that will affect lakes and soil. Firstly, acid deposition and emission concentration in Thailand has been considered in the development of an acidification model. Following this, relative terms, soil pH, and aluminum (Al^{3+}) from site areas in Thailand are presented in this study.

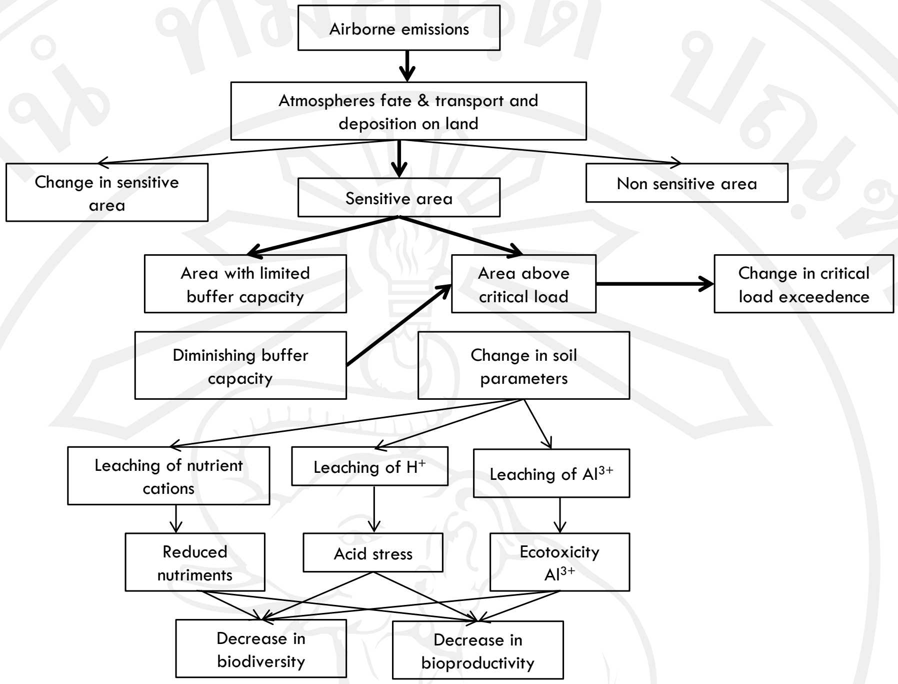

Figure 3.6: Cause and effect chain of acidification
(Source: European Commission, 2010)

3.6 Weighting factors

This research is survey research based on environmental economic principles to study the willingness to pay for environmental improvement by using the CVM technique. The procedure to evaluate weighting factors is presented in Figure 3.7.

The areas of data collection covered many location in Thailand. Sample size was 400 samples. Questionnaires were used introducing the background, objective, why we have to pay, what we pay for, and whom we pay (in Appendix F). The questionnaire consists of three sections as follows:

1st section: general knowledge about environmental problems in Thailand and opinions about damage on human health, social assets, biodiversity, and primary production due to environmental damage.

2nd section: willingness to pay for a management fund. This section described why we have to pay and where the management fund is kept.

3rd section: socio–economic information including opinions about general problems in Thailand, gender, age, education, income, and environmental information access.

Contingent valuation analysis makes estimations using the conditional probit model, based on random utility theory. Finally, an ultimate goal of this survey is to determine an amount of willingness to pay (WTP) for avoiding a unit quantity of damage of every safeguard subject.

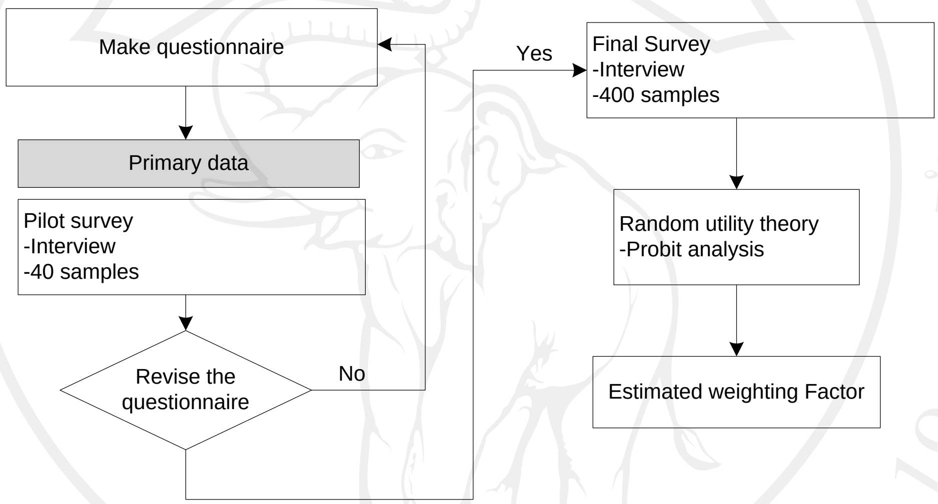

Figure 3.7: Procedure to evaluate weighting factors of safeguard subjects applying contingent valuation

3.7 Integration model

When referring to the problems and background of this study, it can be seen that the environmental problems in Thailand are becoming worse, for example the torrential rains caused heavy flooding in the Bangkok Metropolitan Region and southern Thailand in 2009. The government tried to manage these problems by employing various tools to help inform them in the decision–making process. Impact assessment models are a tool used in assessing environmental impacts, but as they use foreign methods to evaluate the environmental problems in Thailand, the results cannot reflect and solve those environment problems. For this reason, the development impact assessment model integrated with related factors for Thailand would be perfectly appropriate for modeling the impact assessment.

The impact assessment model for Thailand based on endpoint modeling has integrated data from Sections 3.2 – 3.6 with factors of midpoint, endpoint, and weighting. The impact assessment model for Thailand is shown in Figure 3.8.

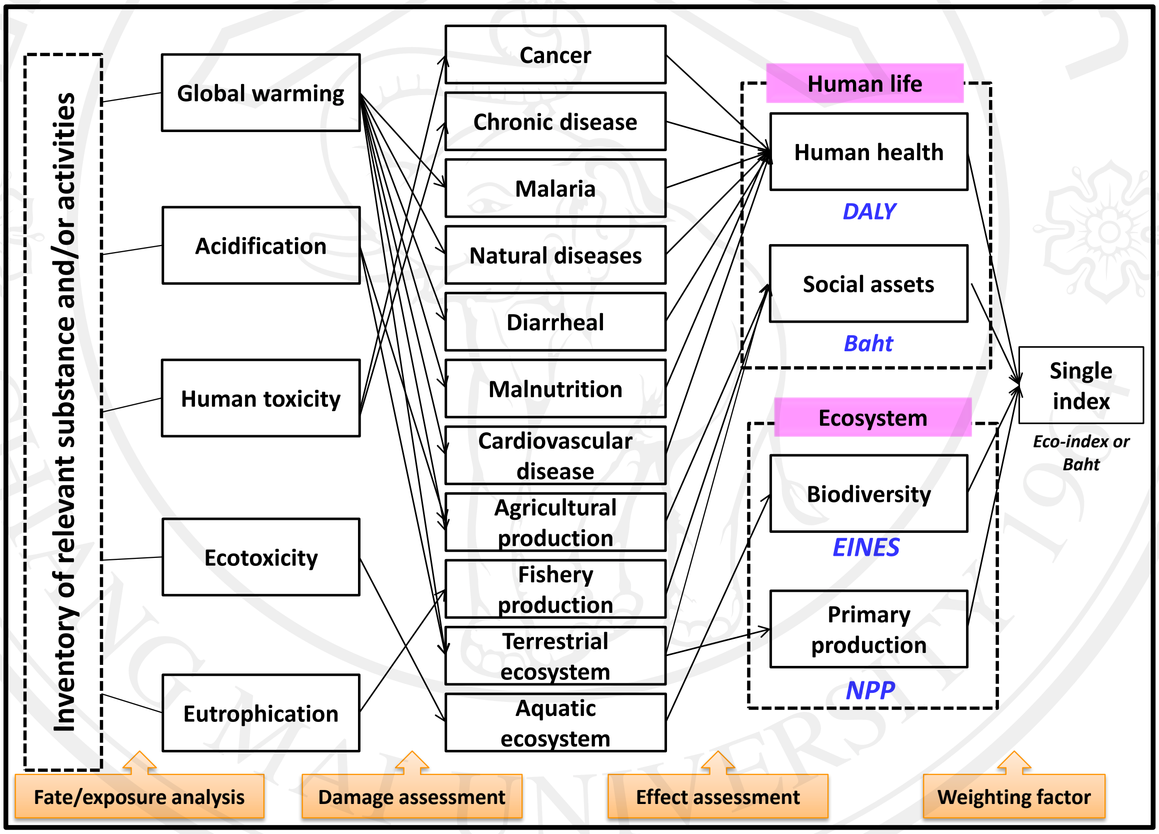

Figure 3.8: Impact assessment model for Thailand based on endpoint modeling