CHAPTER 2
THEORIES

In this dissertation, various environmental and economic assessment tools are applied to identify and evaluate the sustainability of biofuels production and use for transport in Thailand. As the research framework in **Figure 1.1**, LCA is used in *Phase I* to determine the environmental sustainability of biofuels in Thailand. LCC assessment and preliminary assessment of externalities of biofuels are used in *Phase II* to evaluate the costs performance of biofuels compared to conventional petroleum fuels. Estimations of net feedstock balances are conducted in *Phase III* to assess the availability of feedstock supply for future biofuels production in Thailand. For the assessment of socio-economic impact of biofuels, Input-Output Tables are applied in *Phase IV* of works to estimate the employment effects of biofuels production in Thailand. Theories and descriptions of those assessment tools are described as follows:

2.1 Life cycle assessment (LCA)

Life cycle assessment (LCA) is a tool for compilation and evaluation of the environmental impacts of a product or service system throughout its life cycle. Life cycle involves acquisition of raw materials through production, use and waste disposal. The Society of Environmental Toxicology and Chemistry (SETAC) was the first international body to act as an umbrella organization for the development of LCA. SETAC's aims are scientific development in specific areas of research and application of the results in the field of environmental management. Later, LCA has been standardized by the International Organization for Standardization (ISO) as the ISO14040 series [57]. Four main phases of LCA as defined by the ISO are as follows: (1) definition of the goal and scope of the study (2) identification and quantification of environmental loads involved; e.g. the energy and raw materials consumed, the air emissions, water effluents, and wastes generated (inventory analysis); (3) evaluation of the potential environmental impacts of these loads (impact assessment); and (4) assessment of available options for reducing these environmental impacts (interpretation).

2.1.1 Goal & scope definition

The goal and scope definition is the phase that working plan of the entire LCA are made. The goal of the study is formulated in terms of the exact question, target audience and intended application. The scope of the study is defined in terms of system boundaries, temporal, geographical and technological coverage, and the level of sophistication of the study in relation to its goal. Finally, the products that are the object of the analysis are described in terms of function, functional unit and reference flows [58]. The functional unit is the important basis that enables alternative goods, or services, to be compared and analysed. It is not usually just a quantity of material. Practitioners may compare, for example, alternative types of packaging on the basis of 1 m^3 of packed and delivered product—the service that the product provides. The amount of packaging material required, termed the reference flow, can vary depending on the packaging option selected (paper, plastic, metal, etc.) [59]. The obtained results of this phase consist of a clear specification of the goal of the study, the functional unit, and the reference flows for the various alternative product systems. In addition, the scope of the study will guide further choices in subsequent phases. These results form the input for the next phase of the LCA, the Inventory analysis.

2.1.2 Life cycle inventory analysis

The Life cycle inventory (LCI) analysis is the phase in which the product system (or product systems if there is more than one alternative) is defined and the consumption of resources and quantities of emissions caused by processes within a product's life cycle are estimated. In this phase, defining includes setting the system boundaries (between economy and environment, with other product systems, and in relation to cut-off), designing the flow diagrams with unit processes, collecting the data for each of these processes, performing allocation steps for multifunctional processes and completing the final calculations. Its main result is in an inventory table listing the quantified inputs from and outputs to the environment associated with the functional unit, in terms of kg of carbon dioxide, kg of iron ore, or m^3 of natural gas, etc [59]. To perform life cycle inventory, a large amount of data needs assessing. Attention should be given to the following issues: normative choices made prior to modeling the product system; the choice of data sources and data quality requirements (possibly validation) to be enforced; the LCI calculation method, the type of presentation of the LCI results; possible conclusions based on the LCI results; further process planning and process management. The main result of this phase is the inventory table. It will be input of the next phase namely the Life cycle impact assessment. Furthermore, various additional information e.g. aspects that could not be quantified, information related to data quality, and fact finding during collection of primary data at site will be obtained from this phase. These other forms of information are especially useful in the interpretation phase. The inventory of each individual terminal exchange can be expressed as following equation:

$$Q_i = T \times \sum Q_{i,up} + \frac{T}{L} \times \sum Q_{i,p}$$

where Q_i is the sum of terminal exchanges i computed per functional unit; T is the duration of functional unit (years); L is the life span of the product (years); $Q_{i,p}$ is the terminal exchange from process i computed per the number of key units of the process entering into the product system; (p) designates all process; and $Q_{i,up}$ is the terminal exchange per annum from the use process (up) including the process specified by all of the use process's non-terminal exchanges;

2.1.3 Life cycle impact assessment

Life cycle impact assessment (LCIA) is the phase in which the set of results of the inventory analysis is further processed and interpreted in terms of environmental impacts and societal preferences. To this end, a list of impact categories is defined, and models for relating the environmental interventions to suitable category indicators for these impact categories are selected. The actual modeling results are calculated in the characterization step, and an optional normalization serves to indicate the share of the modeled results in a worldwide or regional total. Finally, the category indicator results can be grouped and weighted to include societal preferences of the various impact categories. Various impact assessment methods have been developed in the past; however, they can be categorized into two general groups: "problem-oriented method" such as CML and EDIP method and "damage-oriented method" such as Eco-Indicator 99, EPS and LIME method. In the problem-oriented methods, the environmental burdens are aggregated according to their relative contribution to the environmental effects that they might cause. The impacts most commonly considered in the problem-oriented approach include resource depletion, global warming, ozone depletion, acidification, eutrophication, photochemical oxidant formation, human toxicity and eco toxicity. On the other hand, the damage-oriented methods model the 'endpoint' damage caused by environmental interventions to 'areas of protection', which include human health, natural and human-made environment. An example of linkage between the problems (midpoint categories) and damage (endpoint categories) is shown in **Figure 2.1**. The main results of this phase, which is the input of the next phase, Interpretation, include the environmental profiles, the normalized environmental profile and the weighting profile.

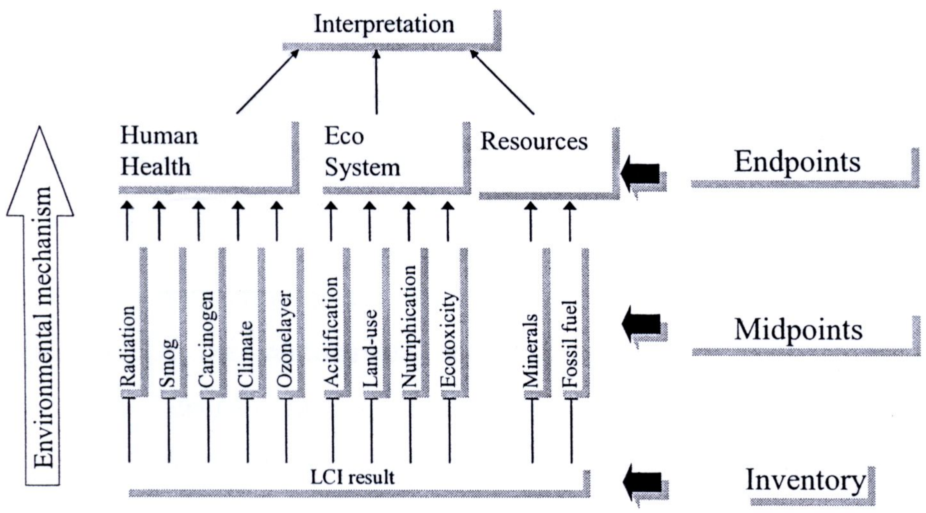

Figure 2.1 The link between environmental interventions, problems (midpoint categories) and damage (endpoint categories) to the environment and human health [60]

The steps of impact assessment phase described as follows.

(1) Classification: This stage classifies the various environmental exchanges according to the impact categories to which they contribute.

(2) Characterization: This stage calculates environmental impact potential for emission. The impact potentials for the product are the sums of the impact potentials for the emission occurring throughout the product system.

$$\sum EP(j)_i = \sum Q_i \times EF(j)$$

where $EP(j)_i$ is the emission potential contribution to the environmental impacts (j); Q_i is the magnitude of emission of substances; $EF(j)$ is the substance's equivalency factor for the environmental impact categoriy (j).

(3) Normalization: This stage describes how the relative sizes of the resource consumption and the impact potentials are assessed via comparison with a background impact.

(4) Weighting: Normalization puts all potential impacts in the same unit; however, it cannot be straightforward to infer that two impacts have the same seriousness. Therefore,

the weighing factor for an environmental impact that reflect the serious of the effects will be expressed in order to be fairly compared. The weighting can be calculated as following equation:

$$WEP(j) = WF(j) \times NEP(j)$$

where $WEP(j)$ is the weighted impact potential; $WF(j)$ is the weighting factor; and $NEP(j)$ is the normalized impact potential.

2.1.4 Interpretation

Interpretation is the final phase of an LCA which the obtained results from LCI analysis and/or LCIA are summarized and discussed as a basis for conclusions, recommendations and decision making in accordance with the goal and scope definition. Life cycle interpretation occurs at every stage in an LCA. If two product alternatives are compared and one alternative shows higher consumption of each material and of each resource, an interpretation purely based on the LCI can be conclusive. A practitioner, however, may also want to compare across impact categories, particularly when there are trade-offs between product alternatives, or if it is desirable to prioritize areas of concern within a single life cycle study. For example, emissions of CO_2 in one life cycle may result in a higher climate change indicator than in another, but the alternative involves more pesticides and has a higher potential contribution to toxicological impacts. A stakeholder may therefore want more information to decide which difference is a higher priority. The concrete of interpretation results involve the systematic procedure to identify, qualify, check, and evaluate information from the results of the LCI and/or LCIA of a product system. The key steps for performing interpretation are consistency check, completeness check and sensitivity and uncertainty analysis.

2.2 Life cycle cost (LCC) and Externalities

2.2.1 Life cycle cost assessment

Life cycle cost assessment is a systematic process for determining all costs arising over an entire product's life cycle from raw material acquisition, installation, operation, maintenance, to final disposal [61-63]. At beginning stage, Life cycle costing was originally not developed in an environmental context. The traditional LCC is just a type of investment calculation which used to rank different investment alternatives [64]. However, due to the strength of life cycle perspective which its value chains analysis have provided an insight to the various stages in product life-cycles, therefore, several groups such as Logistics Engineers (SOLE) have developed life-cycle costing with the idea of taking all internal and external monetary costs of a product into account [65].

Life cycle cost assessment has been recognized as a tool that can be applied in parallel with the life cycle assessment (LCA) by identifying environmental consequences and assigning measures of monetary value to those consequences in order to assess the environmental and economic performance of the projects e.g. municipal waste management systems [66] or the products which also including biofuels such as cassava ethanol [61] and sugarcane ethanol [63]. Nevertheless, life cycle costing has not received much attention by the corporate sector to date due to several reasons. First, in a competitive market the price mechanism should already include the internalized environmental costs of suppliers if the products are priced correctly. Second, the concept of life cycle costing suffers from some problems in practice such as data collection from economic actor outside the company usually result in low quality of data, data inconsistency and high costs of data collection [65]. The following equation is the general LCC formula which all costs arising have to be identified by year and by amount [67]:

$$LCC = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t}$$

where LCC is the total life cycle cost in present-value dollars of a given alternative; C_t is the sum of all relevant costs, including initial and future costs, less any positive cash flows, occurring in year t; N is the number of years in the study period; and d is the discount rate used to adjust cash flows to present-value [67].

2.2.2 Externalities and Economic valuation methods

2.2.2.1 Externalities of Energy

Externalities of energy are the costs imposed on the environment and society that are not accounted for by the producers and consumers of energy, i.e. those are not included in the market price. Externalities include damage to human, the natural and built environment, such as effects of air pollution on health, buildings, crops, forests and global warming; occupational disease and accidents; and reduced amenity from visual intrusion of plant or emissions of noise. Traditional economic assessment of energy has tended to ignore these effects [68]. However, there is a growing interest in adopting a more sophisticated approach involving the quantification of these environmental and health impacts of energy use and their related external costs in order to support making decision of policy makers. The energy sector is a major source of environmental and non-environmental externalities (**Table 2.1**) which these areas of external effects can be either positive (external benefits) or negative (external costs). In general, consideration of the externalities in policy decision's making is to reduce its negative impacts and move towards a more sustainable energy supply and use. However, a reliable externalities assessment of energy could be applied to the other issues as following, i.e. internalization of the external costs of energy, optimization of site selection processes, cost benefit analysis of abatement measures and comparative assessment of energy systems [69].

Table 2.1 Examples of impact categories leading to potential externalities [70]

Environmental	Non-environmental
Human health	Resource use
Ecotoxicity	Employment
Acidification	Security and reliability of supply
Eutrophication	Effects on Gross Domestic Product
Soil quality	Rural development
Climate change	
Amenity (e.g. noise, odors and visual impacts)	
Biodiversity	

2.2.2.2 Economic Valuation Methods

Environmental costs can be estimated either by damage costs or control costs. Damage costs are the costs of damage inflicted on society by pollutants, but control costs are the costs of controlling or mitigating pollution damages. Damage costs, however, are the most relevant costs to be used in the assessment of external costs. When damage related to an energy or renewable energy technology have been identified and quantified by damage function approach. Economic valuation methods need to be applied in order to monetise these damages. Non-market valuation methods can be broadly classified by the source of the data analysed into two categories (based on the source of data analysed) i.e. revealed preference (RP) models, and stated preference (SP) models. Revealed preference approaches make use of data from observations of individual's behavior in actual or simulated markets to infer the value of an environmental good or service. For examples, the value of recreation site may be inferred by expenditures that recreationists incur to travel to the area. The value of noise pollution may be inferred by analysing the value of residential property near an airport. The difference in wage between the wages of workers exposed to an occupational risk and wages of workers no having that risk can be used to estimate the value of the occupational risk by assuming that all other factors are equal. These methods are also referred to as indirect or surrogate market approaches. Examples of RP methods are Travel Cost Method (TCM), Hedonic Pricing Method (HPM), Cost (or Expenditure) Methods, and Benefit Transfer Methods [36].

While, stated preference approaches are based on data from individuals' response to hypothetical questions which aim to elicit individuals' preferences with regards to environmental goods or services. Examples of SP methods are Contingent Valuation Method (CVM), Conjoint Analysis, and Choice modeling. The contingent valuation method, a direct method of state preferences technique, in which individuals are asked the willingness to pay (WTP) for improving environmental quality or the willingness to accept compensation (WTA) for environmental damage, created thus a fictitious market for the goods and services considered. Contingent valuation is useful to estimation of non-market goods and services. For instance WTP may be used to estimate the price of noise from a wind turbine. Conjoint Analysis is a popular technique in marketing research and it has only recently been adapted for valuing environmental goods and services. A major difference between CVM and conjoint analysis is that in the former respondents are required to evaluate only one or two alternatives. On the other hand, the latter requires them to evaluate several alternatives separately [36].

Apart from RP and SP models, non-market items can also be valued indirectly by accounting methods. Accounting methods are used to estimate costs such as medical expenditures, maintenance costs, crops and timber losses with and without the environmental effects. Market prices can often be used indirectly for pricing the environmental effects. For example if the effect of a pollutant is reduced yields of a commercial crop, the external cost may be estimated by multiplying the observed market prices of the crop by the reduction in yield caused by the pollutant [71].

2.3 Input-Output (IO) analysis

Input-output (IO) analysis is a tool to study the interrelationships within and between economic sectors of a country and it can be used to determine the impacts of an economic activity on the whole economy [72-73]. This IO analysis is generally performed based on a country's IO table which is available from national statistical bureaus.

However, the regional IO tables are also available to calculate regional and inter-regional impacts [74-76]. The advantage of IO analysis is that direct, indirect and induced impacts an economic activity on the whole economy can be calculated. The detailed description of IO analysis, its basis and origin can be seen in Leontief (1963), Miller and Blair (1985) and Suh (2009) [77-79].

2.3.1 Input-Output tables [80]

Input-Output (IO) tables are developed for monetary quantifying the relationship between production and consumption as well as the interrelation among industries in a whole economy [80]. It divides an economy for specific area (e.g. nation, region) into a number of sectors (e.g. agriculture, steel making, household-consumption), and describes all the flow of goods and services between sectors with in a specific period of time (usually for a single year). IO tables can provide a framework to assess the direct and indirect (induced) on a whole economic system through intermediate transactions. A schematic representation of IO tables is presented in **Table 2.2**. The top of the table matrix indicates sectors of the demand side, which consists of *Intermediate Demand sectors* and *Final Demand sectors*. Shaded area in Intermediate Demand sectors describes the inter-industrial transactions of goods and services between intermediate demand (production) sectors of an economy. These sectors trade raw materials (e.g. irons, steels etc.), fuel, intermediate goods and the related services. Final demand sectors show the purchases of final products. For example, manufactured goods, not destined for further processing, such as cars and television sets are sold to final demand sectors, while raw materials are not sold directly to consumers etc. Major final consumers are households, investors, governments and foreign countries [80].

The left side of the table indicates sectors in the supply side, which consists of *Intermediate input sector* and *the Gross Value Added sector*. Examples of Gross Value Added sectors are employee's salaries (the purchase of labour services from the household sector) and the depreciation and earnings of industries and the tax and fees paid to public authorities. The figures (e.g. x_{11}, x_{12}, F_{1C}) in a row of the table horizontally show how much output from one supply sector is distributed to demand sectors. The figures in a vertical column show how much output from supply sectors is obtained by one demand sector. The flow between sectors such as x_{ij} usually is denoted by monetary value (Baht, Yen, and Dollar etc.).

Table 2.2 Example of the structure of an IO table [80].

	Intermediate demand (Purchasing Sector)			Final Demand			Imports (substraction)	Total Output
	Sector 1	Sector 2	Sector 3	Consumption	Investment	Exports		
Sector 1	x_{11}	x_{12}	x_{13}	F_{1C}	F_{1I}	F_{1E}	M_1	I_1
Sector 2	x_{21}	x_{22}	x_{23}	F_{2C}	F_{2I}	F_{2E}	M_2	I_2
Sector 3	x_{31}	x_{32}	x_{33}	F_{3C}	F_{3I}	F_{3E}	M_3	I_3
Value added	V_1	V_2	V_3					
Total Input	X_1	X_2	X_3					

2.3.2 Input-Output model and Final Demand Approach [72, 80]

The key concept of IO analysis is a fundamental relationship between supply and demand i.e. the balance of inputs and outputs of goods and services in a whole economy. The relationship reflects the technological structure of an economy, and formulated as a system of linear equations using *input (technical) coefficients matrix*. There are two approaches for assessing the impacts on the economy by the IO model when a new industry is introduced to the economy. The first method is based on creating a new final demand vector, while the second method is based on including the new industry in the technology matrix. The study focuses on the first method i.e. final demand approach which is popular due to its simplicity even though it is developed based on the ideas that the introduction of a new industry to the economy only affects the final demand. The second method has the advantage that it accounts for the impacts of the introduction of a new sector in a more complete manner i.e. it does not only accounts for the inputs being bought by the new sector from the existing sectors, but can also account for its outputs being consumed by the existing sectors. However, to introduce a new sector to the technology matrix making requires a lot of reliable information to represent the new sector's income and expenditure structure, both a new row and a new column need to be created.

The Input-Output (IO) model is developed based on three fundamental assumptions [81]:

(1) Each sector produces only one output with one input structure and substitution does not exist between the outputs from several sectors (homogeneity assumption);

(2) The inputs into each sector, including the intermediate deliveries, are proportional only to the level of output of that sector;

(3) The total effect of carrying out production in several sectors is the sum of the separate effects.

According to assumption (3), then, the total output can be determined by adding all intermediate and final deliveries, the left-hand side of equation (2.1) below. The total output should also equal the sum of all inputs (right-hand side of equation (2.1)). Thus,

$$X_j = \sum_{i=1}^{n} x_{ij} + F_i \qquad (2.1)$$

From assumption (2) it follows that

$$a_{ij} = \frac{x_{ij}}{X_j} \qquad (2.2)$$

where x_{ij} is the value of the input from sector i used in making a dollar's worth of output in sector j. a_{ij} is termed "input coefficient" or "technical coefficient of production".

The normalized matrix A, also called "input coefficient matrix" or "technology matrix", is defined by the elements a_{ij}, and the left-hand side of equation (2.1) can be rewritten in matrix format as

$$X = AX + F \qquad (2.3)$$

or

$$(I - A) \times X = F \qquad (2.4)$$

The general solution for the unknown vector X can be deduced by inverting the matrix $(I - A)$;

$$X = (I - A)^{-1} \times F \qquad (2.5)$$

where I denotes an identity matrix. $(I - A)^{-1}$ is known as "Inverse matrix or Leontief inverse matrix". If it is now assumed that the technology matrix is representative also for the marginal variation in the total output (ΔX) as a result of a marginal variation in the final demand (ΔF), then

$$\Delta X = (I - A)^{-1} \times \Delta F \qquad (2.6)$$

Equation (2.6) represents the basic I-O model which it is possible to assess the economic impacts of an external shock to the economy, such as an additional investment to one of the intermediate sectors, decreased consumer spending on a sector's product caused by a change in taxation of the product, or the introduction of a new industry to the economy. For the final demand approach which is assumed that the inputs needed for the production in the new industry are requested from the existing sectors of the economy. Since the new industry's production is not yet accounted for in the IO table, its demand for inputs from the intermediate sectors is considered exogenous and is accounted for by an additional final demand vector. This vector is determined by splitting the costs of production of the new industry so that each cost item can be assigned to one of the sectors defined for the IO table. Then, equation (2.6) is applied to assess the impacts on the total output of each of these sectors. Whereas, ΔF is the additional final demand for the new industry's production; and ΔX is the changes in total output of the existing sectors as a result of the new industry's production