CHAPTER III
METHODOLOGY

3.1 Materials and Equipment

3.1.1 Equipment

- Desktop computer (Pentium IV, RAM 1 GB, Window XP and Microsoft Office 2003)

3.1.2 Software

- SimaPro version 7.3

3.2 Methodology

3.2.1 Preparation

a.) Study and review background of warm-mixed asphalt production including raw materials, process, technology and conduct literature survey on LCA studies on the environmental impacts.

b.) Contact manufacturers/companies to explain about the importance and scope of this work and ask for their corporations.

c.) Develop the process and flow diagrams.

d.) Design data templates and distribute to the company for collecting data as shown in Table 3.1.

Table 3.1 Template of data collection for production of mixed asphalt

Production of Asphalt							
Input Inventory				**Output Inventory**			
Description	**Unit**	**Amount**	**Remark**	**Description**	**Unit**	**Amount**	**Remark**
Resources				***Products***			
Asphalt	kg			Asphalt binder	kg		
Additive	kg						
...				....			
Utilities				***Emissions***			
Electricity	kWh			CO_2	kg		
...							

3.2.2 Goal, Scope, Functional Unit, and System Boundary

a.) Formulate and specify goal of the LCA study.

The goal of this LCA study is to assess the environmental impacts of warm mix asphalt. The inventory data collection will be compiled by using SimaPro 7.3 software and the environmental impacts of warm mix asphalt will be evaluated using Eco-Indicator 95 and CML 2 baseline 2000.

b.) Identify Functional Unit (FU) of the study.

In this research, the functional unit is set to be 1 km pavement (7 m. width and 5 cm. thick) and 1 ton of asphalt production is used functional units for both HMA and WMA

c.) Determine scope and system boundaries of that warm mix asphalt production and make assumptions based on the goal definition.

The scope of this research covers data collection of asphalt production, evaluation of the environmental impacts of the hot-mixed asphalt and warm-mixed asphalt product, and comparison of hot-mixed asphalt and warm-mixed asphalt product. The system boundary includes provision of asphalt, WMA processing, apply

paving, maintenance, demolition or recycling and transportation at all stages as shown in Figure 3.1.

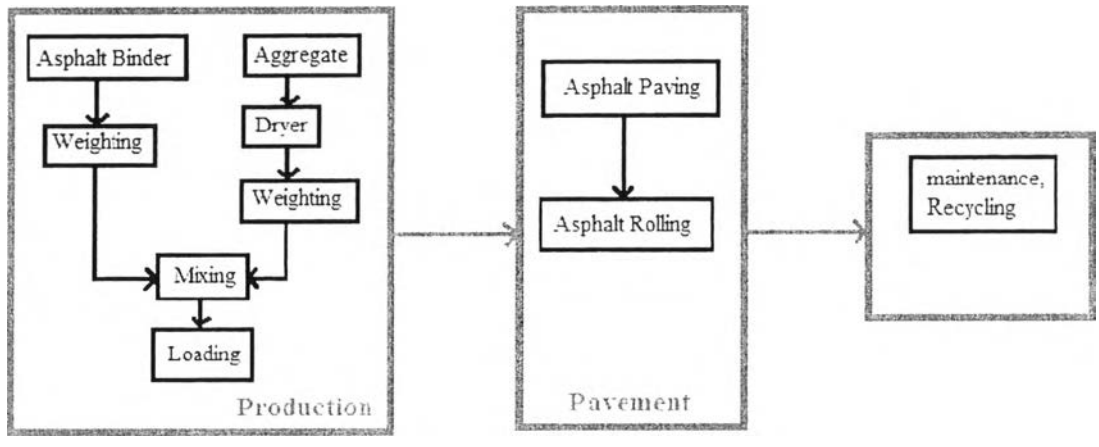

Figure 3.1 System boundary of the LCA warm mix asphalt study.

3.2.3 Inventory Analysis

a.) Collect both numerical and qualitative data for all activities based on the system boundary concerning about all energy inputs, raw materials, chemicals, utilities, and emissions in each process as shown in Table 3.2.

b.) Quantify the flow of material and energy as well as environmental load attributable to each stage of product's life cycle based on the functional unit.

- The result of the inventory analysis is the inventory table which is a list of all inputs and outputs per functional unit.

Table 3.2 Source of data

Phase	Process	Type of Data	Data Source
Raw Materials	-	Secondary Data	Eco-indicator 95 and CML 2 baseline 2000
Transportation	Transporting by truck	Primary Data	Thaiwat Engineering Co., Ltd (Bangbuatong and Sriracha)
Asphalt Concrete Production	Hot-Mixed Asphalt Production	Primary Data	Thaiwat Engineering Co., Ltd (Bangbuatong)
	Warm-Mixed Asphalt Production	Hybrid*	Thaiwat Engineering Co., Ltd (Sriracha)
Pavement	Hot-Mixed Asphalt Paving	Hybrid*	Thaiwat Engineering Co., Ltd (Bangbuatong)
	Warm-Mixed Asphalt Paving	Hybrid*	Thaiwat Engineering Co., Ltd (Sriracha)
End of life (Optional)	Maintenance and Recycling	Secondary Data	Literature

*Combination of primary and secondary data.

3.2.4 Impact Assessment

a.) Calculate impact potentials based on the LCI results by using software named—SimaPro version 7.3—with almost Eco-indicator 95 and CML 2 baseline 2000 methods as shown in Table 3.3.

b.) Analyze and compare the impacts on human health and the environment burdens associated with raw material and energy inputs and environmental releases quantified by the inventory, for example:

- Global warming
- Energy use
- Acidification
- Eutrophication
- Ozone layer depletion

Table 3.3 Sources of data for calculation

Phase	Source of Data Collection	Database for Environmental Profile
Raw Material		
Bitumen	Secondary Data	Ecoinvent Process
Aggregate	Secondary Data	Ecoinvent Process
Transportation		
Transporting	Primary Data	Thai LCI Database
Asphalt Concrete Production		
Hot-Mixed Asphalt Production		
Fuel	Primary Data	Ecoinvent Process
Electricity	Primary Data	Thai LCI Database
water	Primary Data	Ecoinvent Process
Grease	Primary Data	Ecoinvent Process
Waste	Primary Data	Ecoinvent Process
Water Emission	Primary Data	Ecoinvent Process
Air Emission	Primary Data	Ecoinvent Process
Bitufresh	Primary Data	Ecoinvent Process
Warm-Mixed Asphalt Production		
Sasobit	Secondary Data	Ecoinvent Process
Fuel	Secondary Data	Ecoinvent Process
Electricity	Secondary Data	Thai LCI Database
water	Primary Data	Ecoinvent Process
Grease	Primary Data	Ecoinvent Process
Waste	Primary Data	Ecoinvent Process
Water Emission	Primary Data	Ecoinvent Process
Air Emission	Primary Data	Ecoinvent Process
Pavement		
Hot-Mixed Asphalt Paving		
Paving		
Time/Distance	Primary Data	Ecoinvent Process
Specification and fuel consumption of paver	Secondary Data	Ecoinvent Process
Breakdown rolling		
Time/Distance	Primary Data	Ecoinvent Process
Specification and fuel consumption of breakdown	Secondary Data	Ecoinvent Process
Finish rolling		
Time/Distance	Primary Data	Ecoinvent Process
Specification and fuel consumption of Static pneumatic tried	Secondary Data	Ecoinvent Process
Warm-Mixed Asphalt Paving		
Paving		
Time/Distance	Primary Data	Ecoinvent Process
Specification and fuel consumption of paver	Secondary Data	Ecoinvent Process
Breakdown rolling		
Time/Distance	Primary Data	Ecoinvent Process
Specification and fuel consumption of breakdown	Secondary Data	Ecoinvent Process
Finish rolling		
Time/Distance	Primary Data	Ecoinvent Process
Specification and fuel consumption of Static pneumatic tried	Secondary Data	Ecoinvent Process
End of life (Optional)		
Maintenance and Recycling	Secondary Data	Literature

3.2.5 Interpretation

This step involves the combination and interpretation of the results of the inventory and impact assessment to provide conclusions and recommendations consistent with the goal and scope of the study.

3.2.6 Assumptions and limitations

3.2.6.1 Assumptions and limitations of raw-material and production

- The asphalt production process is followed by Standard Drawings for Highway Construction.
- Amount of aggregates used and air emission generated in hot-mixed production and warm-mixed production are assumed to be the same.
- Amount of asphalt binder in hot-mixed production equals amount of asphalt binder including Sasobit additive in warm-mixed production.
- Based on primary data received from Thaiwat (Bangbuatong), it is assumed that the electricity consumption in habitation within the plant is the same every month.
- Hot oil consumption in the production process is constant and the same for both HMA and WMA.
- Ambient temperature is estimated from average temperature of Thailand which is 27°C.
- Equipments for production processes are not included in this study.
- As limited by data provider, the data for asphalt production, raw materials used and electricity consumption are based on 3 months (June, July and August). The embedded energy or feedstock energy of bitumen in asphalt is not included this study as it could be considered as it is borrowed from the nature and returned without being used at end of life (Oers *et al.*, 2002). The value of this embedded energy is treated as heavy fuel oil (HFO). In addition, it is assumed that pavement step for both HMA and WMA is the same in terms of process, energy and utility usage. For WMA, due to the unavailability of completed primary data at the

asphalt plant, calculations based on Kristjansdottir et al. (2007), Olard, Héritier and Beduneau (2008) and Lecomte *et al.* (2007) were used in this study for the reduction in energy consumption and emissions, respectively.

3.2.6.2 Assumptions and limitations of pavement

- The asphalt pavement process is followed by Standard Drawings for Highway Construction
- Thickness and area of hot-mixed pavement and warm-mixed pavement are the same.
- Specifications of machines/equipments for paver, breakdown and static pneumatic rolling used in hot-mixed pavement and warm-mixed pavement are the same.
- Equipments for production and pavement processes are not included in this study.

3.2.6.3 Assumptions and limitations of end of life

- Useful life for hot-mixed pavement and warm-mixed pavement are assumed to be the same.