Analysis of Production Process Improvement with Life Cycle Assessment Technology~ Example of HDPE Pipe Manufacturing

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Abstract

Life Cycle Assessment (LCA) aims to analyze possible impact upon manufacturing process and availability of products, and also study the environmental considerations and potential influence during entire life cycle ranging from procurement, production and utilization to treatment (namely, from cradle to tomb). Based on high-density polyethylene (HDPE) pipe manufacturing of company A, this case study would involve evaluation of environmental influence during the production process. When the manufacturing process has been improved during "production process" and "forming cooling" stage, it is found that capital input on "electric power" and "water supply" could be reduced, thus helping to sharpen the competitive power of company A, and also ensure sustainable economic and industrial development in accordance with national policies on environmental protection.

Key Words: Life Cycle Assessment, HDPE Pipe, Eco-Indicator 95

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1. Introduction

In the forthcoming digital communication era in the 21th century, Life Cycle Assessment (LCA) will play a key role in boosting the development of public utilities (e.g. electric power, telecom, gas supply, water supply and wired TV, etc). This is because LCA enables you to make well aware of various stages of an entire life cycle (from procurement of raw materials, manufacturing and assembly to utilization, recycling and waste treatment, as shown in Figure 1 (Ishii *et al.*, 1994)).

A variety of underground pipelines represents the development level of a country. Thus, the purpose of this research is to: (1) evaluate the environmental impact of piping material of Taiwan's underground pipelines~ high-density polyethylene (HDPE) pipe, through development and application of "Life Cycle Assessment" technology; (2) develop recommendations on improvement of manufacturing process with environmental impact; (3) select environmental-friendly construction methods and piping materials through "green product design," providing a reference to the decision-makers. Based on the piping materials of Taiwan's underground pipelines~ HDPE pipe, this case study is intended to evaluate the environmental impact of manufacturing process and provide a reference for further improvement.

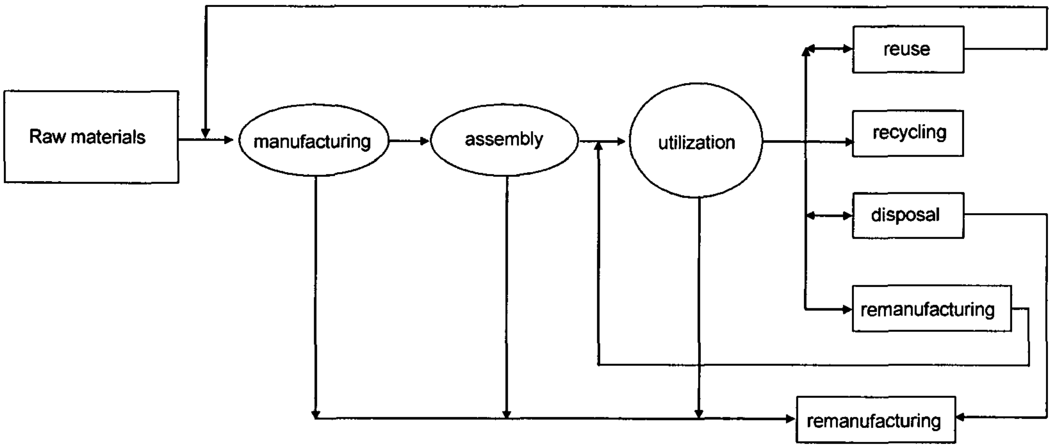


Figure 1. Life cycle of products

2. Literature Review

2.1 Overview of Underground Pipelines in Leading Countries

The archaeological research shows that interleaved drainage pipelines existed in Taiwan in Qin Dynasty (Culture of Qing, 2000). The underground pipelines, previously originated from

Babylon in the 19th century and then in Rome, were applied only to local drainage facilities. In the early stage, some contingency accidents often occurred since the water supply and telecom pipes were collectively placed in the sewage line without sufficient safety monitoring devices (Yu, 1999). The modern underground pipelines were originated from London (Hsu, 1998); and underground pipelines were also constructed in Germany in 1842 after the outbreak of cholera in Paris in 1832. It can thus be seen that underground pipelines are widely applied in the municipalities.

2.2 History of Underground Pipelines in Taiwan

Open drainage system was built only in some areas in Taiwan prior to World War II. Taipei underground drainage system was designed in 1970, and regional underground drainage system for entire Taipei area designed in 1971. In February 1991, "Common Duct Department" was established by New Construction Office and Public Works Department of Taipei City Government. Up to now, a wired and wireless communication network is set up across Taiwan to ensure its smooth communication.

2.2.1 Overview of Underground Pipeline Excavation Methods

The underground pipelines are available with the following two construction methods according to the construction modes and different purposes:

Table 1. Common pipe jacking methods

Impact pipe jacking	The pipes are hammered into earth and pushed forward slowly. It is suitable for viscous or muddy earth, with exception of colluvial sand soil with water inflow.
Hydraulic type pipe jacking	As a most commonly used method, a retaining wall is arranged on the rear wall of drill hole for pipe jacking, and the pipes are pushed slowly into earth by hydraulic-type jack.
Auger pipe jacking	The spiral drill is rotated to excavate the soil, and extrude the broken soil to form a pipe hole using the rotary extrusion of spiral vane. It is suitable for viscous or muddy earth and fine-grained gravel soil, with exception of colluvial sand soil. Amongst all pipe jacking methods, its drilling straightness is the poorest.
Cleaning pipe jacking	It is divided into two methods: (1) Casing: a drill head mounted at front end of pipe body is rotated continuously to excavate the soil and remove it through washing water. It is very suitable for hard rock soil preventing collapse of fragile sand soil; (2) Core Pipe: a core pipe or Fish Tail Bit is mounted at front end of drill rod of core pipe, such that the drill rod is rotated to excavate soil and remove with washing water. It is suitable for drilling compact and hard soil, rather than soft soil leading to possible collapse.
Combined pipe jacking	It is used together with Casing and Auger pipe jacking methods. This method is suitable for a wide range of soil, especially for soft soil. It also has a higher drilling straightness than other methods.
Hume Concrete Pipe Jacking	This method is applied to concrete pipe with inner size of 60cm ~ 2m. A cutting blade sleeved into front flange of pipe makes it easy to insert into soil and push the pipe body with jack. Then, the excavated soil is removed by tow trucks or belt provers, enabling you to link continuously concrete pipes to build an underground pipeline.

1. Excavating construction: divided into three types: (1) Concrete enclosure (RC); (2) Sand filling; (3) Drawing pipeline.
2. Non-excavating construction: divided into two types: (1) Pipe jacking, listed in Table 1; (2) Horizontal Directional Drilling, which is now well-recognized and implemented efficiently.

2.2.2 LCA for Underground Pipeline

The life cycle of underground pipeline is depicted in Figure 2 (Liao, 1999).

1. Preliminary stage; 2. Approval stage; 3. Construction stage; 4. Operation/maintenance stage; 5. Post-treatment stage

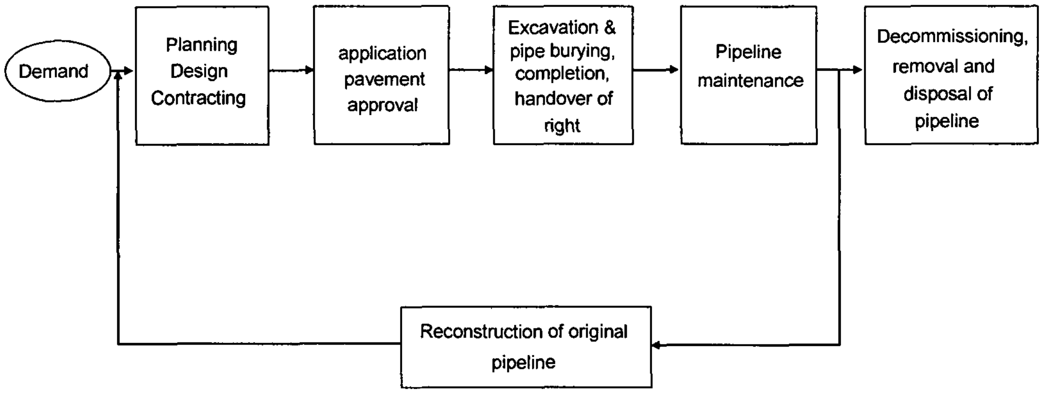


Figure 2. Life cycle of underground pipe

The road regulatory agencies are categorized into highway and urban road administrations as listed in Table 2 (Liao, 1999).

Table 2. Road regulatory agencies

Highway system	Highway Department is responsible for engineering departments at various levels and engineering sections within its jurisdiction. In general, the engineering section is authorized to decide the emergency or recovery works or those with excavation area less than $50\,m^2$.
Urban road	The complex urban road includes at least 3 types: (1) Municipal level (Taipei, Kaohsiung): the Highway Departments is charge of applications for excavation due to sufficient staff and expertise; (2) County level: the township governments are designated to take the responsibility; (3) Urban road of municipalities: the municipal engineering (construction) bureau takes charge.

2.3 Technical Evolution and Definition of LCA

Coca-Cola Co. was the first one to perform LCA for its production process of beverage vessels. It also evaluated and quantified the environmental impact for further improvement (Lai, 1997). In 1997, Yang (1996, 1997a, 1997b) made the definition of LCA as follows: analyze the entire process from upstream to downstream with the concept of "product life cycle," and evaluate the environmental impact during "life cycle" of products from development, manufacturing to utilization and disposal.

2.4 Framework and Discussion of LCA

Following ISO 14001 and ISO 14010, ISO published ISO 14040 governing the principle and framework of LCA in June 1997. The framework of LCA is divided into four parts:

2.4.1 Goal and Scope Definition

This is the first task for LCA, of which the goal and scope of LCA shall be clearly defined to meet the expectations. The goal and scope are described below:

1. Goal: describing the expected applications, reasons and expected objects for communication.
2. Scope: the following system functions shall be considered and described while the scope of LCA is defined.

2.4.2 Life Cycle Inventory

The basic framework of Lyu (1996a) life cycle inventory is shown in Figure 3. This contains data collection and computing program, whereby the program in Figure 4 (SETAC, 1993; Lyu, 1996a/1996b) could be performed in accordance with SETAC and ISO 14040.

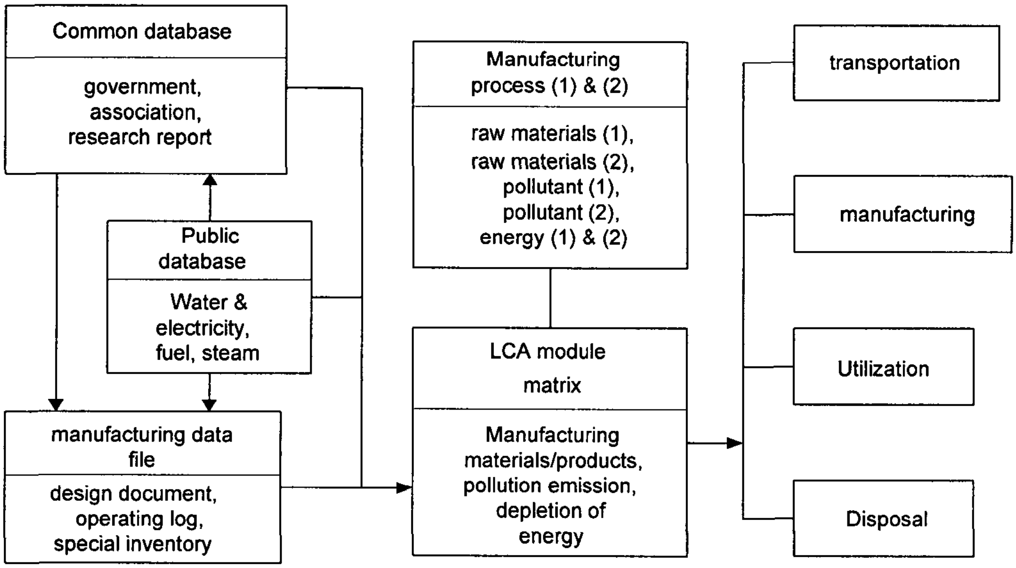


Figure 3. Basic framework of life cycle inventory

To improve the data quality of life cycle inventory, Lyu (1996b) pointed out that the following jobs had to be carried out: (1) set up a common life cycle inventory database open to the public; (2) document the quality of life cycle inventory by developing a "minimum quality standard" or "data quality classification system." The simplified schematic diagram according to Shen and Gu (1994) is shown in Figure 5.

2.4.3 Life Cycle Impact Assessment

It involves assessment of life cycle inventory. The relationship between impact assessment and inventory data as well as between impact assessment and environment interface is shown in Figure 6 (Owens, 1996).

2.4.4 LCA Interpretation

It combines inventory and impact assessment. Alternatively, during the life cycle inventory, it makes the inventory results consistent to the defined goal and scope while describing clearly the direction and restriction of applications.

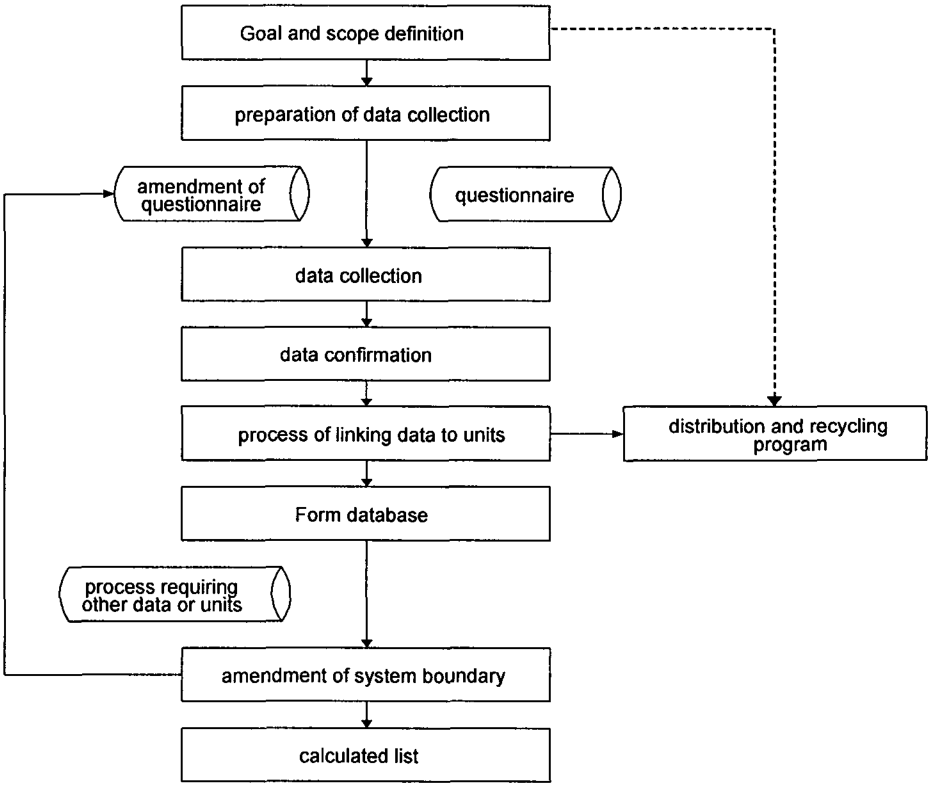


Figure 4. LCA inventory program

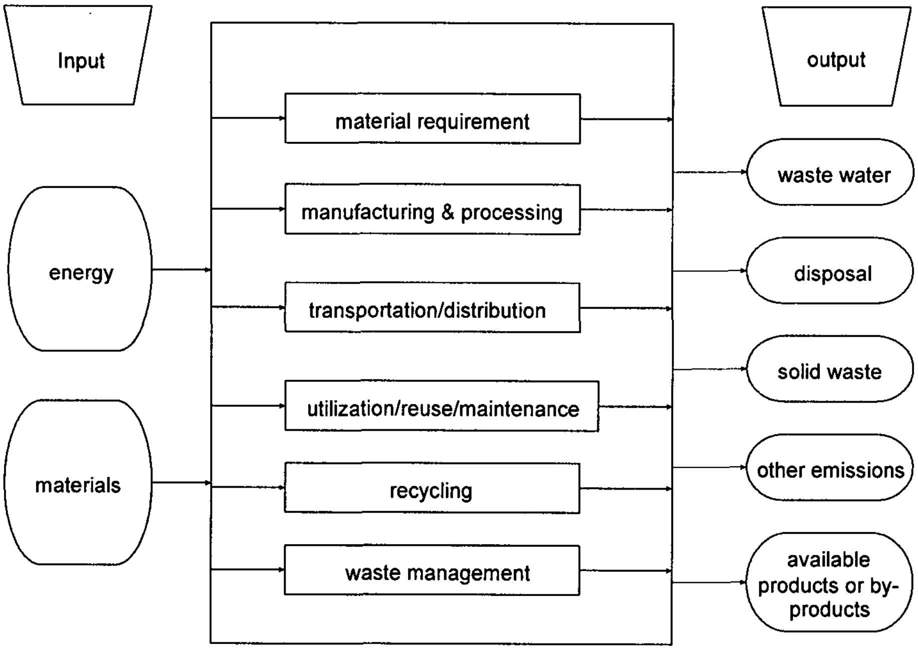


Figure 5. Simplified schematic diagram of common inventory

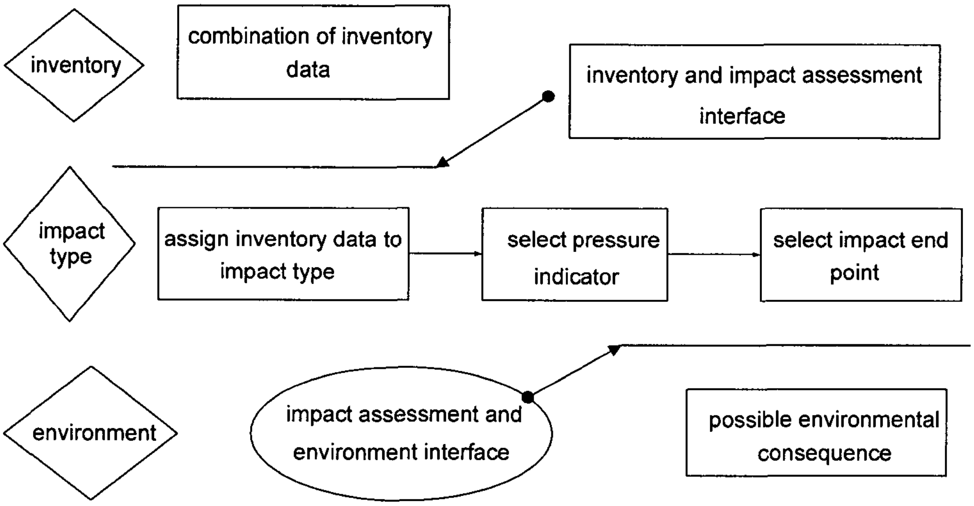


Figure 6. LCA impact assessment mechanism

2.5 LCA Literature Review

LCA technology is widely applied after ISO-14040 Life Cycle Assessment Principle was officially publicized in June 1997. The life cycle activities in Taiwan are listed in Table 3 (Wu, 2000).

Table 3. List of life cycle activities in Taiwan

Client	Research program	Research period
National Science Council	Application and development of LCA	Completed in 1994
	Study of environmental design	1995~1998
	Applications of environment risk evaluation in LCA	1997~1998
	Feasibility study of local LCA	1997~1998
	Study of local LCA technology	1998~1999
	Application of cost efficiency analysis in life cycle impact assessment	Completed in 1994
Environmental Protection Administration	Discussion on environmental impact of Taiwan's EPS utilization and disposal and relevant control policies	Completed in 1994
	Product life cycle analysis for public utility waste	Completed in 1996
	Planning of setting a system to reuse waste household appliances	Completed in 1997
	Analysis of waste electronics' life cycle, flow direction investigation and handling capacity in 3 years	Completed in 1999
	Evaluation of notebook computer recycling technology	Completed in 1999
	Taiwan's recycling policy of common waste vessels	Completed in 1999
	Life cycle analysis of waste tyres	Completed in 1999
	Establishment of vehicle environment management system, environment performance assessment and LCA technology	Completed in 1999
Industrial Standard Bureau	Promotion of LCA-King Car	Completed in 1999
Department of Industrial Technology, MOEA	Study of best percentage of Taiwan's waste paper to industrial paper	Completed in 1995
	Simulation of applications of LCA basic industrial database in the environmental-protection design	Completed in 1998
	Establishment of applied LCA technology	1997~2001
Academia	Discussion and application of framework of product life cycle	Completed in 1997
Common waste recycling fund	Study of vehicle life cycle (including resource recycling)	Completed in 1996
Unileve	Empirical study of life cycle of Unileve washing powder with reduced packaging capacity	Completed in 1997
Civil society	Life cycle environmental protection responsibility system of computer and refrigerator	2000 (in progress)

The proposed LCA mechanism and framework in Taiwan are shown in Figure 7 (Yang, 1996, 1997a).

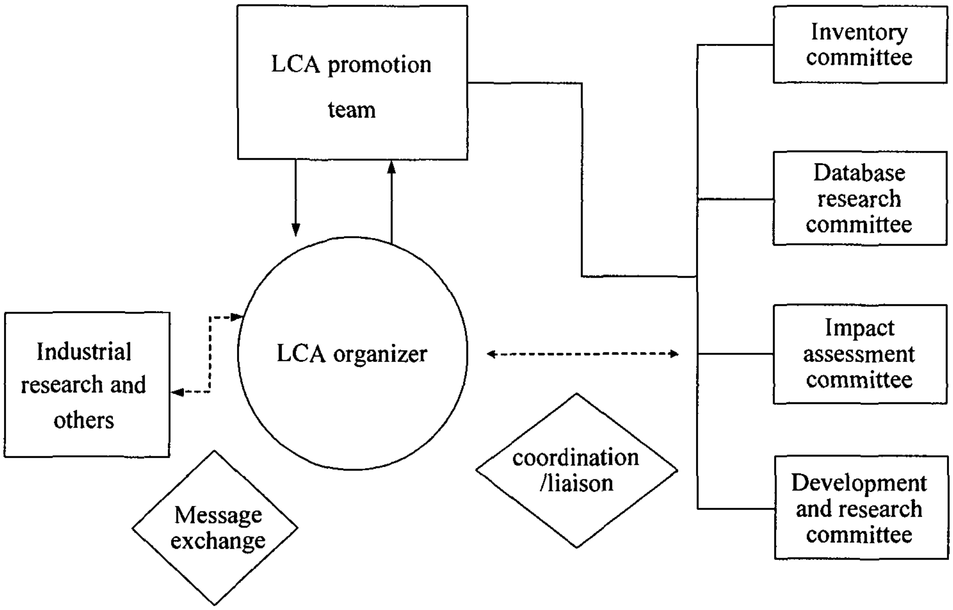


Figure 7. Proposed LCA mechanism and framework in Taiwan

3. Research Method

3.1 Research Framework

The purpose of this research is to explore the environmental impact of HDPE pipe manufacturing process via the concept of "HDPE pipe life cycle." Meanwhile, "Eco-Indicator 95" method is introduced to propose recommendations for improvement of environmental impact, thus providing a reference for the decision-makers in terms of clean production and environmental friendliness.

3.1.1 Data Collection

Based on ISO-1400 environmental management standard Table 4 and relevant literature of LCA as mentioned in section 2, this paper provides a further insight into LCA.

Life Cycle Assessment means that environmental stressors generated during life cycle (pollution, drainage, energy consumption and resource depletion) are assessed scientifically with respect to their impacts on natural environment or recipients.

Table 4. Framework of ISO 14000 environmental management standard

ISO 14000 Environmental management standard		
	Organizational assessment (third-party certification)	Product assessment (consumer-oriented)
Implementation index	Environmental management system (EMS) 14004: criterion and operating instruction	Guide 64 (EAPS): guidance for environmental considerations of product standards
Specification for verification	**Environmental management system (EMS)** 14001: criterion and operating instruction	**Environmental protection standards** 14020: general requirements 14021: self-announced environment doctrine 14022: labeling 14023: test and inspection 14024: category 1 environmental protection standards 14025: category 2 environmental protection standards
Auditing tools	**Environment audit (EA)** 14010: general requirements 14011: operating procedures 14012: auditor qualification principle **Environment performance evaluation** 14031: common methods	**Life cycle assessment (LCA)** 14040: general requirements 14041: order inventory 14042: impact assessment 14043: interpretation
Nomenclature	**14050: terms and definition (T&D)**	

3.1.2 Data Analysis for LCA

"Degree of data acquisition" and "data quality" are two biggest problems encountered during LCA. So, an important task is to acquire data, verify the reliability and integrate into a database.

3.2 Case Study

To measure the environmental load of underground HDPE pipe with LCA technology, the environmental impact is weighted by SimaPro software, and then ECO-Indicator 95 is introduced to improve its international competitiveness and create more business opportunities.

3.3 Introduction to SimaPro Software

SimaPro software is designed in such a manner that "Life Cycle Assessment" can be implemented easily for clean production and environmental protection, without needing more efforts of design engineers to learn the process and data of "Life Cycle Assessment."

3.3.1 Analysis and Applications of SimaPro Software

SimaPro software could be fully applied into various phases of LCA, inventory and life cycle impact assessment, or different life cycle stages, e.g. from cradle to tomb:

3.3.1.1 Inventory

The inventory covers different manufacturing processes, distribution, utilization and final treatment, each of which is associated with pollution emission and environmental impact. Firstly, various energy resources and materials are decomposed simultaneously with data collection. And, input and output of every product along with quantity and unit are entered into PRE database. Next, the entered data could be converted into system units using computer program.

3.3.1.2 Classification and Characterization

The inventory data, such as energy source, substances and pollution for specific product, must be classified to help judge the environmental impact. LCA impact types are listed in Table 5.

Table 5. Description of LCA impact types

Impact types	Description of environmental impact
Depletion of the Ozone Layer	Ozone Layer is 10km over the atmospheric layer. The toxic ozone could absorb solar radiation. At present, numerous CFC_s/$HCFC_s$ (life cycle up to 50~100 years) generated by the human beings pose damage to Ozone Layer, making the earth surface exposed to excessive UV radiation and leading to great damage of ecological state or even greater possibility of skin cancer. According to Montreal Protocol on Substances that Deplete the Ozone Layer, CFC_s/$HCFC_s$ were prohibited globally starting from 1992, and some developing countries in 2001.
The Green House Effect	This phenomenon is caused by excessive infrared ray in the air. It is expected that CO_2 and other similar substances could have interrupted the heat balance of the earth and brought about climatic and ecological change. In addition, some countries concluded a relevant agreement in Kyoto at end of 1997 (The Green House Effect gas contains CO_2, CH_4, NO_x, CFC_s).
Acidification	This phenomenon is caused by sulfur oxide, nitrogen oxide and ammonia for agricultural use.
Eutrophication	Excessive nutrient sources of nitrogen and phosphorus will lead to simplified varieties of land plants and numerous breeding of phycophyta for ecological damage.
Heavy Metals	Divided into heavy metals in water and air, both of which lead to long-lasting damage to the human beings and ecological system.
Carcinogens	Many carcinogenic chemical substances generated by the human beings, such as pesticides and polychlorinated biphenyl, exert great negative impact upon human beings and ecological system.
Winter smog	Suspended particles and sulfur dioxide in the air may lead to respiratory virus. It is reported that a winter smog in London in 1952 resulted in a death toll of 4,000. East and Middle Europe is most seriously affected by this problem.
Summer Smog	Nitrogen oxide and carbohydrate exposed to solar radiation will generate excessive ozone against the human beings, animals and agricultural crops.
Depletion of Energy	Regenerative sources of energy, such as wind power, water power and solar energy, etc, have extremely high cost, while the reserves of fossil fuel and nuclear uranium ore are very limited. Thus, depletion of energy is generally considered as an environmental impact.
Waste Display	Many developed countries face the serious problem of many wastes to be disposed.
Other Problems	Odour, noise, scenery damage, radiant pollution and depletion of non-regenerative resources.

3.3.1.3 Normalization

It aims at providing different environmental indicators, i.e. relative comparative value, based on per capita effect everyday or within a certain period, which is given weighting. The effect score is the result of characterization multiplied by the weighting from normalization.

3.3.1.4 Evaluation

When a group of environmental impact data is obtained from pollution-related energy consumption, SimaPro software requires weighting according to common understanding of a region or country, or individual opinions. Then, a single value is calculated to compare which is an "environmental-friendly" package. Hence, the so-called "evaluation" means that the normalized effect is multiplied by weighting, showing the relative importance of environmental effect.

3.3.1.5 Indicator

If SimaPro software is used for analysis, different environmental effect scores could be added to compare the environmental impact of materials or manufacturing process in various products or a single product, namely, Eco-Indicator. The impact evaluation methods of "Characterization," "Normalization," "Evaluation" and "Indicator" are listed in Table 6 (Wu, 2000).

If SimaPro is used for LCA, select LifeCycle in the menu box, and then enter the name, utilization process and disposal data, or if necessary, other relevant life cycle data, namely, from cradle to tomb analysis.

Table 6. Impact evaluation methods

Evaluation methods	Description
Characterization	The environmental impact for every class could be added to obtain an effect score, and then given weighting according to bigger effect of certain substances.
Normalization	It provides environmental indicators, i.e. relative comparative value, based on per capita effect everyday or within a certain period, which is given weighting. The effect score is [result of Characterization] x weighting.
Evaluation	A weight is generated according to common understanding of a region or country, or individual opinions. Then, a single value is calculated to compare which is an "environmental-friendly" package, namely, [normalized effect] x weighting, showing the relative importance of environmental effect.
Indicator	Different environmental effect scores could be added to compare the environmental impact of materials or manufacturing process in various products or a single product.

3.4 Description of SimaPro Database Framework

SimaPro software has 5 databases, with the types, contents and highlights or disadvantages listed in Table 7 (Lyu, 1998).

Table 7. Contents of SimaPro database

Type	Contents
Method database	Stores the relative indexes of different environmental impacts, such as: ODP or GWP of various pollutants, and evaluates the weight of methods.
Manufacturing process database	Stores data like Boustead, containing substances, energy sources, transportation, manufacturing process, utilization, disposal and waste treatment. But, no restriction is placed on the field of Input Table.
Percentage database	Stores the percentage of waste burying, incineration and recycling.
Substance database	Stores the name and unit of gas, water, waste and feedstock.
Unit conversion database	Stores measurement system for unit conversion.

3.5 Setup of Eco-Indicator

Eco-Indicator 95 is used by SimaPro software to measure the environmental effect upon "ecological state" or "human health." It is a weighting method based on European scales. 100 indicators for raw materials and production processes are listed in Table 8 (Pre' Consultants, 1999).

Eco-Indicator may be represented as [Eco-Indicator points (Pt)]. In practice, it is often represented by a permillage, e.g. 1.5 mPt = 0.0015 Pt.

Table 8. Setup of Eco-Indicator

Items	Description
1. Raw materials	1 kg raw materials on main production process
2. Processing procedure	Processing and manufacturing processes of raw materials, showing that every processing unit is also suitable for special process(unit/m^2 or kg/m^2)
3. Transportation process	Represented by t-km, or per ton.
4. Energy generation	Including units such as: electric power, heat energy and mechanical energy, etc.
5. Disposal	Unit: kg; divided into types of raw materials and disposal methods
6. Remarks	"Disposal process" and "recycling process" are based on the data of Netherlands.

3.6 Environmental Effect of Eco-Indicator 95

The relationship among environmental effect, weight factor and criterion is listed in Table 9; while the weighting principle of Eco-Indicator 95 is shown in Figure 8.

Table 9. Weight factor of environmental effect

Environmental effect	Weight factor	Criterion
The Green House Effect	2.5	A temperature rise of 0.1℃ every 10 years leads to degeneration of 5% ecological system
Depletion of Ozone Layer	100	The probability of one fatality in every 1 million people every year
Acidification	10	Degeneration of 5% ecological system
Eutrophication	5	Rivers and lakes lead to degeneration of 5% ecological system
Summer smog	2.5	Complaints, especially from asthma patients and the old, as well as for agricultural damage
Winter smog	5	Complaints, especially from asthma patients and the old
Pesticide	25	Degeneration of 5% ecological system
Heavy metals in the air	5	Lead content in children's blood leads to lower average life span of unknown groups and learning performance
Heavy metals in the water	5	Cadmium content in the river has impact upon the human beings (same as heavy metals in the air)
Carcinogens	10	The probability of one fatality in every 1 million people every year

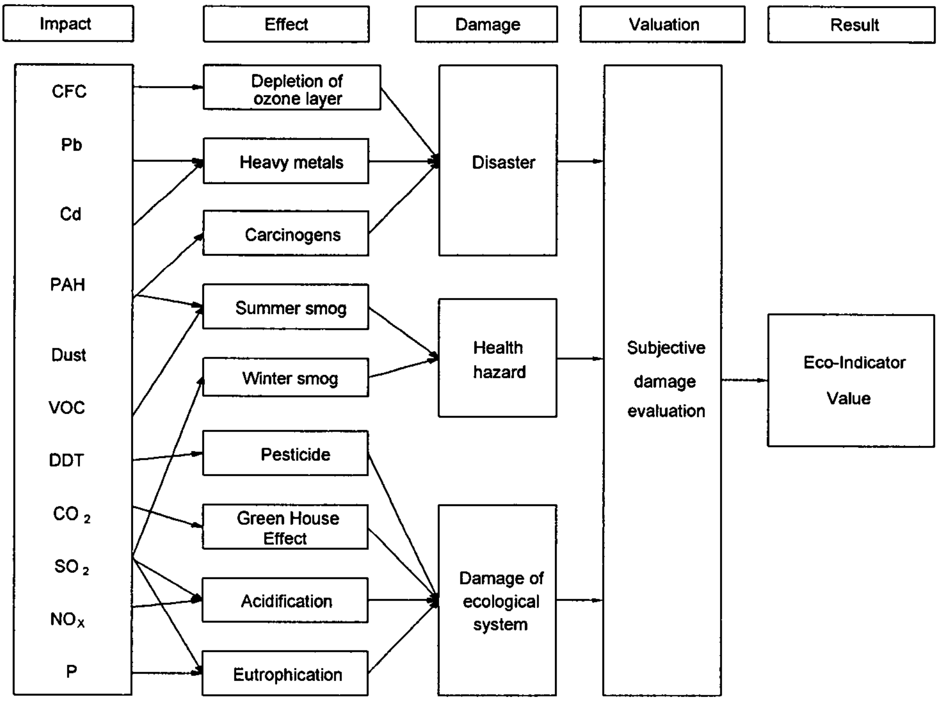


Figure 8. Weighting principle of Eco-Indicator 95

4. Case Study

4.1 Market Overview of HDPE Pipe

In addition to 5 small-sized manufacturers, there are 6 Taiwan's PE pipe manufacturers certified with ISO 9002: (1) Shun Ming Plastic Industrial Corp.; (2) Yuan Shun Plastics Industrial Corp.; (3) Rong Min Plastic Corp.; (4) Tung Fu Plastic Corp.; (5) Hsu Tung Plastic Corp; (6) Ri Jin Plastic Corp. Company A, founded on Nov 19, 1996 with approval by the Ministry of Economic Affairs, set up a factory on Feb 26, 1997 in No. 287-1, Fengye Li, Yangmei Township, Taoyuan County. This factory has the state-of-the-art Krauss Maifei piping machines delivering top-quality HDPE pipes.

4.1.1 Description of HDPE Pipe Manufacturing Process

The HDPE is defined by a density of greater or equal to 0.941 g/cc. HDPE has a low degree of branching and thus stronger intermolecular forces and tensile strength. HDPE can be produced by chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts. The lack of branching is ensured by an appropriate choice of catalyst (e.g. Chromium catalysts or Ziegler-Natta catalysts) and reaction conditions. The major manufacturing processes of HDPE pipe are divided into: (1) preparation; (2) pipe-making; (3) forming cooling; (4) manufacturing inspection. The manufacturing process of HDPE pipe is shown in Figure 9. The first step is to prepare raw materials (including inspection of incoming materials, automatic measuring/proportioning), followed by pipe-making in the second step, forming cooling in the third step and manufacturing inspection in the fourth step as listed in Table 10.

Table 10. Input and output of HDPE pipe manufacturing process

Manufacturing Units	Input	Output
Preparation	Electric power, feed pipe, HDPE raw materials, piping machine, template and conveyer belt	Inspection of incoming materials, automatic measuring/proportioning
Pipe-making	HDPE raw materials, electric power, inspection of incoming materials, automatic measuring/proportioning, mixing and drying	Heating and melting HDPE Preforming HDPE pipe
Forming cooling	Conveyer belt, water and electric power, formed HDPE pipe	Forming cooling for water cooling machine Formed HDPE pipe
Manufacturing inspection	Formed HDPE pipe Conveyer belt and electric power	Manufactured HDPE pipe
	Manufactured HDPE pipes, stacker or crane	HDPE pipes at storage site

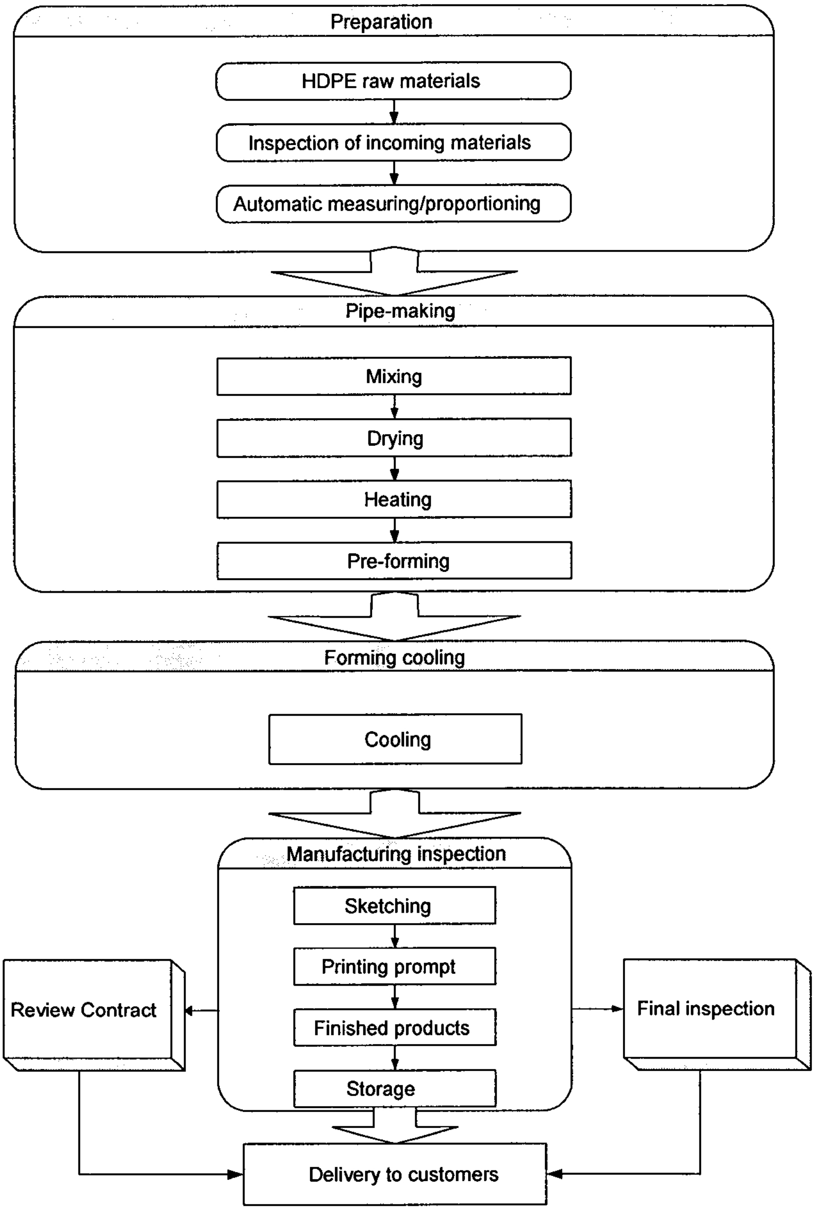


Figure 9. HDPE pipe manufacturing process

4.1.2 Major Pollution Emission Sources and Characteristics of HDPE Pipe Manufacturing Process

The pollution emission sources and characteristics of HDPE pipe manufacturing process are listed in Table 11.

Table 11. Pollution emission sources and characteristics of HDPE pipe manufacturing process

Manufacturing units	**Emission sources**	**Emission characteristics**							
		Waste gas		**Waste water**		**Solid waste**		**Noise**	
		Intermittent	**Continuous**	**Intermittent**	**Continuous**	**Intermittent**	**Continuous**	**Intermittent**	**Continuous**
Pipe-making	Mixing and transport of HDPE raw materials		x			x			x
	Compression of piping machine		x						x
	Pipe-drawing of piping machine	x						x	
Forming cooling	Handling and assembly of templates					x		x	
	Cooling of HDPE pipe				x			x	
Storage site	Conveyance by stacker	x						x	
	Binding/ conveyance	x				x		x	
	Hoisting by crane					x		x	
Waste water treatment Water supply device	Circulating supply of cooling water				x				x
	Discharge water treatment			x					
HDPE pipe rejection	Treatment of rejected HDPE pipes					x			
Maintenance Workshop cleaning	Discharge of lubricant			x					
	Sanitary and cleaning water discharge			x				x	

4.2 Research Purpose and System Range

The purpose of this case study is to quantify the environmental load of HDPE pipes with LCA technology. Then, Eco-Indicator is introduced to convert the fuzzy environmental impact into an indicator with environmental effect, thus providing a reference for decision-makers in developing energy-saving measures and reducing emissions in greenhouse for green production. The system range of this study is shown in Figure 10.

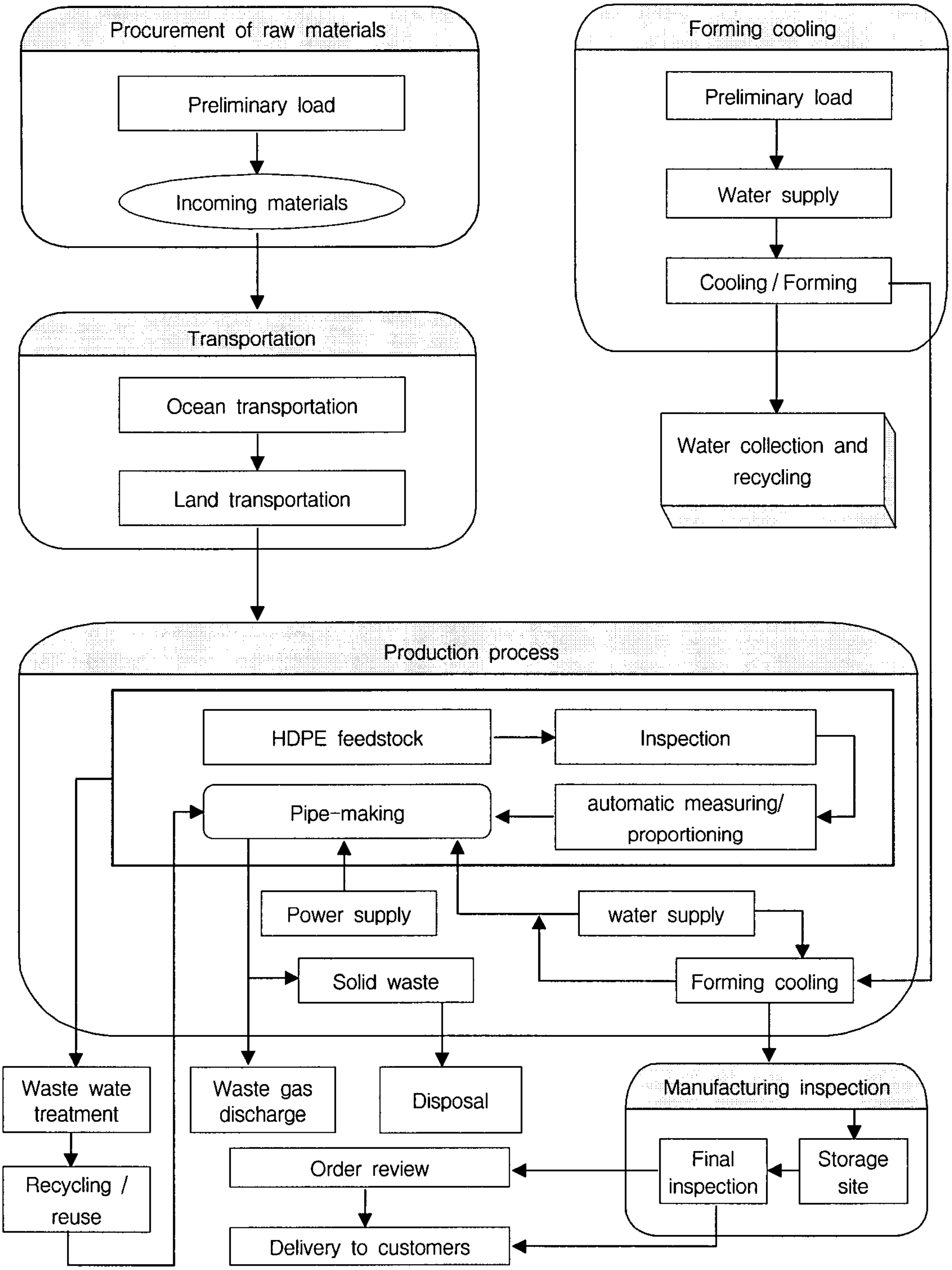


Figure 10. System range of this research

4.3 System Inventory

The system inventory items are divided into five subsystems: procurement of raw materials, transportation, production process, forming cooling and storage site, as listed in Table 12.

Table 12. System inventory data

System Name	**Raw Materials Preparation Subsystem**
Source of raw materials	HDPE raw materials
Quantity	3,150 (ton)
Output	HDPE pipe: 3,000 ton/year

Loss rate of HDPE pipe manufacturing process is about 5%

System Name	**Transportation Subsystem**
Inventory item	Transportation mode, distance and tools.
Inventory result	The ocean transportation distance from place of origin (Singapore) to Keelung harbor is estimated about 5,500km, plus 70km transferred by 25t trucks from Keelung harbor to the factory.

The ocean transportation difficult for inventory is estimated according to original load.

System Name	**Production Process Subsystem**		
Inventory item	Total water consumption (cu.m/year)	Total power consumption (kW/year)	Solid waste (ton/year)
Quantity	2,555	50,400,000	40
Output	HDPE pipe: 3,000 ton/year		

The yield of HDPE pipe accounts for 95% of total production of this company. So, energy and water consumption is calculated based on 95%. Solid waste that can be recycled is neglected.

System Name	**Forming cooling Subsystem**		
Inventory item	Water consumption (cu.m/year)	Power consumption (kW/year)	Waste water (cu.m/year)
Quantity	1,825	9,108,434	1,785
Output	HDPE pipe on production line: 3,000 ton/year		

About 100t waste water is discharged every two weeks. So, annual discharge of waste water (no pollution) registers about 1,785t. The electric power for printing is neglected.

System Name	**Storage Subsystem**			
Inventory item	Oil volume for stacker (kl./year)	Power consumption of crane (kW/year)	Tyres for stacker (unit)	Battery cell for stacker (12V)
Quantity	2,500	2,300	8	4
Output	Stored HDPE pipe: 3,000 ton			

4.4 Analysis of Impact Assessment Results

By taking LCA software-SimaPro as environmental impact assessment mode, this study has assessed the specific yield based on 1t HDPE pipe samples. The analytical results from LCA software show that: "production process subsystem" 21.2Pt and "forming cooling subsystem" 34.7Pt have biggest environmental impact due to energy consumption, of which "acidification" and "heavy metals" during "forming cooling" stage take a biggest share. Hence, this study plans to propose some measures for improvement of "production process" and "forming cooling," and then compare the results for the decision-makers.

4.5 Improvement of Manufacturing Process

This case study shows that, "production process subsystem" and "forming cooling subsystem" have biggest environmental impact due to energy consumption. So, the following solutions are provided for the decision-makers.

1. Power supply: It is found from life cycle inventory that, company A has currently 3 production lines equipped with Krauss Maifei piping machines. The actual assessment results are. (1) 162 thousand kilowatt-hour electric power could be saved annually. (2) the night-time efficiency is about 110% of daytime efficiency. 300 thousand kilowatt-hour electric power could be saved based on 24 hour operation per day. (3) off-peak electric power about 3 months is available during summer. So, 942 thousand kilowatt-hour electric power could be saved annually if equipment upgrading plan is taken into consideration.
2. Water supply: It is found from life cycle inventory that, monthly turnover of company A is averaged about NT$20 million, but only NT$10,000 is used for water supply. To reduce overall environmental impact, it is expected that 2t water could be saved every day, and 700t annually.

4.6 Comparison of Improved Manufacturing Process

The data of improved manufacturing process is as follows. (1) the data of "production process

Table 13. "Production process subsystem" after improvement of manufacturing process

System Name	Production Process Subsystem		
Inventory item	Total water consumption (cu.m/year)	Total power consumption (kW/year)	Solid waste (ton/year)
Quantity	2,021	47,116,980	40
Output	HDPE pipe: 3,000 ton/year		

Total water consumption = 2,427 - (700 × 58%) = 2,021 (cu.m/year)
Total power consumption = 47,880,000 - (942,000 × 81%) = 47,116,980 (KW/year)
The yield of HDPE pipe accounts for 95% of total production of this company. So, energy and water consumption is calculated based on 95%. Solid waste that can be recycled is neglected.

Table 14. "Forming cooling subsystem" after improvement of manufacturing process

System Name	**Forming Cooling Subsystem**		
Inventory item	Water consumption (cu.m/year)	Power consumption (kW/year)	Waste water (cu.m/year)
Quantity	1,531	8,929,454	1,085
Output	HDPE pipe on production line: 3,000 ton/year		

Water consumption = 1,825 - (700 × 42%) = 1,531 (cu.m/year)
Power consumption = 9,108,434 - (942,000 × 19%) = 8,929,454 (KW/year)
Waste water = 1,785 - 700 = 1,085 (cu.m/year)

About 700t waste water could be saved annually after improvement of manufacturing process. So, annual discharge of waste water (no pollution) registers about 1,085t. The electric power for printing is neglected.

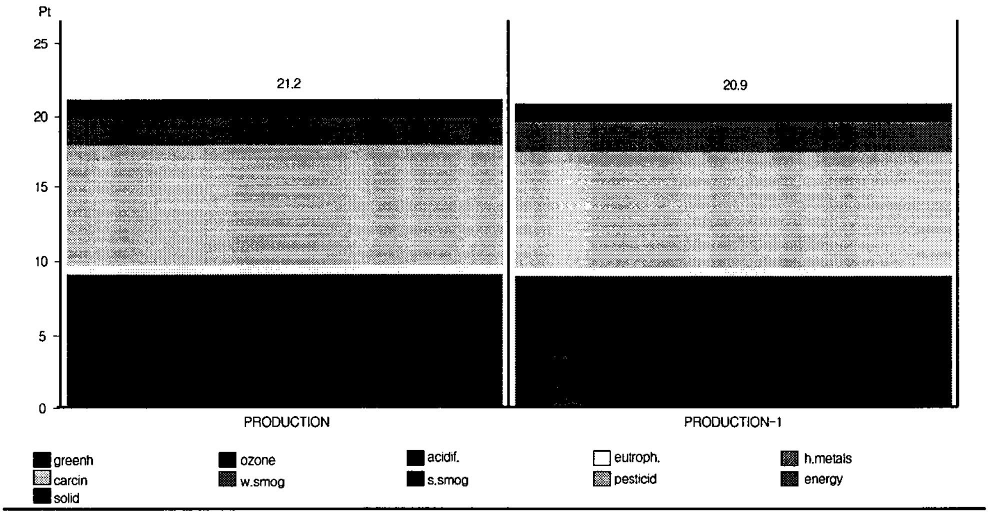
subsystem" with improved manufacturing process is listed in Table 13. (2) the data of "forming cooling subsystem" with improved manufacturing process is listed in Table 14.

4.6.1 Comparison of Production Process before or after Improvement

The indicators of production process before or after improvement are compared and assessed through SimaPro software, with the results shown in Figure 11.

4.6.2 Comparison of Forming Cooling before or after Improvement

The indicators of forming cooling before or after improvement are compared and assessed through SimaPro software, with the results shown in Figure 12.



Compare boxes: Method: SimaPro 3.0 Eco-indicator 95/ Europe e/ indicator

Figure 11. Comparison of indicators of production process before or after improvement

4.6.3 Comparison of Improved Production Process and Forming Cooling

The indicators of improved production process and forming cooling are compared and analyzed through SimaPro software. It is clearly seen from Figure 13 that the environmental impact for both processes is reduced markedly.

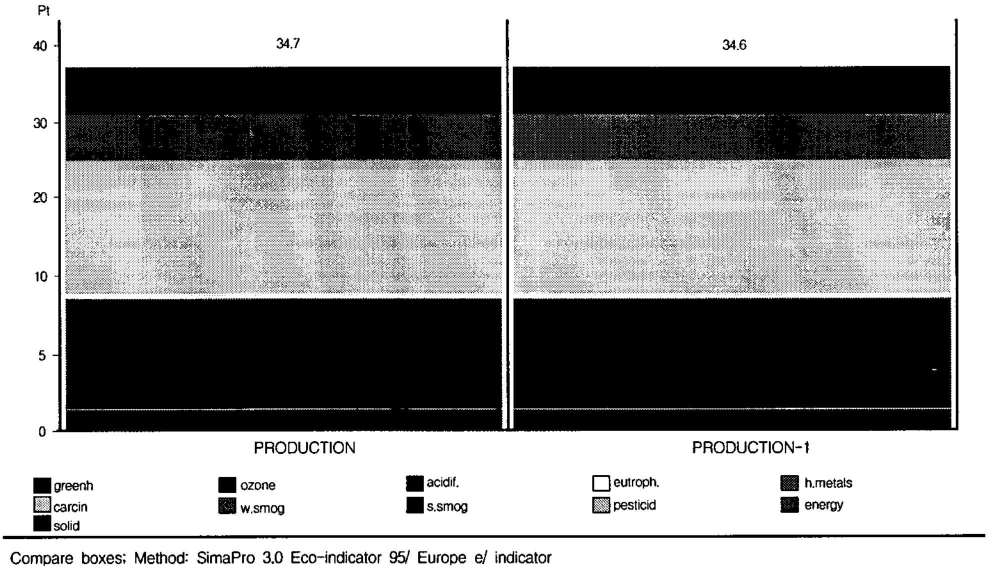


Figure 12. Comparison of indicators of forming cooling before or after improvement

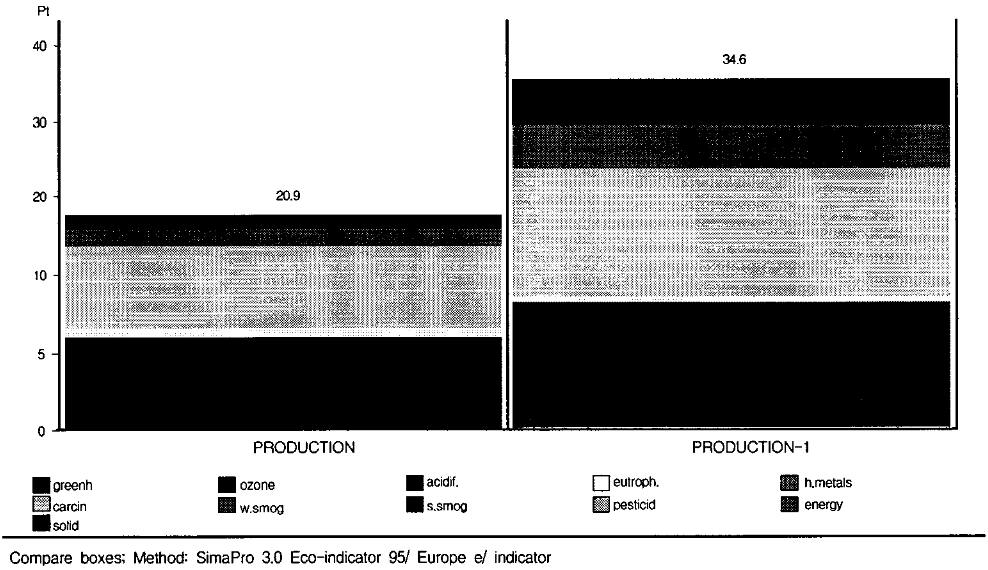


Figure 13. Comparison of indicators of improved production process and forming cooling

4.7 Analysis of Saveable Operating Cost after Improvement

In the backdrop of a competitive environment, the industrial operators' common objective is to reduce efficiently their operating cost and improve their market competitiveness in accordance with environmental-protection policies. The saveable operating cost after improvement is analyzed below:

4.7.1 Power supply

If interface devices are improved, the cost of power supply could be annually saved up to NT$14,816,967 if off-peak power cost is NT$0.65/Kilowatt-hour, and peak power cost is NT$1.78/kilowatt-hour.

4.7.2 Water supply

It is found from life cycle inventory that, if the mean cost of water supply is NT$11.5/ton, the total cost of improved water supply is: NT$14,816,967 for total power cost that can be saved annually + NT$5,283 for total water supply cost that can be saved annually = NT$14,811,684. According to the analysis of saved cost and operating cost after improvement, monthly average turnover of company A is about NT$20,000,000, and annual average turnover is totalized about NT$240,000,000, with the reduced operating cost up to 6.2%. This may assist in achieving clean production and improving market competitive power in accordance with environmental-protection policy.

5. Conclusions

A variety of underground pipelines represent the development level of a country, especially for Taiwan focusing on industrial and trade development. However, there is a pressing demand on underground pipelines with fast economic development and ever-growing living standard. So, a high priority shall be placed on how to select properly piping materials and methods to reduce environmental impact and ensure the living quality of people in the densely-populated municipalities with high traffic volume.

5.1 Research Findings

Based on the example of piping material of Taiwan's underground pipeline--HDPE pipe, this research has obtained the following findings via the help of LCA software: amongst HDPE pipe manufacturing processes, "production process subsystem" and "forming cooling subsystem" have biggest environmental impact due to energy consumption, of which "acidification" and "heavy metals" during "forming cooling" stage take a biggest share. Hence, this study strives to propose some measures for improvement of "production process" and "forming cooling," and then compare the results before and after improvement for the decision-makers and industrial operators. (1) the biggest environmental impact of HDPE pipe manufacturing process is caused by numerous cooling water for forming cooling, and energy consumption for heating and melting. (2) preparing energy-saving measures and improving energy efficiency will contribute to minimize the environmental impact of manufacturing process.

5.2 Research Conclusions

1. The manufacturing process is recommended for improvement to reduce its environmental impact. And, LCA technology could be used to assess the environmental impact of manufacturing process and then develop a solution for improvement.
2. This case study has found through LCA software analysis that: "production process subsystem" and "forming cooling subsystem" have biggest environmental impact due to energy consumption.
3. How to save energy during "production process" and "forming cooling," namely, reduce the capital input on "electric power" and "water supply" during "production process" and "forming cooling," is helpful to reduce the environmental impact.
4. After manufacturing process is improved and the capital input on "electric power" and "water supply" during "production process" and "forming cooling" is reduced, 942 thousand kilowatt-hour electric power and 700t water could be saved annually, with the reduced operating cost up to 6.2%; this may assist in achieving clean production and improving market competitive power in accordance with environmental-protection policy.

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